4 TECHNIQUES TO CONSIDER IN THE DETERMINATION OF BAT

4.1 Introduction

This chapter sets out techniques considered generally to have potential for achieving a high level of environmental protection in the industries within the scope of the document. Management systems, process-integrated techniques and end-of-pipe measures are included, but a certain amount of overlap exists between these three when seeking the optimum results.

Prevention, control, minimisation and recycling procedures are considered as well as the re-use of materials and energy.

Techniques may be presented singly or as combinations to achieve the objectives of the IPPC Directive. Annex IV to this Directive lists a number of general considerations to be taken into account when determining BAT and techniques within this chapter will address one or more of these considerations. As far as possible, a standard structure is used to outline each technique, to enable comparison of techniques and an objective assessment against the definition of BAT given in the IPPC Directive.

The content of this chapter is not an exhaustive list of techniques and others may exist or be developed which may be equally valid within the framework of IPPC and BAT.

The standard structure used to outline each technique is shown in Table 4.1

Type of information considered	Type of information included
Description	Technical description of the technique (including drawings, schematics if necessary)
Achieved environmental benefits	Main environmental benefits (including energy, water, raw material savings, as well as production yield increases, energy efficiency, etc) addressed by the technique
Cross-media effects	Main environmental side effects and disadvantages to other media caused by using the technique. Details of the environmental effects of the technique in comparison with others
Operational data	Data on consumption and emission levels from operational plants using the technique (including any reference conditions and monitoring methods used). Any other relevant information on how to operate, maintain and control the technique
Applicability	Indication of the type of plants in which the technique may be applied, considering, e.g. plant age, (new or existing), plant size (large or small), techniques already installed and type or quality of product
Economics	Information on costs (both investment and operational) and any possible savings (e.g. reduced raw material or energy consumption, waste charges) or revenues including details on how these costs/savings or revenues have been calculated/estimated
Driving force for implementation	Local conditions or requirements which lead to or may stimulate implementation. Information on reasons other than environmental ones for implementation (e.g. increase in productivity, safety)
Example plants	Reference to (a) plant(s) in which the technique is applied and from which information has been collected and used in writing the section
Reference literature	Literature or other reference material (e.g. books, reports, studies, websites) that was used in writing the section and that contains more details on the technique

Table 4.1: Information breakdown for each technique described in this chapter

This chapter as seven main sections, which cover:

- melting technique selection
- materials handling
- techniques for controlling emissions to air from melting activities
- techniques for controlling emissions to air from non-melting activities
- techniques for controlling emissions to water
- techniques for minimising other wastes
- energy.

The main environmental impact of the glass industry as a whole arises due to emissions to air from melting activities. Techniques to reduce these emissions are described in Section 4.4, which is the largest and most detailed section of this chapter. Most of the techniques described are relevant to the majority of installations in the glass industry and share a common basis. For this reason, Section 4.4 is structured with a substance-based approach and for each substance, the various emissions reduction techniques are described. The techniques have been described in the section relating to the substance on which they have the greatest effect, but there are inevitably multi-substance effects for many of the techniques. Where appropriate, the effects on other substances have been described and cross-referenced to other sections.

In various parts of the document the terms "primary and secondary abatement measures" are used. These terms are rather imprecise but help to categorise some of the techniques. In general, primary techniques are those which reduce or avoid the formation of the pollutants; and secondary techniques are those which act on the pollutants to render them less harmful (e.g. by converting to other species) or to collect them in a form that can be re-used, recycled or disposed of. Some of the techniques described do not fall conveniently into either category, and where appropriate this is made clear in the text.

To be able to compare and assess the performance of the various techniques, data will be explained, as far as information is available, in terms of methods used for sampling, analysis and data processing (averaging, etc).

Data on emissions may be expressed as absolute or concentration values, and relative to actual production or production capacity. The most relevant economic aspects of each of the techniques will be described to identify, where possible, the overall economic impact of any given technique. Various expressions may be used for costs and consumption, referring to units of production or time.

An important consideration for this chapter is that a technique, which is successful in one application, may have very different implications if used in a different sector or even at a different installation in the same sector. The costs, environmental performance and associated advantages and disadvantages can differ widely for different sectors and for individual installations. For each technique, its availability and likely applicability in a range of situations is discussed.

In assessing the applicability of any technique described in this chapter to a continuous melting process, it is necessary to consider whether it can be applied to the furnace during the campaign, or if it can only be applied (or is best applied) at a rebuild. An important feature of the glass industry is the fact that furnaces have a limited operational life, after which time they must be repaired or rebuilt, to varying degrees. In general, fossil fuel fired furnaces producing container glass, flat glass, glass wool, and continuous filament glass fibre, operate continuously for 8 to 12 years. Special glass and domestic glass fossil fuel fired furnaces usually operate continuously for 3 to 8 years. Electrically heated furnaces tend to have shorter operating lives in all applications, i.e. 2 to 7 years. Some other furnaces such as cupola furnaces and batch melters for glass frits production are operated for much shorter periods, from a few days to several weeks.

There are two main categories of rebuild for continuous processes:

- in a “normal” rebuild, the refractory of the furnace and, where appropriate, the regenerators are repaired by the full or partial replacement of the material. The furnace frame is not significantly adjusted and the furnace dimensions remain basically unchanged. Where there is no significant change in furnace requirements or technology, this is the most common type of rebuild between campaigns
- a “complete” rebuild usually involves a major adjustment or replacement of the furnace frame in addition to the replacement of the refractory material. This can be comparable to the construction of a new furnace although, in many cases, much of the existing infrastructure and particularly the regenerators may be retained. This type of rebuild is less common and is usually undertaken where a major change in furnace requirements (e.g. significantly increased melting area or major changes in firing capacity) or technology is involved. A complete rebuild generally involves significantly higher costs than a normal rebuild.

During a furnace campaign, the opportunity to modify the furnace is limited. Although hot repairs to replace or shore up damaged refractories are often undertaken, and burner modifications or replacement can also be relatively straightforward. Major changes affecting melting technology are usually most economically implemented if coincided with furnace rebuilds. This can also be true for complex secondary abatement measures. However, many improvements to the operation of the furnace, including the installation of secondary techniques, are possible during the operating campaign. Where appropriate, these issues are discussed in the consideration of the applicability of the various techniques.

The distinction between a “normal” rebuild and a “complete” rebuild is not absolute and there are a number of increments between the simplest normal rebuild and the complete demolition and total replacement of a furnace. For example, a small repair can be carried out either hot or cold to repair specific damage or to introduce a minor modification. Also minor rebuilds may occur where a scheduled cold repair is made but most of the refractory is retained and only damaged parts replaced. The most important difference, which affects both the cost and the freedom to implement new technology, is whether there is a significant change to the furnace frame and therefore its dimensions.

For smaller furnaces with more frequent rebuilds and lower capital costs, the advantages of co-ordinating environmental improvements and furnace repairs are less significant; however, even in these cases, environmental improvements may be more economical if coordinated with other operations and investments planned for the melting furnace.

4.2 Melting technique selection

The melting techniques used within the glass industry are described in Chapter 2. They range in size from small pot furnaces to large regenerative furnaces producing up to 900 – 1000 tonnes of glass per day. The choice of melting technique depends on many factors but particularly the required capacity, the glass formulation, fuel prices, and existing infrastructure. The choice is one of the most important economic and technical decisions made for a new plant or for a furnace rebuild. The overriding factors are the required capacity and the glass type.

The choice between a regenerative or a recuperative furnace is normally based on economical and technical reasons. Therefore, the environmental aspects are only discussed briefly here. The choice between conventional air-fuel firing and electrical or oxy-fuel melting is an important factor in determining BAT and these techniques are described separately. Similarly other specific melting techniques, e.g. the LoNO_X® melter, are discussed separately in the substance-specific sectors.

Each of the techniques described in Chapter 2 has its inherent advantages, disadvantages and limitations. For example, at the time of writing (2009), the best technical and most economical way of producing high volume float glass is from a large cross-fired regenerative furnace. The alternatives are either still not proven in the sector or compromise the economics or technical aspects of the business (e.g. electric melting or recuperative furnaces).

The environmental performance of the furnace is a result of a combination of the choice of melting technique, the method of operation, and the provision of secondary abatement measures. From an environmental perspective, melting techniques that are inherently less polluting or can be controlled by primary means are generally preferred to those that rely on secondary abatement. However, the economic and technical practicalities have to be considered and the final choice should be an optimised balance.

The environmental performance of the various melting techniques will differ greatly depending on the glass type being produced, the method of operation and the design. For example, the emissions (before secondary abatement) from a recuperative furnace producing TV glass with added nitrate and nearing the end of a campaign, will bear little resemblance to the emissions from a newly built recuperative continuous filament glass fibre furnace which has optimised geometry, formulation and firing. These factors make a direct quantitative comparison of the various melting techniques difficult and of limited value, and the sections below only summarise the main environmental considerations for each of the techniques described in Chapter 2. Oxy-fuel melting and special furnace designs are covered in Sections 4.4.2.5 and 4.4.2.3 respectively. The differences in emissions from the different furnace types are discussed, where appropriate, in the substance-specific sections of this chapter.

Electric melting differs from the other techniques described below, because it is a fundamental change in technology and has very significant effects on emissions. Electric melting is presented as one of the specific techniques for consideration in determining BAT. However, due to its impact on all emissions, it does not fit conveniently into the substance-based approach of this chapter; therefore, it is presented in this section.

The specific energy consumptions for container glass classified by furnace type and size are shown in Table 3.10 and Figure 3.3.

Regenerative furnaces

These furnaces are generally more energy efficient than other conventional fossil fuel fired furnaces due to the more efficient combustion air preheating system. The low energy use per tonne of glass melted leads to reductions in many of the pollutants associated with combustion. However, the high preheat temperatures favour higher NO_X formation. These furnaces have shown very good results with primary emission control techniques, particularly for NO_X. Of the two types of regenerative furnace, the end-fired furnaces tend to show better energy efficiency and lower emissions. Potentially, cross-fired regenerative furnaces can produce a better glass quality than end-fired furnaces.

The high capital cost of regenerative furnaces means they are normally only economically viable for large-scale glass production (generally >100 tonnes per day although there are examples of smaller furnaces). For production rates of >500 tonnes per day, cross-fired furnaces are generally used to obtain good heat control along the full length of the furnace.

Recuperative furnaces

These furnaces are less energy efficient than regenerative furnaces, but still recover a substantial amount of heat via the recuperator system. Further improvements in energy efficiency are possible using further techniques, e.g. electric boost, waste heat boilers, gas preheating, and batch/cullet preheating. Preheat temperatures are lower than in regenerative furnaces and good results can be achieved with primary NO_X controls.

However, specific emissions of regenerative and recuperative furnaces, expressed in kg NO_x/tonne glass are comparable, with the exception of special design recuperative furnaces ($LoNO_X$® furnace).

Combined fossil fuel and electric melting

There are two principal approaches to the use of this technique, predominantly fossil fuel firing with an electric boost or predominantly electrical heating with a fossil fuel support. Provision for electric boosting is installed in many furnaces and can contribute 2 – 20 % of total energy input. Generally in container and float glass furnaces, the amount of electric boosting is very limited (<5 %) due to the cost of electricity. Electric boosting will reduce the direct emissions from the furnace by the partial substitution of combustion by electrical heating for a given glass pull rate. As discussed in Section 4.2.1 below, if a more holistic view is taken, the reductions achieved on-site should be considered against the emissions associated with power generation.

The high costs associated with electric boost mean that it is not generally a practicable long-term emissions reduction option for base level production. It is an operational tool, the use of which is determined by economic and technical issues. Electric boost has a beneficial effect on furnace emissions and can be used in association with techniques such as low NO_X burners to improve melting and reduce emissions, but it is not a cost-effective option when used in isolation. Electric boost can also be used to improve the convective currents within the furnace, which helps heat transfer and can aid refining. However, the evaluation of the overall environmental benefits of electric boost should take into account the efficiency of electricity production at the power plant.

Fossil fuel over-firing on a predominantly electrically heated furnace is a much less commonly used technique. It allows many of the environmental benefits of electric melting to be realised by overcoming some of the technical and economicl limitations of the technique. The use of the burners increases the melting rate of the raw materials. Clearly there are emissions associated with the fuel combustion and these will depend on the ratio of the heat supply. Many of the emissions reduction techniques discussed in this chapter can be applied in these furnaces, including low NO_X burners and oxy-fuel melting.

Discontinuous batch melting

The technique traditionally used for low volume discontinuous melting is the pot furnace, although other techniques such as day tanks and the Flex®melter are becoming more common. The choice of technique will usually depend on the logistics of the specific installation, particularly the scale of production, the number of different formulations produced, and customer requirements. Many of the primary abatement measures described in this chapter will be applicable to these furnaces to a greater or lesser degree. The most effective techniques are likely to be the optimisation of batch formulations and combustion techniques. Due to the design of pot furnaces the techniques will generally give better results for day tanks and semi-continuous furnaces. Where the use of day tanks or continuous/semi-continuous melting is practicable, better energy efficiency and lower emissions will usually be achieved.

Stone wool melting

The most commonly used technique for stone wool melting is the hot blast cupola, although there are examples of electric melting and gas-fired furnaces. In several cases these other options have been designed as full-scale developmental plants to study the long-term viability of the techniques, or they have been chosen due to particular local circumstances. The hot blast cupola has a number of operational advantages and is the preferred technique within the sector. The alternatives either do not show any substantial environmental advantages or are not proven to be technically and economically viable for wider application.

4.2.1 Electric melting

Description

The technique is described in Section 2.3.4 because it is a basic melting technique common in several sectors. Electric melting has important effects on pollutant emissions and so is also discussed in this chapter as a "primary" abatement measure.

Achieved environmental benefits

The complete replacement of fossil fuels in the furnace eliminates the formation of combustion products; namely, oxides of sulphur (when fuel oil is used), thermal NO_X, and carbon dioxide CO_2. The remaining emissions arise from particulate carryover and the decomposition of batch materials, particularly CO_2 from carbonates, NO_X from nitrates and SO_X from sulphates. In most cases where electric melting is applied, sulphate use in the batch composition is quite low, since the use of other refining and oxidising agents is more common (e.g. nitrates).

There may also be low levels of halide emissions, e.g. hydrogen fluoride (HF) or metals where these materials are present in the raw materials. However, emissions can be significant from added fluoride formulations. The emissions of all volatile batch components are considerably lower than in conventional furnaces due to the reduced gas flow and the absorption, condensation and reaction of gaseous emissions in the batch blanket which usually covers the whole surface of the melt.

The furnaces are usually open on one side and there are significant air currents due to the gaseous emissions and the heat from the melt. It is usually necessary to provide some form of ventilation to allow dust, gases and heat to escape without entering the work place. This is achieved either by natural draught or by extraction. The waste gas emitted by natural draft will have a very low volume but may have a high dust concentration, and poor dispersion characteristics.

Dust emissions can be controlled by extraction to a dust abatement system, which due to the low volumes involved is usually a bag filter. This arrangement results in very low dust emissions and also allows for the treatment of HF emissions by dry scrubbing if necessary. See Sections 4.4.1.3 and 4.4.3.

The actual emissions achieved will depend greatly on the batch formulation, and due to the low waste gas flows, a comparison of emission concentrations can be misleading. However, as a broad indication, overall direct emissions are reduced by a factor of between 10 and 100 compared to a conventional air-fuel fired furnace of comparable pull rate. Some actual quantitative data are given in Section 3.8.2.2 for mineral wool installations, and in the example installations presented in this document.

Cross-media effects

Direct emissions from the furnace are greatly reduced using electric melting and the thermal efficiency is very high. However, when considering the overall environmental performance of the technique, the environmental impact of power generation can offset some of the advantages. A full quantitative analysis is impossible within the scope of this document. The environmental issues associated with electricity generation are very complex, and differ widely across the EU and sometimes between installations.

Electricity can be supplied from the national supply or from a local or dedicated supply, which can affect both the cost and the efficiency of supply. If the power is taken from the national grid network, it can be from a wide variety of sources. Power generation from coal, oil, gas, nuclear, hydro and other renewable sources all have very different environmental issues associated with them.

The difference in thermal efficiency between electric melting and fossil fuel melting is also reduced when the efficiency of electricity generation is considered (primary energy).

Again it depends very much on the source of electricity, but for a traditional fossil fuel fired power plant, the efficiency from primary fuel to point of electricity use is in the region of 30 - 35 %. For a combined cycle natural gas turbine plant, the figure would be closer to 50 %.

Indirect emissions of CO_2 and NO_x associated with the production of electric energy have been estimated for a small furnace producing 20 tonnes/day of non-lead crystal glass. In this case, the reduction of 14 tonnes/year of NO_x emissions, achieved by switching from a fossil fuel fired furnace to electric melting furnace, is completely offset by the amount of indirect emissions accounted for the production of electricity, equivalent to 15 - 16 tonnes NO_x/year and 6300 tonnes/year of indirect CO_2 emissions. This is not always the case; for lead crystal glass furnaces, the net NO_x and CO_2 emissions (indirect + direct emissions) are slightly lower for the electric furnace than for the fossil fuel fired one, but the difference between the two is rather small. The data reported above do not represent a general conclusion, since they refer to specific examples of lead crystal and non-lead crystal glass productions.

Due to the low waste gas volumes associated with the technique, the cost of any downstream abatement equipment is greatly reduced and the low volumes of collected dust can be readily recycled. The low volatile loss also reduces the consumption of raw materials, which reduces both emissions and costs. This is particularly beneficial for some of the more expensive and/or toxic components such as lead oxides, fluorides, arsenic compounds, borax, etc.

Operational data

In general, electric melting produces a very homogenous high quality glass. For some domestic and special glass applications, this can be one of the primary reasons for choosing electric melting.

The traditional view within the glass industry is that sodium nitrate or potassium nitrate are required in cold-top electric furnaces to provide the necessary oxidising conditions for a stable, safe and efficient manufacturing process. The use of nitrates directly affects the emissions of NO_X and although not necessary for all applications, this can reduce some of the environmental benefits of electric melting. The use of nitrates as oxidising agents becomes more important where waste material which contains organic compounds is recycled to the melter. The use of high external cullet levels (or other recycled materials) can sometimes cause odour problems.

A summary of the main advantages and disadvantages associated with the application of electric melting is shown in Table 4.2

Advantages

- very low direct emissions
- potentially increased melting rate per m^2 of furnace area
- improved direct energy efficiency
- in some cases lower raw material costs
- in many cases electric melting gives a better quality and more homogenous glass
- reduced capital cost and furnace space requirements
- potentially simpler operation

Disadvantages

- high operating cost
- reduced campaign length
- not currently technically and economically viable for very large-scale glass production
- less flexible and not adapted to large pull variations for high quality glasses
- associated environmental implications of electricity generation

Table 4.2: Main advantages and disadvantages of electric melting

An example installation is presented in Table 4.3 for the production of domestic glass, particularly crystal and lead crystal.

Operating conditions			**Associated emission levels(1)**	
	Furnace 1	**Furnace 2**	**Pollutant**	**Emission levels (mg/Nm^3, dry gas at operating O_2 content)**
Type of furnace	Cold top electric furnace	Cold top electric furnace	Particulate matter (2)	2.8
Furnace age	4 yrs	7 yrs	NOx (nitrates in the batch)(3)	Furnace 1 (lead crystal) 420 - 560 mg/Nm^3 (8.1 kg/t)
Capacity	27 t/d	15 (magnesium crystal glass) 20 t/d (lead crystal glass)		
Average production	25 t/d (2006)	15.8 t/d (2005)		Furnace 2 (magnesium crystal) 340 - 460 mg/Nm^3 (10.4 kg/t)
Type of glass	Lead crystal glass	Magnesium crystal glass, lead crystal	SO_2 (3)	Not relevant - no sulphur in the batch composition
Cullet	100 % internal only	100 % internal only	HCl (3)	<3
Use of filter dust	yes	yes	HF (3)	<1
Specific energy consumption	Melting: 4.32 GJ/t glass Total: 7.70 GJ/t glass	Melting: 7.20 GJ/t glass Total: 10.58 GJ/t glass	Sb (3)	gaseous <0.01 particulate <0.01
Flue-gas volume	15000 – 20000 Nm^3/h (dry gas at operating O_2 content)	15000 - 20000 Nm^3/h (dry gas at operating O_2 content)	Pb (3)	gaseous <0.01 particulate 0.04

1. Abatement measures/techniques applied: bag filter for each furnace; the fumes from hot-end glass processing (volatilization of lead) are extracted.
2. Average of three half hour continuous measurements
3. Single measurements every two years (half-hour mean values)

Table 4.3: Example installation for the application of electric melting in the domestic glass sector (crystal and lead crystal glass)

[110, Austria, Domestic glass plants 2007]

Applicability

Electric melting is applicable in many parts of the glass industry and is widely used in several sectors including high temperature insulation wools, mineral wool, special glass, domestic glass and, to a lesser extent, in container glass. Electric melting can clearly only be installed at a furnace rebuild. There are no known full-scale examples of electric melting in the flat glass or frits sectors. The technique is commonly used for the production of potentially highly volatile, polluting glasses (e.g. lead crystal and opal glass) and for high value added products.

The wider use of the technique is limited by the operating costs and by some technical considerations. As discussed above, the main constraint is the operating cost and, depending on a range of factors, this sets an upper size limit on the economic viability.

At the time of writing the document (2008), the technique is not in use for large volume glass production (>300 tonnes per day) and so cannot be considered fully proven either technically or economically. The application of electric melting to the production of continuous filament glass fibre is not considered to be currently economically or technically viable, since E-glass often used for this type of product has a low alkali content resulting in very low electrical conductivity.

An experimental float glass line with an electrically heated furnace was in operation in the UK from 1989 to 2000. This plant was built to demonstrate the principle of cold top electric melting for float glass production. The plant has operated successfully on this pilot scale and it has been used to produce a range of exotic glasses, the emissions from which would have been very difficult to control from a conventionally fired furnace. The application demonstrated that operating a full-scale float glass line (>500 tonnes per day) with an all-electric furnace is not currently economically viable due to the high operating costs. The furnace is no longer in operation.

Economics

The economic viability of electric melting depends mainly on the price differential between electricity and fossil fuels. At the time of writing (2008), average electricity costs per unit energy are 4 to 5 times the cost of fuel oil. Electricity costs can vary by up to 100 % between Member States, but fossil fuel prices tend to show less difference. Fuel prices and their variations are discussed in Section 4.4.3.1. Electric furnaces are very thermally efficient; in general, 2 to 4 times better than air-fuel fired furnaces. The comparison for large, energy efficient furnaces is at the lower end of this range, and for smaller furnaces at the upper end.

Electric furnaces have much lower capital costs than conventional furnaces which, when annualised, partially compensate for the higher operating costs. However, the furnaces have shorter campaign lives before they require rebuild or repair, i.e. 2 to 6 years compared to 10 to 12 years for conventional furnaces. For small air-fuel conventional furnaces (up to around 50 tonnes/day), the heat losses are relatively high compared to larger furnaces. In the range of 10 to 50 tonnes/day, because of the higher specific heat losses of air-fuel furnaces, the electric furnace can be more competitive.

The comparison between an all-lectric melting furnace of about 30 tonnes/day, in the tableware/crystal glass sector, and a recuperative unit melter furnace shows a higher investment cost of about EUR 3 million, due to the shorter life time of the furnace, but lower operating costs (EUR 350000 lower). This results in slightly lower costs per tonne of molten glass.

Based on current practice, the following is proposed as a very general indicative guide to the size of electrical furnaces which may be viable, i.e. those which can potentially be a practicable alternative. There are inevitably exceptions due to local circumstances:

- furnaces below 75 tonnes per day are generally viable
- furnaces in the range 75 – 150 tonnes per day may be viable in some circumstances
- furnaces greater than 150 tonnes per day are generally unlikely to be viable.

The financial considerations can also be greatly affected by site-specific factors including: prevailing energy costs; product quality requirements, available space, costs of alternative abatement measures, prevailing legislation; ease of operation; and the anticipated operating life of alternative furnaces.

In those Member States where the price difference between fossil fuels and electricity is at the upper end of the range given, the option of electric melting may appear less attractive. In such cases this could lead the operator to select a combination of other techniques in preference to electric melting.

When using electric furnaces, the emissions of CO_2 associated with the melting process are low, since they only arise from the batch composition. The related operational costs would hardly be affected by European Directive 2003/87/EC, establishing an Emissions Trading Scheme for greenhouse gas emissions (EU-ETS). However, whether or not electric furnaces can be considered more "carbon" efficient will depend on the source of electricity. This may in turn have an indirect effect on the cost of electricity by the generator passing on EU-ETS costs.

An example installation, presenting the costs associated with the electric melting technique applied to the production of special, borosilicate glass is given in Table 4.4.

	Furnace 1	**Furnace 2**	**Air pollution control system and associated costs**	
Type of furnace	Electric furnace	Electric furnace	Filter type	Bag filter
Planned campaign	60 months	60 months	Temperature before filter	80 ºC
Max. crown temperature	230 °C	230 °C	Sorbent	$Ca(OH)_2$
Capacity	38 t/d	48 t/d	Amount of sorbent	3 (kg/h)
Current pull rate	35 t/d	45 t/d	Filter dust	Landfill
Type of glass	Borosilicate, white	Borosilicate, white	Energy consumption including ventilator	20 (kWh/h)
Cullet	70 %	70 %	Investment/ replacement costs	EUR 440000
Specific energy consumption	4.45 GJ/t glass	3.91 GJ/t glass	Duration of amortization	10 yrs
Use of filter dust	no	no	Operating costs	EUR 50000
			Annual amortization costs	EUR 58520
			Total annual costs	EUR 108520
			Estimated costs per tonne of glass	EUR 3.71/ t glass
Associated emission levels				
	Furnace 1		**Furnace 2**	
	$mg/Nm^{3(1)}$	**kg/t glass**	**$mg/Nm^{3(1)}$**	**kg/t glass**
Particulate matter	1.2	0.0017	0.8	0.0008
NOx [(2)]	72	0.39	103	0.29
SO_2	0.7	0.0037	4.7	0.013
HCl	5.1	0.028	22.0	0.061
1. Concentrations are referred to the measured oxygen content 2. NO_X emissions arise form the use of nitrates in the batch formulation				

Table 4.4: **Example installation for the application of electric melting in the special glass sector**

[75, Germany-HVG Glass Industry report 2007]

Driving force for implementation

The thermal efficiency of an electric furnace is better than the equivalent conventional furnace. Waste gas volumes are very low (only gases from batch decomposition). In Member States, where the energy strategy and policies favour nuclear, hydroelectric and wind power generation, the price of electricity might be more stable than the price of fossil fuels.

Example plants

Schott, Mainz, Germany - Special Glass.
British Gypsum Isover Ltd, Runcorn, UK - Glass Wool.
Saint-Gobain Desjonqueres, Mers-les-Bains, France - Container Glass.
Bormioli Luigi, Parma, Italy - Domestic Glass
Bormioli Rocco e Figlio, Bergantino, Italy - Container borosilicate glass

Reference literature

[65, Glass for Europe-Proposals for GLS revision 2007] [94, Beerkens - APC Evaluation 2008]

4.2.2 Operation and maintenance of furnaces

Description

The operation and maintenance of the melting furnace is a primary technique for minimising the environmental impact due to glass furnace ageing. This technique is normally applied to regenerative long life furnaces, but some of these recommendations can also be applied to other furnaces.

Combustion glass furnaces can be in operation for a long period of time and the tendency is to increase this period more and more; over 12 years in many cases. Refractory wearing and ageing as well as movement (expansion and contraction) happens throughout the furnace life and consequently losses of heat and energetic efficiency, along with cracks in the furnace superstructure can be produced. Depending on the furnace pressure, cracks can produce parasitic air infiltration.

Therefore, it is very important to establish permanent monitoring to ensure that the necessary maintenance is carried out for minimising the ageing effects and for optimising the operating conditions and their parameters.

The most important operations for refractory maintenance are:

- to ensure at all times that the furnace and regenerator walls are sealed to avoid parasitic air infiltrations
- to close and/or seal all furnace openings (e.g. peepholes, other holes for monitoring probes, dog houses and burner blocks) when not in use
- to improve heat transfer in regenerative furnaces, clean checkers when necessary, and to provide adequate maintenance of the heat exchangers in recuperative furnaces
- to keep the maximum insulation possible for the current furnace condition.

Regarding furnace operations, the established parameters must be kept constant depending on the production process and the primary techniques used by making the following adjustments, for instance:

- positioning burners and ensuring that they are sealed with burner blocks
- controlling the stabilised flame conditions, e.g. length, brightness and temperature distribution
- controlling air/fuel ratio.

Furnace monitoring and control is essential for obtaining the best results. An adequate maintenance programme should be established for the equipment used. Probes are usually less reliable than other electronic devices and need to be checked regularly.

Achieved environmental benefits

The most important benefits of this technique are the energy consumption and NO_X emissions reduction. Another benefit can be the reduction of dust emissions by decreasing carryover due to better positioning of the burners and better flame conditions.

In a well maintained furnace, ageing produces an increase in energy consumption that can be estimated for regenerative furnaces of between 1.5 and 3 % yearly, due to less insulation and less efficiency in the heat exchange. Poor maintenance can significantly increase these consumptions by more than an additional 0.5 % yearly.

Parasitic air infiltrations reduce energy efficiency because this air is not preheated and also because of a change in the combustion conditions. Also, the additional nitrogen coming into the furnace with the air increases NO_X production in an uncontrolled way. Special attention should be taken with the oxy-fired furnaces in order to avoid air infiltrations caused by a poor sealing of the furnace and/or the burner blocks which would generate NOx formation.

In addition to the reduction of NO_X emissions and energy consumption, this technique can improve productivity and the quality of the glass produced because it can increase the melting stability. Information assessing these improvements is not available yet.

In general, in a well- maintained furnace, the lifetime of the silica crown increases.

Cross-media effects
A solid waste stream is produced from the cleaning of checkers, which might be contaminated with refractories and/or metals. In this case, the dust (mainly sodium sulphate) cannot be recycled back to the melting furnace and the solid waste will have to be disposed of.

Operational data
Monitoring furnace parameters and closing all the furnace holes should be included in the good practices of furnace operation. The monitoring schedule will depend on the furnace (e.g. type, size, age, wear, type of checkers), the type of glass melted and produced, the type of fuel used (oil or gas), etc.

As an example, a monitoring schedule could be as follows:

- for parasitic air entries (holes, fissures): daily visual inspection and action (to seal) when necessary
- for regenerators: visual inspections to be carried out regularly by plant operators; clean checkers when necessary.

The cleaning of checkers produces sulphate dust.

In addition to NO_X and the reduction of energy consumption, the maintenance of the furnace can improve productivity and the quality of the glass produced because it can improve the melting stability. Information assessing these improvements is not available yet.

Applicability
This technique can be applied during the life of existing or new furnaces. It is more useful for recuperative and long life regenerative furnaces. It can also be considered for other furnaces, but requires a specific assessment in every case.

Economics
The costs associated with the application of this technique include the training of qualified personnel for supervision and maintenance, the purchase of necessary equipment, such as cameras, sensors for oxygen and for temperature measurements. If sulphate dust is sent to landfill, an additional cost will be incurred.
However, maintenance costs do not compare to the benefits obtained from the energy savings, better quality products and greater productivity.

Driving force for implementation
Legal requirements for NO_X emissions can be more difficult to accomplish at the end of the life of a furnace. Only maintaining the furnaces in the best possible condition can reduce the increase of these emissions.

Example plants
Most large glass container companies, such as Saint Gobain, Owens-Illinois (O-I), Ardagh Glass are applying this technique to their furnaces. {More plants should be indicated}

Reference to literature
[75, Germany-HVG Glass Industry report 2007] [78, DUTCH oxi-firing furnaces 2007] [79, TNO OxyFiring2005ATIVFinal 2005] [85, Spanish BAT Glass Guide 2007]

4.3 Techniques for materials handling

The diversity of the glass industry results in the use of a wide range of raw materials. The majority of these materials are solid inorganic compounds, either naturally occurring minerals or man-made products. They vary from very coarse materials to finely divided powders. Liquids and, to a lesser extent, gases are also used within most sectors. The general techniques used for materials handling are described inSection 2.1. There are very few issues regarding emissions to air from materials handling that are specific to the glass industry. Therefore, this section only summarises those techniques, which are generally considered to constitute good practice when handling these types of materials.

Bulk powder materials are usually stored in silos, and emissions can be minimised by using enclosed silos, which are vented to suitable dust abatement equipment such as fabric filters. Where practicable, collected material can be returned to the silo or recycled to the furnace. Where the amount of material used does not require the use of silos, fine materials can be stored in enclosed containers or sealed bags. Stockpiles of coarse dusty materials can be stored under cover to prevent windborne emissions.

Attention must be paid to the storage of post-consumer cullet, being a potential source of dust, fugitive emissions and odour deriving from the organic residues contained in the raw material. Where dust is a particular problem, some installations may require the use of road cleaning vehicles and water damping techniques.

In general, dust from flue-gas treatment systems is very fine and may contain significant amounts of unreacted alkaline reagent. Consequently, the handling and storage of this material require particular care.

Where materials are transported by above ground conveyors, some type of enclosure to provide wind protection is necessary to prevent substantial material loss. These systems can be designed to enclose the conveyor on all sides. Where pneumatic conveying is used, it is important to provide a sealed system with a filter to clean the transport air before release. To reduce dust during conveying and carryover of fine particles out of the furnace, a percentage of water can be maintained in the batch, usually 0 - 4 %. Some processes (e.g. borosilicate glass production) use dry batch materials, and where dry materials are used, the potential for dust emissions is higher and, therefore, greater care is needed.

An area where dust emissions are common is the furnace feed area. The main measures/techniques for controlling emissions in this area are listed below:

- moistening of the batch
- application of a slightly negative pressure within the furnace (only applicable as an inherent aspect of operation)
- use of raw materials that do not cause decrepitation phenomena (mainly dolomite and limestone)
- provision of extraction, which vents to a filter system, (common in cold top melters)
- use of enclosed screw feeders
- enclosure of feed pockets (cooling may be necessary).

Dust emissions can occur directly to the air or may occur within the process buildings. Where this occurs, dust can build up within the building and can lead to fugitive emissions by the movement of air currents in and out of the building. In potentially very dusty areas such as batch plants, the buildings can be designed with the minimum of openings and doors, or dust curtains can be provided where necessary. In the furnace buildings, it is often necessary to ensure a degree of natural cooling and so vents, etc. are provided. It is important to ensure a good standard of housekeeping and that all dust control measures (seals, extraction, etc) are properly functioning.

Areas of the process where dust is likely to be generated (e.g. bag opening, frits batch mixing, fabric filter dust disposal, etc) can be provided with extraction which vents to a suitable abatement plant. This can be important at smaller installations where a higher degree of manual handling takes place. All of these techniques are particularly relevant where more toxic raw materials are handled and stored, e.g. lead oxide and fluorine compounds.

Volatile raw materials can be stored so as to minimise emissions to air. In general, bulk storage temperatures should be kept as low as practicable and temperature changes due to solar heating, etc. should be taken into account. For materials with a significant vapour pressure, or for odorous substances, specific techniques may be necessary for reducing releases arising from tank breathing or from the displacement of vapour during liquid transfers.

Measures/techniques for reducing losses from storage tanks at atmospheric pressure include the following:

- use of tank paint with low solar absorbency
- control of temperature
- tank insulation
- inventory management
- use of floating roof tanks
- use of vapour return transfer systems
- use of bladder roof tanks
- use of pressure/vacuum valves, where tanks are designed to withstand pressure fluctuations
- application of a specific release treatment e.g. adsorption, absorption, condensation
- subsurface filling.

Reference to literature
[121, Reference Document on Best Available Techniques on Emissions from Storage, European Commission 2006]

4.4 Techniques for controlling emissions to air from melting activities

4.4.1 Particulate matter

For the purposes of this document, the term 'particulate matter' is taken to mean all material that is solid at the point of measurement, and for emissions from melting activities is considered to be synonymous with the term dust. Both of these terms are used interchangeably throughout this chapter. The term 'total particulate matter' is taken to mean all inorganic and organic solid materials (with no lower size limit), droplets and aerosols. The temperature at the point of measurement is particularly important for glass furnaces because some of the materials that form dust (particularly borates) can be volatile at quite low temperatures. Also the nature of the dust from these processes makes accurate measurement very difficult.

The nature of the dust emissions from glass furnaces varies for different processes, but depends mainly on the furnace design and operation, and on the glass composition.

The three main sources of dust from melting are:

- batch material carryover
- volatilisation and reaction of substances from batch materials and the glass melt
- metal impurities in the fuels
- chemical reaction between gaseous pollutants and alkaline reagents used for waste gas treatment.

For fossil fuelled furnaces, the volatilisation and subsequent reaction/condensation of volatile materials released from the hot glass surface, represents by far the largest proportion of the overall dust emissions. In general, 80 to 95 % of the dust emissions will be produced in this way. It is therefore important to ensure that any volatile species have been condensed before the waste gas is treated or measured. This is not a problem for sodium sulphate (melting point approx. 888 °C) but is a consideration for flue-gases which contain borates.

Carryover of batch materials usually accounts for less than 5 % of the final emissions from a modern, well-operated furnace. This dust is made up of the components of the batch, and is dominated by the lightest materials.

Metal impurities in fuels (vanadium and nickel) will contribute to dust emissions, but at a level generally significantly below 5 % of the total. These impurities arise mainly with fuel oil, which may also add a small amount of ash to the total. Metal impurities also occur in cullet and other raw materials.

The mechanisms of material volatilisation and particulate formulation are not fully understood for all glass types. In particular, for SO_2 rich flue-gases (oil-fired furnaces) the mechanism of particulate formation is rather complex at temperatures below 400 °C, with different compounds that can be formed (sodium hydrogen sulphate $NaHSO_4$, sodium pyrosulphate $Na_2S_2O_7$ and sulphuric acid H_2SO_4) which could heavily affect the reliability of particulate concentration measurements if not taken into account. Approximately 90 % of all glass produced in the EU is soda-lime glass, and most information is available for these compositions. Dust from soda-lime glass furnaces is predominantly composed of sodium sulphate. Up to 98 % of the dust is made up of soluble materials; of this, 80 – 90 % is sodium sulphate. The remainder will depend on the precise glass composition, but will contain mainly sulphates, particularly potassium sulphate (K_2SO_4). The insoluble fraction contains mainly silica, with lower levels of metals (e.g. Al, Fe, and Cr). If external cullet is used, the dust may contain other components (e.g. Pb). The particle diameter is generally in the range of 0.02 to 1 µm, but the small particulates readily agglomerate into larger particles. A number of different volatilisation processes can be distinguished and are discussed inSection 4.4.1.1 below.

For glasses that contain substantial levels of boron in the composition (e.g. continuous filament glass fibre, glass wool, and borosilicate glass), borates are a major component of the emitted dust. The remainder will be made up of sulphates, silica and compounds dependent on minor batch components and impurities.

Since the batch compositions may differ strongly for the different types of glasses, the resulting dust emissions are also diverse and follow different formation mechanisms. In the mineral glass wool production, the batch composition contains high levels of boron oxide but also large amounts of sodium oxide that, during melting, evaporate and subsequently form solid sodium metaborate ($NaBO_2$) at temperatures of below 900 °C, down to 650 – 700 °C. Small quantities of boron are emitted in gaseous form, mainly as metaboric acid (HBO_2). Boric acids, HBO_2 and H_3BO_3, condensate to form particulates at much lower temperatures, and some gaseous fractions can still be present at 60 °C.

In the production of E-glass for continuous filament glass fibre, the low concentration of alkali oxides (typically around 1 % in mass) affects the mechanism of dust formation leading to a dominant evaporation of metaboric acid (HBO_2),compared to sodium metaborate ($NaBO_2$)or potassium metaborate (KBO_2) evaporation. During flue-gas cooling, almost all sodium and potassium will condensate to form sulphates, generated by the presence of SO_2 from fining the glass melt with sodium sulphate and, to a lower extent, alkali borates. In this case, most boric acid species will be present in the flue-gas as gaseous compounds at temperatures below of 200 °C, but also as low as 60 °C. In the case of borosilicate glasses, the mechanism formation of dust strongly affects the capability of filtration systems to remove boron species present in the flue-gas, since the operating temperatures could be too high for capturing boric acid species, unless a suitable scrubbing agent is injected upstream of the filtering unit.

In many cases, when gaseous boron compounds are present in the flue-gas of the melting furnace, the particulate content (as measured) strongly depends on the measuring method applied and on the temperature of the waste gas at the sampling point.

In lead glass (TV and crystal glass), lead volatilisation will produce lead oxide or sometimes lead sulphate condensations.

In cold top electric melters, the emissions of dust are much lower and arise almost exclusively from batch material carryover. The absence of the high temperature combustion atmosphere precludes the formation of particulate matter by reactive volatilisation. In stone wool cupola furnaces, the dust emissions are a combination of raw material dust, combustion products, and condensed volatiles released during melting.

The emissions to air of metals from glass processes are largely contained in the particulate matter. For this reason, metals are not treated separately in this chapter but are discussed in respect to dust emissions and, where appropriate, references are made to other sections. However, in some circumstances there can be significant gaseous metal emissions, for example, selenium from bronze or decolourised glasses, lead from some lead crystal or special glass processes, or impurities from external cullet (lead, selenium, etc).

The main sources of metals are impurities in raw materials, the use of specific substances and additives in the batch formulation utilised to impart specific properties (e.g. lead oxides, and colourants/decolourants), cullet and fuel. External cullet is an important source of metal contamination particularly for lead (in some cases >400 ppm) but also for other metals; for example, mercury contamination can occur if cullet contains mercury vapour light tubes. Information on metal emission levels is given in the sector-specific sections in Chapter 3 and in Table 3.3.

There are three main approaches for controlling emissions of metals either within the dust or as gaseous components:

1. raw material selection to minimise contamination and where practicable to use alternative additives. Raw material selection includes cullet sourcing and sorting
2. dust abatement techniques, particularly bag filter systems and electrostatic precipitators. Where emissions contain significant metal concentration, up to 70 - 80 % of total dust (i.e lead crystal glass production), high efficiency dust abatement systems can generally reduce both dust and metal emissions to <5 mg/Nm^3
3. gaseous metal emissions (e.g. selenium) can be substantially reduced by the use of dry or semi-dry scrubbing techniques in combination with dust abatement (see Section 4.4.3.3).

In some instances, and particularly in Germany, a major factor in the driving force for the installation of dust abatement combined with dry or semi-dry scrubbing has been the reduction of metal emissions.

4.4.1.1 Primary techniques

[tm18 CPIV, tm30 Dust][19, CPIV 1998][31, CPIV 1998]

A glass furnace is a very dynamic environment and any changes to the chemistry or operating conditions can have consequential effects within the melting process, and on other emissions. For this reason it is important to consider all the primary techniques described in this document as a package rather than simply as individual techniques. However, for clarity, the techniques have necessarily been described separately, but consequential effects have been discussed where possible.A low level of emissions from material carryover is achieved by maintaining a level of moisture in the raw materials and by controlling the batch blanket coverage, particle size, gas velocity and burner positioning. For those processes which require dry batch materials, and/or very fine batch materials, the figures may be slightly higher.

However, the contribution to the overall emissions will still be minor compared to the volatile species contribution. Issues relating to dust arising from material charging are dealt with in Section 4.3 above.

Because the dust emissions arise mainly from volatile species, the primary abatement techniques discussed here concentrate on this source. From dust analysis of soda-lime furnaces, it can be concluded that sodium species are the major components leading to dust formation in flue-gases. Volatile species from the batch (e.g. NaCl) and from the melt (e.g. NaOH) react with sulphur oxides to form sodium sulphate (Na_2SO_4) which condenses in the waste gas below 1100 °C. In most cases, sodium sulphate is used as the fining agent. The dissociation of the sodium sulphate in the molten glass leads to sulphur oxide concentrations, which are much higher than the sodium component concentrations in the combustion chamber and in the flue-gases. The oxides of sulphur from fuel combustion or batch sulphate are available in stoichiometric excess compared to the volatilised sodium, which is the governing parameter for dust formation. The main sources of sodium are the cullet or soda ash and, to a minor extent, sodium sulphate. However, the use of high amounts of sodium sulphate in the batch composition causes an increase in dust emissions.

In very sulphur lean gases, sodium chloride, sodium fluoride or sodium carbonate particles can be formed during the cooling of the flue-gases to below 900 °C. This is not common, and can only occur when natural gas is used and when sodium sulphate is replaced by another fining agent, like antimony. This is never the case for container or flat glass but could happen in special applications.

A number of different volatilisation processes can be distinguished in soda-lime glass:

- reactive volatilisation from the molten glass surface. The sodium oxide (Na_2O) in the silicate melt reacts at the surface with water vapour: Na_2O (melt) + $H_2O \rightarrow 2$ NaOH (g). This type of volatilisation may be the major source of dust emissions in soda-lime glass furnaces
- volatilisation of the NaCl present as an impurity in synthetic soda. This volatilisation leads not only to sodium sulphate dust but also to HCl formation
- volatilisation of sodium sulphate from the surface of molten glass
- reactive volatilisation by chemical reactions at the batch blanket surface with components in the furnace atmosphere. The water vapour in the combustion chamber is thought to be important for the reaction of soda ash to form sodium hydroxide vapours, with similar reactions for potassium compounds: $Na_2CO_3 + H_2O \rightarrow 2NaOH(g) + CO_2$
- volatilisation of raw material components from the surface of the batch blanket (e.g. sand, feldspars, lime, soda ash, dolomite and sodium sulphate) is generally very low. Vapour pressures are very low below 1200 °C, and above 1000 °C, the single components have already reacted to form silicates
- volatilisation of sodium compounds in gas bubbles during the fining process is also of relatively minor importance
- in the case of the recycling of external cullet (container furnaces), emissions of lead components (PbO, $PbCO_3$, $PbSO_4$) might take place because of lead glass, mirror fragments and metallic lead contaminants in the cullet.

The situation is different for other glass types. For boron glasses containing low alkali (e.g E-Glass), reactive volatilisation is thought to be the main source of particulate matter. The emitted dust is made up mainly of the reaction products of sodium and potassium with SO_2 and partly of alkali borates. As already explained in Section 4.4.1, metaboric acid is formed by the reaction of boric acid with water vapour - B_2O_3 (liquid) + $H_2O \rightarrow 2HBO_2$(gas) and is present in a gaseous form in the flue-gases even at low temperatures. For higher alkali-boron containing glasses (e.g. glass wool), the emitted dust is mainly composed of alkali borates, with lower levels of boric acids. Dust formation by volatilisation occurs very readily for glasses which contain boron and the concentration of unabated emissions is generally higher than for soda-lime glasses. In some cases they are more than ten times higher.

The types of volatilisation mechanisms described for soda-lime glass are the general basis of volatilisation in most other glasses, but clearly there is variation depending on the chemistry.

The most important factors affecting volatilisation are temperature, water vapour content in the furnace atmosphere, and the velocities of the gases at the surface of the melt. The availability of reactive species is also an important factor, particularly sodium and sulphates in soda-lime glass, and boron in boron glasses. However, this factor is often limited by the glass chemistry.

A particular situation occurs when oxy-fuel combustion is applied for the melting process. The reduced flue-gas volume with lower flue-gas velocities and the significantly different composition of the combustion gases in contact with the glass melt (much higher concentration of water vapour and CO_2) affect the volatilisation processes resulting, in general, in a reduced dust formation and lower emissions in terms of kg/tonne glass, although this effect strongly depends on the furnace design, type and positioning of the burners.

The most important primary measures that can be taken to reduce dust emissions are outlined below:

a. Raw material modifications

Sodium chloride can be a significant factor in emissions of dust and chlorides. It is used in some special glasses as a refining agent, but is more usually present as a low level impurity in soda ash made by the Solvay process. Pressure from the glass industry has led soda ash producers to lower NaCl levels significantly (now generally around 1 kg/tonne). A further significant reduction in the short term would probably require further processing and therefore an increase in price. Natural soda ash is available which is virtually NaCl-free, but this material is generally more expensive in the EU due to taxes and transport costs from the countries of origin.

In most furnaces, the batch sulphate levels have been reduced to the minimum commensurate with good fining and maintaining the correct oxidation state of the glass. Alternatives to sodium sulphate can pose a greater environmental problem, e.g. arsenic and antimony-based fining agents. Further progress in this area is not expected to yield substantial emissions reductions. The limiting factor is thought to be the concentration of the sodium containing vapours, but for gas-fired furnaces, very reduced sulphate concentrations would limit the reaction in the gas phase.

In glasses containing boron, the boron is essential to the forming of the products and the product characteristics. In recent years, substantial reductions have been made in boron levels, but further progress is becoming difficult without affecting the productivity, energy consumption and quality. Boron-containing materials are relatively expensive and every effort is made to reduce consumption. At the time of writing no credible alternatives to boron are available and the difficulties have led many operators to install secondary abatement techniques, particularly for glass wool and borosilicate furnaces. In general, abated dusts are recycled to the furnace.

A number of companies in the continuous filament glass fibre sector have developed glass compositions that have low levels of boron and fluorine or only contain these elements due to trace levels in the raw materials. Emissions below 0.14 kg/tonne melted glass have been reported, to be compared with values of around 2 kg/tonne melted glass for formulations containing boron where no primary measures are applied, which demonstrate the importance of boron in the dust formation. This type of glass requires a higher melting temperature, is more difficult to fiberise, and the long-term effects on refractory life have yet to be determined. The details of the technique are proprietary, and therefore, although extremely promising, the technique cannot yet be considered as generally available. Progress varies between the different companies, but several of these formulations are now marketable.

b. Temperature reduction at the melt surface

The crown temperature is an important factor in particulate formation, as more volatile species are generated at higher temperatures. A correlation between crown temperature, the glass melt surface temperature and particulate formation has been shown in soda-lime furnaces. Reduction of furnace temperature must be balanced with glass quality, the productivity of the furnace, and other environmental aspects such as the NO_X concentration in the flue-gas. Measures which have the greatest effect in reducing dust per tonne of glass are those which improve the energy efficiency and particularly the heat transfer to the glass. The main points are:

- furnace design and geometry to improve convective currents and heat transfer. These modifications can only be implemented at the furnace rebuild. Larger furnaces are generally more energy efficient also resulting in lower emissions per tonne of glass
- use of electric boost which helps to reduce the crown temperature by putting energy directly into the melt and improving convective currents. The positioning of the electrodes is important, but this is difficult to change except at the furnace rebuild. The use of electric boost is usually limited by the cost of electricity
- the increased use of cullet which will reduce the melting energy requirement allowing operation at a lower temperature and lower fuel usage. Also, because cullet has already been melted its use helps to reduce the level of some of the volatile and reactive species, which contribute to dust formation, e.g. sodium chloride and batch sulphates. This is particularly relevant in oil or mixed oil/gas fired furnaces where a reduction in the fuel requirement, due to the use of cullet, reduces SO_2 levels. Cullet usage is limited by the availability of cullet at the correct quality, composition and affordability. For example, container glass furnaces use 5 – 95 % cullet (internal and external), soda-lime domestic glass and flat glass furnaces generally 10 – 40 % (usually only internal), and continuous filament glass fibre furnaces rarely use any cullet.

c. Burner positioning

Another important factor in the rate of volatilisation from the melt is the rate of replacement of the gases above the melt. A high gas velocity or a high level of turbulence at the surface of the melt will increase the rate of volatilisation. Progress has been made with burner positioning to optimise combustion air velocity and direction, and fuel velocity and direction. Further work has also been carried out involving combining these changes with modifications to the furnace width and length of the unfired portion of the blanket, with the aim of reducing the flue-gas velocity over the glass melt and the stripping effect on volatile components of the batch formulation. Changes that involve modifications to furnace design can only be implemented at furnace rebuild, and other changes are sometimes most effective when implemented with furnace redesign. When changing the positioning of the burners, it is important to avoid reducing flames touching the melt, since this would increase dust emissions and would promote refractory attack in the superstructure, with possible effects on the glass quality.

d. Conversion to gas firing (or very low sulphur oils)

Conversion from fuel oil firing to natural gas firing can give substantial reductions in dust emissions. The reasons for this are probably the particular condensation reactions for particulates with gas firing than with oil, although in some cases the reduced SO_X levels might also be a factor.

For example, the flat glass sector has reported dust emission reductions in excess of 25 % for the conversion from oil to gas firing. The flat glass sector has also reported a significant effect from reducing the sulphur content of the oil (20 mg/Nm^3 reduction in dust per 1 % reduction in oil sulphur content). A similar effect was observed in domestic glass with low sulphur oil (<1 %). Conversion to natural gas firing is discussed in more detail in Section 4.4.3.1. The main points are summarised below:

- the majority of plants are already equipped to use either fuel, although some may not have access to a natural gas or a fuel oil supply
- costs of the technique will depend mainly on the prevailing fuel prices
- there is concern within the industry that heat transfer to the melt is poorer than with oil firing due to the lower luminosity/emissivity of the flame
- natural gas firing can result in higher NO_X emissions compared with oil firing
- some cases of mixed combustion, using both types of fuels simultaneously in one furnace, may give interesting compromises of the two types of melting processes. Emissions of NO_x, SO_x and dust can be balanced according to the local environmental requirements.

e. Other techniques

Emissions from cold top electric melters can be minimised by reducing airflows and turbulence during charging, and by raw material grain size and moisture optimisation. Primary measures are rarely implemented for dust emissions from stone wool cupolas. The main action that could be taken would be washing the raw materials to remove dust. However, most cupolas are fitted with bag filters and so there is little incentive to take primary measures, because they are very unlikely to change the need for secondary measures.

The main advantages and disadvantages of primary techniques for the reduction of dust emissions are shown in Table 4.5.

Advantages

- low cost
- focus on prevention rather than abatement
- techniques do not involve the use of energy or the potential solid wastes that can be associated with secondary techniques

Disadvantages:

- primary measures/techniques cannot meet the emission levels associated with secondary techniques such as electrostatic precipitators. This is unlikely to change in the foreseeable future
- primary measures/techniques place additional operating constraints on the process

Table 4.5: Main advantages and disadvantages of primary techniques for dust reduction

Achieved environmental benefits

The emission levels achievable using primary techniques are difficult to quantify, because of the wide range of factors that can affect the results and the wide variation in furnace types and glass formulations.

For flame-fired furnaces, the lowest emission levels, using only primary abatement techniques, are achieved by furnaces producing soda-lime glasses. Average mass emissions are around 0.4 kg/tonne of glass melted, and the majority of the emission concentrations fall into the range of 100 – 300 mg/Nm^3. There are some furnaces achieving less than 100 mg/Nm^3 for dust, but these are not common.

At the time of writing, few plants have dust emission levels of below 100 mg/Nm^3 without secondary abatement, and 100 – 200 mg/Nm^3 ($\leq$0.4 kg/tonne of glass) is considered currently achievable with primary measures.
It is unlikely that these figures could be achieved for compositions other than soda-lime glass. In general, for other compositions the optimisation of primary techniques could be expected to reduce emissions by 10 – 30 % of the starting value associated with a condition when no specific measures are applied to limit dust emissions.

Cross-media effects

In general, the techniques described prevent emissions without using additional chemicals/substances so the cross-media effects are assumed to be positive. However, a modification of the raw materials used for the preparation of the batch composition, with the scope of reducing volatile components, could result in an increase of specific energy consumption. For instance, the addition of water to the batch composition to suppress carryover or the substitution of a raw material with one less volatile but requiring a higher melting temperature normally results in an increase of energy consumption. A temperature reduction at melt surface might affect the quality of glass, leading to higher rates of rejected finished articles and higher specific energy consumption per unit of saleable product. A different positioning of the burners applied to minimise volatilisation phenomena might cause a decrease in the energy efficiency of the furnace with a consequent increase of specific emissions from combustion; in addition, a modification of the evaporation/condensation phenomena of the deposited salts may occur with potential damage to the refractories exposed to the flue-gas.

The conversion from fuel oil firing to natural gas firing is normally associated with an increase of NO_x emissions.

Operational data

Included in the descriptions.

Applicability

The techniques described are considered to be generally applicable to all parts of the industry within the constraints identified. However, techniques successfully implemented in one furnace may not have the same effects for other furnaces. In the short to medium term, primary measures for dust abatement are likely to achieve more significant reductions for soda-lime formulations than for other glass types. An exception may be represented by the continuous filament glass fibre produced with low or boron-free formulations.

Economics

Very little information is available on the costs of primary techniques, but the industry has reported that the costs of the measures implemented to date (2009) are considered to be low. Indeed those techniques that reduce energy usage may result in cost savings. Costs relating to gas firing are discussed in Section 4.4.3.1.

Primary measures can involve varying costs depending on the level and time scale of the application. The measures are an overall package and it is the optimisation of the package that determines the costs and results. For example, the use of low chloride or natural soda ash is unlikely to reduce dust emissions to levels comparable to secondary abatement, and depending on other factors the costs may be disproportionate to the benefits. However, it is one aspect of the package of measures, the costs and results of which, must be considered as a whole.

Driving force for implementation

The implementation of primary measures for the reduction of dust emissions is often based on economic and operational benefits deriving from the application of the selected techniques, such as avoiding the clogging of regenerators, corrosion or damage of the materials, reducing volatilisation and the consequent loss of valuable raw materials, etc.

Example plants

The application of some of the primary techniques described in this section is common within the glass industry.

Reference literature[tm18 CPIV, tm30 Dust] [19, CPIV 1998] [31, CPIV 1998] [103, Beerkens Fining glass. Boron 2008]

4.4.1.2 Electrostatic precipitators

Description

The electrostatic precipitator (ESP) is capable of operating over a wide range of conditions of temperature, pressure and particulate burden. It is not particularly sensitive to particle size, and can collect particulates in both wet and dry conditions. The ESP consists of a series of high voltage discharge electrodes and corresponding collector electrodes. Particles are charged and subsequently separated from the gas stream under the influence of the electric field generated between the electrodes. The electrical field is applied across the electrodes by a small direct current at a high voltage (up to 80kV). In practice, an ESP is divided into a number of discrete zones (up to five fields can be used) as shown in Figure 4.1.

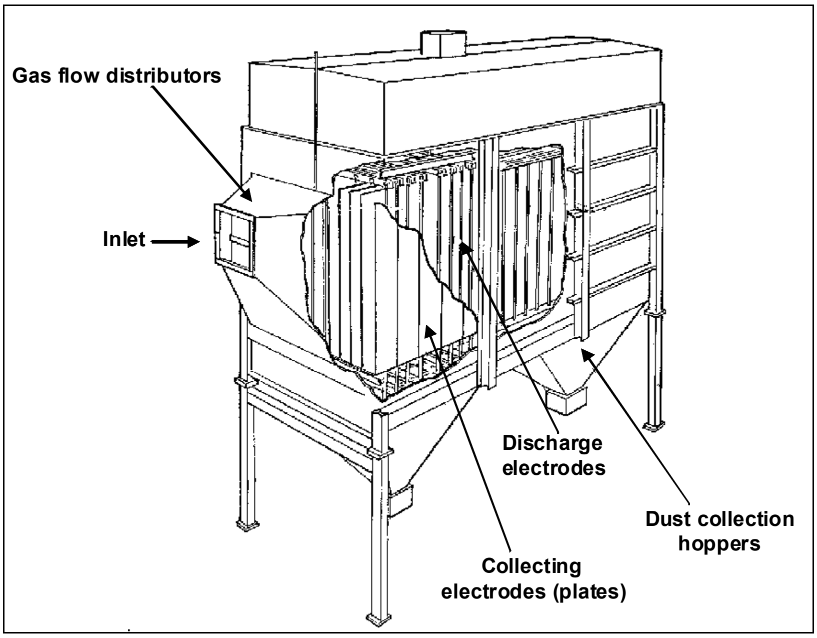


Figure 4.1: **Electrostatic precipitator**

Particles are removed from the gas stream in four stages:

- application of an electrical charge to the particles
- migration of the particles within the electrical field
- capture of the particles onto the collecting electrode
- removal of the particles from the surface of the electrode.

The discharge electrodes must be rapped or vibrated to prevent material build-up and their mechanical strength must be compatible with transmission of the rapping blow or vibration. The mechanical reliability of the discharge electrodes and their supporting frame is important as a single broken wire can short out an entire electrical field of the precipitator. In wet precipitators, the collected material is removed from the collector plates by flushing with a suitable liquid, usually water, either intermittently or by continuous spray irrigation.

The performance of an ESP follows the Deutsch Formula, which relates dust collection efficiency to the total surface area of collector electrodes, the volumetric flow rate of the gases and the migration velocity of the particles. For a given material, maximising the surface area of the collector electrodes and the residence time in the electrical fields are two of the most important parameters. Also, the larger the distance between collecting electrodes, the higher the voltage that can be applied. This distance is dependent on the supplier design.

Good rectifier design includes the use of separate rectifier sections for each zone or portion of a zone of the ESP.

This allows the applied voltage to be varied in the inlet and outlet zones, in order to take account of the reduced particulate load towards the outlet, and allows operation of the zones at progressively higher voltages. Good design is also influenced by the use of automatic control systems, which ensure that the optimum high-tension (HT) voltage is applied to the electrodes. Fixed HT power supplies are unlikely to provide optimal collection efficiencies.

The resistivity (the inverse of the conductivity) of the particulate material is particularly important. If it is too low, the particles reaching the collector electrode lose their charge easily and particulate re-entrainment can occur. When the particulate has too high a resistivity, an insulating layer is formed on the electrode, which hinders normal corona discharge and leads to reduced collection efficiency. Most particulates encountered in the glass industry have a resistivity within the correct range. However, if necessary collection can be improved by conditioning the particulate, e.g. ammonia and sulphur trioxide can be used, but this is not generally necessary in glass processes. The resistivity can also be reduced by reducing the gas temperature or by adding moisture to the gas.

Achieved environmental benefits

ESPs are very effective in collecting dust in the range of 0.1 to 10 µm, and overall collection efficiency can be 95 – 99 % (depending on inlet concentration and ESP size). Actual performance varies depending mainly on waste gas characteristics and ESP design, but emission concentrations in the range of 5 to 10 mg/Nm^3 can be achieved with new installations. For existing ESPs, the possibilities for significant upgrading can be limited, due to construction and operating restrictions and in such cases the achieved performance may be in the range of 20 - 30 mg/Nm^3. Although an important factor, the performance does not depend exclusively on the number of electrical fields applied. A two-stage ESP of one design may be as efficient as a three-stage ESP of a different design or in a different application, and the choice will depend on the necessary performance level. The efficiency of ESPs in collecting dust from flue-gases containing boron compounds may vary significantly depending on the positioning of the filter, and weather or not condensation of boric acid takes place before or after the filter.

Cross-media effects

The use of electrostatic precipitators involves an increase in energy consumption, but this is low relative to the energy consumption of the furnace, less than 1 % (which is equal to 1 - 3 % of energy cost). There will be a resultant environmental effect at the point of electricity generation, which will depend on the source of the electricity.

In many applications within the glass industry, it will be necessary to remove acid gases prior to treatment. This will usually be achieved by dry or semi-dry scrubbing which creates a solid material stream up to ten times greater than the dust abated. If this can be recycled to the furnace there will be an overall reduction in the consumption of raw materials; if not, there will be a waste stream to dispose of.

In practice, the collected dust can be recycled in most cases and, depending on the sorbent chosen, the material can replace a portion of the other raw materials particularly sodium sulphate (and where appropriate materials containing fluoride and lead). Problems could occur in the container glass sector where the sulphate requirements may be low, due to high cullet levels and for reduced glasses, where the sulphur solubility is relatively low.

This could limit the potential for recycling dust especially if a high sulphur fuel oil is used, and a portion of the collected dust would have to be disposed of off-site. A further problem could occur if multiple furnaces producing different types and/or colours of glass are attached to a single ESP. In some sectors, the ability to recycle the collected dust may be limited by product quality constraints and glass chemistry, for example, where a very high optical quality is required.Additional limitations to the possibility of recycling filter dust are present when dry batch preheating is applied, due to the fine dust which can cause severe carryover and plugging of the regenerators.

The recycling of filter dust with high concentrations of NaCl, normally originated from treating the waste gases with sodium-based absorption agents, can cause damage to the refractories in the combustion chamber and/or in the regenerators, depending on the temperature and the composition of the checkers.

The costs of disposing of a dust that cannot be recycled (including the costs for classification of the residue) and the costs of lower sulphur fuels (e.g. low sulphur oil or natural gas) might have to be compared in many circumstances (particularly for container glass) in order to evaluate whether it would be more convenient for an operator to change fuels rather than create a solid waste stream for disposal. One of the main purposes of the acid gas scrubbing phase is often to condition the gas for the ESP, in order to avoid corrosion, with consequently lower overall acid gas emissions. If the filter dust is recycled, a dynamic equilibrium between sulpur input and output will form.

In the glass industry, the majority of the particulate matter emitted is formed by reactive volatilisation. It is therefore important to ensure that the gas stream is below the particulate formation temperature, which depends on the species present. The major constituent of dust from soda-lime silica glass production is sodium sulphate with a formation temperature at ≈ 800 °C; while for borosilicate glasses, the complete condensation of boron species may occur well below 200 °C.

In regenerative furnaces, the waste gas temperature is generally around 400 °C and cooling is not usually required either to condense volatiles or to achieve the ESP operating limits. In recuperative furnaces, the waste gas temperature is usually around 800 °C and cooling is required, both to condense the particulate matter and to cool the gas to the limits of the ESP. As already reported above, for glasses which contain boron (e.g. glass wool), it may be necessary to reduce the gas temperature to below 200 °C prior to abatement, whilst ensuring that condensation and the associated risk of corrosion are minimised in the system. The waste gas temperature from oxy-fuel furnaces is usually >1000 °C and substantial cooling is required.
A summary of the main advantages and disadvantages associated with the use of ESPs is shown in Table 4.6.

Advantages:

- high dust removal efficiency
- collected dust is generally in a form that permits re-use
- low pressure drop relative to bag filters, and so operating costs are relatively low
- can form part of an integrated treatment system e.g. with scrubbers and SCR
- ESPs are not easily blocked due to high load or moisture content, which can be a problem with fabric filters
- in general (i.e. not restricted to the glass industry), there is more operating experience at high temperature than for bag filters
- can be designed to allow addition of further fields at a later date

Disadvantages:

- energy use. Although this is low relative to furnace energy (<1 %), costs are more significant because it is electricity. Indirect emissions are associated with the use of electricity (CO_2 and other emissions at the power station)
- solid waste streams generated are not always possible to recycle
- many processes require acid gas scrubbing and in these cases an absorbent is consumed. Indirect emissions are associated with the use of alkaline reagents (production cycle of the material)
- ESPs can involve higher capital costs than some other systems
- it is critical to maintain plant operations within the design conditions or performance can drop considerably
- safety precautions must be observed in the use of high voltage equipment
- ESPs can be very large and the space requirement must be considered

Table 4.6: Main advantages and disadvantages of electrostatic precipitators

Operational data

In most applications, a well designed two or three stage ESP could be expected to achieve less than 10 mg/Nm^3 and less than 0.04 kg dust per tonne of glass melted. For certain existing ESPs, this can be limited to less than 30 mg/Nm^3 dust emissions. In the glass industry, almost all examples of ESPs are two or three stage and the most recent installations can achieve the figures indicated. In many applications, ESPs can achieve figures below these levels either due to favourable conditions or because high efficiency designs are used. Emission levels for ESPs lower than 5 mg/Nm^3 are measured in a number of installations; however, except where favourable conditions exist, to guarantee performance at this level would generally involve costs higher than those identified in this section.

The application of an ESP is, in general, common at installations with several furnaces.

At the time of writing this document (2009), many big furnaces/installations were equipped with continuous particulate or opacity monitoring. In regenerative furnaces with reverse firing, representative data should always be an average of the emissions produced during a multiple of firing time.

To achieve the best performance from an ESP, it is essential that the gas flow through the unit is uniform and that no gas bypasses the electrical fields. Correct design of inlet ducting and the use of flow distribution devices within the inlet mouthpiece, must achieve uniform flow at the inlet to the precipitator. In general, the operating temperature must be kept below 430 °C. The performance of an ESP will reduce during prolonged operation. Electrodes can rupture, become misaligned or scaly, and regular overhaul is necessary, particularly in older equipment.

In applications where the gas stream may contain significant concentrations of acid gases (particularly SO_X, HCl and HF), it is generally considered necessary to use some form of acid gas scrubbing prior to the ESP. This usually consists of dry or semi-dry scrubbing using calcium hydroxide, sodium carbonate or sodium bicarbonate. These techniques are discussed in Section 4.4.3.3.

The acid gases arise from the raw materials, including recycled cullet, and from the sulphur contained in fuel oil used for combustion and without acid gas removal, the ESP could suffer severe corrosion problems. With some glasses containing boron, the alkali also helps to precipitate volatile boron compounds. If waste gases do not contain high levels of acid gases (i.e. gas firing and low sulphur raw materials), pretreatment may not be necessary, e.g. in most glass wool processes.

In the flat glass sector, dust emissions associated with the use of a four fields ESP, e.g. McGill type, and using hydrated lime for acid gas scrubbing, are in the range of 10 - 20 mg/Nm^3, for a removal efficiency of SO_X between 25 – 33 %. Better efficiencies might be possible depending on the scrubber temperature, type of hydrated lime and molar ratio of injected lime versus SO_X + HCl + HF present in the flue-gases (see Section 4.4.3.3).

Some examples of dust emission levels associated with the use of electrostatic precipitators are presented in Table 4.7

Production	**Fuel/melting technique**	**Total production**	**ESP characteristics**	**Dust emissions AELs [1]**	
		Tonnes/day		mg/Nm^3, dry gas at 8 % O_2	kg/t glass
Container glass					
Soda-lime green/white	Natural gas	470	1 field – dry scrubbing with $Ca(OH)_2$	17 [2]	0.027
Soda-lime	Natural gas	640	5 fields – dry scrubbing with $Ca(OH)_2$	7.6	0.016
Flint	Natural gas	275	3 fields - no scrubbing system	23.8	0.037
Amber	Fuel oil + natural gas	297	2 fields - dry scrubbing with $Ca(OH)_2$	1.2	0.0019
White/amber	Fuel oil	547	2 fields - dry scrubbing with $Ca(OH)_2$	18	0.027
Emerald green/UV green	Natural gas	367	2 fields - dry scrubbing with $Ca(OH)_2$	27	0.040
Flat glass					
White/coloured	Fuel oil	259	2 fields - dry scrubbing with $NaHCO_3$	3.0	0.0048
White	Fuel oil + natural gas	700	4 fields - dry scrubbing with $Ca(OH)_2$	1.5	0.0031
White	Natural gas	600	3 fields - dry scrubbing with $Ca(OH)_2$	30	0.084
Domestic glass					
Not specified	Fuel oil	110	Not specified	16.5	0.034
Special glass					
Not specified	Fuel oil + natural gas	170	2 fields - dry scrubbing with $Ca(OH)_2$	20	0.127

1. Emission levels represent average values of discontinuous measurements (30 - 60 minutes).
2. Monthly average value of continuous measurements.

Table 4.7: Dust emission levels associated to the use of ESPs for example installations
[75, Germany-HVG Glass Industry report 2007] [84, Italy-Report 2007] [86, Austrian container glass plants 2007] [120, Portugal 2009]

Applicability

In principle, this technique is applicable to all new and existing installations in all glass sectors. In the case of existing installations, an upgrade of the filter with additional fields can be carried out only when the melting furnace is under repair, on condition that the necessary space is available. Similarly, the setting up of an ESP is generally required to be carried out during a cold repair or the rebuild of the furnace/s.
ESPs are not used with stone wool cupolas due to the explosion risk associated with carbon monoxide (CO).

Economics

The major factors affecting ESP costs are:

- waste gas volume
- required efficiency
- number of fields
- waste gas conditioning
- if acid gas scrubbing is required, efficiency of the scrubber and scrubbing agent (i.e. hydrated lime, sodium hydrogen carbonate, sodium carbonate)
- plant characteristics (space availability, layout, required site preparation, etc)
- the local specific costs for energy, electricity, water and manpower
- dust disposal costs (if not possible to recycle).

Each additional electrical field over two will increase capital costs by about 10 - 15 %, but the total increase of these complete air pollution control (APC) systems, including scrubber and operational costs, is only about 5 %.

Costs associated with the installation of ESPs are likely to be higher for existing plants than for new plants, particularly where there are space restrictions and where the location of the filter at relatively long distances would require additional piping (often to be insulated).

For electric furnaces and smaller conventional furnaces (<200 tonnes per day) the high capital costs may lead operators to choose alternative techniques, particularly bag filters.

Specific costs can be significantly higher for smaller productions and for oil-fired furnaces, although this also depends on the degree of SO_x reduction to be achieved. As an example, Figure 4.2 shows the specific costs of filtering and dry scrubbing with the use of $Ca(OH)_2$, related to four different situations for float glass furnaces, depending on the melting pull rate and assuming the disposal of all filter dust.

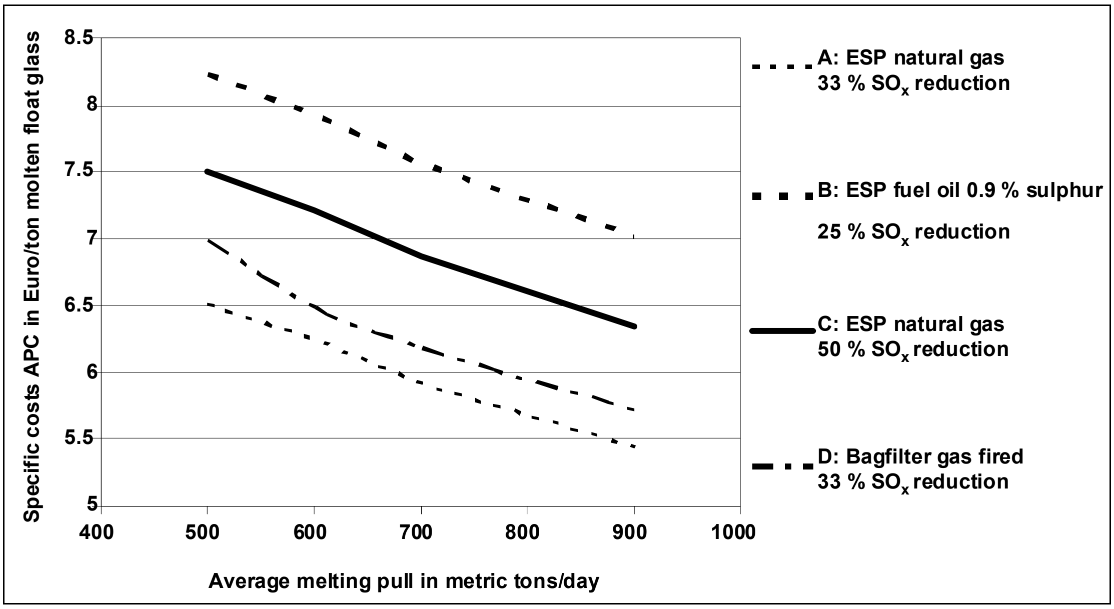


Figure 4.2: Specific costs per tonne molten glass for air pollution control by dry scrubbing and filters for float glass furnaces depending on melting pull

[94, Beerkens - APC Evaluation 2008]

For the cost estimation of air pollution control techniques applied to float glass furnaces, the reference study considers the following achievable emission levels:

- dust emissions are considered in the range of 10 - 20 mg/Nm^3, with possible values ranging from 5 and 10 mg/Nm^3 for ESP with 3 - 4 fields and optimum operating conditions
- a limited SO_X emission reduction of only 25 - 33 % is assumed as the standard operating condition.

Other data and hypothesis concerning the estimation of costs can be found in Section 8.1 (calculation methodology). The main results of the study are the following:

- the investment costs for an air pollution control system (four fields filters) for float glass furnaces range from about EUR 4 - 5.5 million for the size range of 500 - 900 tonnes molten float glass per day. The operational costs for these furnaces range from EUR 375000 to 575000 per year, in case of complete filter dust recycling in the batch. The annual operating costs can increase by almost 100 % (from EUR 685000 to 1140000) when all filter dust has to be externally disposed of (assuming a cost for disposal of EUR 400 per tonne).
- supposing an initial concentration level of SO_2 in the flue-gases of 800 - 1000 mg/Nm^3 (8 % O_2, dry) for gas-fired float furnaces and about 1800 - 2000 mg/Nm^3 for oil-fired float glass furnaces, the typical specific costs (costs per tonne melted glass) are EUR 3.90 for a 900 tonnes/day float glass furnace up to EUR 4.80 for smaller furnaces with a capacity of 450 - 500 tonnes/day, considering that all the filter dust will be recycled to the batch formulation
- in case of complete disposal of the filter dust (EUR 400 per tonne dust disposal), specific costs per tonne of molten glass are about EUR 1.5 - 2 higher. In these calculations, the SO_x emission reduction is assumed to be only about 30 %; if more hydrated lime is used for improving the removal efficiency, the costs for disposal and for the alkaline reagent will increase. An increase of SO_X removal efficiency from 35 % to 50 % SO_x, by adding more hydrated lime, will cause an additional cost of EUR 1 per tonne molten glass, in case of gas-fired furnaces, assuming that the resulting filter dust cannot be recycled in the batch, and the cost for disposal is EUR 400 per tonne dust. In case of oil-fired furnaces, an increase of SOx removal efficiency from 35 % to 50 % is associated with an additional cost of EUR 2.5 per tonne of molten glass. The costs per unit of reduced emissions (dust and SO_x) for the two different situations remains almost the same; EUR 0.45 to 0.7 per kg SO_2 and EUR 9 to 15 per kg dust removed, the higher values are associated with the cases where filter dust has to be totally disposed of
- the additional costs associated with the use of higher amounts of absorption agent are less important when the filter dust can be completely recycled; in this case a modification of the removal efficiency of SOx emissions from 33 to 50 % is associated with a specific cost increase of only about 5 %, equivalent to EUR 0.20 - 0.30 per tonne molten glass.

A summary of the estimated costs concerning the application of air pollution control systems (APC), consisting of electrostatic precipitator and dry scrubbing, applied to the flue-gases of glass melting furnaces is showed in Table 4.9. Data presented in the table refer to both APC applied before 2007, and systems implemented in 2007 and 2008.

This table (4.9) shows the total investment costs (second column), the investment costs (depreciation & interest) per year, operational costs and specific costs for different furnaces in three glass sectors, with or without filter dust recycling for ESP plus scrubbers. Also the costs per kg SO_2 or per kg dust removed from the flue-gas are presented. These costs depend on many factors and, for the same type of glass and tonnes of melted glass, the costs for scrubbing and filtering may be different due to different flue-gas volumes, hydrated lime addition and over-sizing of the equipment (to be able to operate the APC even at the highest production levels).

Part of the total cost is assumed to be associated with dust removal and the other part to the reduction of SOx emissions. The methodology used for the calculation is illustrated in Section 8.1.4.

The figures given may vary by plus or minus 15 % for capital costs and 30 % for operating costs, depending on a number of site-specific factors. For installations that do not require acid gas scrubbing, the capital costs will be approximately 15 - 20 % lower and operating costs 30 - 40 % lower.

The infrastructure costs will vary depending on the size of the ESP and on the local circumstances for each installation. As mentioned above, ESPs can be quite large and on existing installations, substantial civil work may be necessary where space is restricted.

Examples of actual cost data are reported in Table 4.8, for installations producing different glass types (container, flat, special glass and mineral wool) under diverse operating conditions.

Driving force for implementation

The accomplishment of the legal emission limits is the most important driving force.

An additional factor in the driving force for the installation of dust abatement is the requirement to reduce metal emissions and/or gaseous emissions (SO_X, HF, HCl, etc), which often involve the use of a solid reagent and the production of high levels of particulate emissions.

Example plants

There are many examples of ESPs used successfully within the glass industry; more than 90 furnaces in Germany and more than 40 in Italy are fitted with ESPs and acid gas scrubbing, and also in the other European countries, ESPs are the most common filter used in the glass industry. The ESP has been the technique favoured by the industry particularly for large-scale glass installations.

In 2005 in the container glass sector, there were more than 65 furnaces operating with ESP dust abatement. After 2005, most repaired furnaces were also equipped with electrostatic precipitators. The same tendency is foreseen when all furnaces come to the end of their working life.

In 2007, more than 60 % of all float furnaces were equipped with an electrostatic precipitator. Since 2005, existing float glass installations have been equipped with the abatement system during a cold repair of the furnace.

Reference literature

[tm32 Beerkens][33, Beerkens 1999] [64, FEVE 2007] [94, Beerkens - APC Evaluation 2008] [75, Germany-HVG Glass Industry report 2007]

	Flat glass(1)	**Container glass (2)**	**Special glass(3)**	**Glass wool(4)**
Type of furnace	Cross-fired, regenerative	Cross-fired, regenerative	Cross-fired, regenerative	Oxy-fuel fired
Fuel	Fuel oil	Natural gas	Natural gas/light fuel oil	Natural gas
Furnace capacity	350 t/day	350 t/day	220 t/day	206 t/day
Actual pull rate	259 t/day	275 t/day	170 t/day	170 t/day
Electric boosting	Yes	yes	yes	yes
Type of glass	White, extra white, bronze, yellow	Flint	Not specified	C-glass
Cullet	30 %	60 %	25 %	66 %
Specific energy consumption	5.71 GJ/t glass	3.78 GJ/t glass	16.44 GJ/t glass	3.55 GJ/t glass
ESP fields	2	3	2	2
Temperature before filter	300 °C	200 °C	350 °C	Not available
Type of sorbent	$NaHCO_3$	None	$Ca(OH)_2$	None
Amount of sorbent	55 - 80 kg/h (5)	-	22 kg/h	-
Re-use of filter dust in the batch formulation	100 %	100 %	0 %	100 %
Energy consumption for ESP, including ventilator	125 kWh/h	194 kWh/h	250 kWh/h	Not available
Service interval	Annually	As required	Not specified	Not specified
Associated emission levels (AELs)	Half-hour average values	Half-hour average values	Half-hour average values	Measured data are not available
mg/Nm^3, dry gas at 8 % O_2	Dust: 3.0 SO_X: 1150	Dust: 23.8 SO_X: 386	Dust: 20 SO_X: negligible	-
kg/t glass	Dust: 0.0048 SO_X: 2.78	Dust: 0.037 SO_X: 0.60	Dust: 0.127 SO_X: negligible	Dust: <0.1
Investment costs (6)	EUR 2.2 million	EUR 1.5 million	EUR 2.8 million	EUR 910000
Duration of amortization (6)	10 yrs	10 yrs	10 yrs	8 yrs
Operating costs (6)	EUR 205000/yr	EUR 120000/yr	EUR 275000/yr	EUR 60000/yr
Annual amortization costs (6)	EUR 292600/yr	EUR 199500/yr	EUR 372400/yr	EUR 158750/yr
Total annual costs (6)	EUR 497600/yr	EUR 319500/yr	EUR 647400/yr	EUR 218750/yr
Estimated costs per tonne of glass (6)	EUR 5.26/t glass	EUR 3.18/t glass	EUR 10.4/t glass	EUR 3.01/t glass

1.The installation is equipped with a heat recovery system, installed before the ESP.
2. The amount of sorbent depends on the type of glass produced.
3. Cost data refer to the filtration and dry scrubbing system.
4. The installation is equipped with a heat recovery system, installed after the ESP.
5. The installation is equipped with SCR technique for NO_X reduction
6. Cost data refer to an existing installation. Emission data indicate the expected levels.

Table 4.8: Examples of actual costs of electrostatic precipitators applied to the glass manufacturing of flat, container, special glass and mineral wool

[75, Germany-HVG Glass Industry report 2007]

APC methods and applications(1) (2)	Total investment EUR	Investment/yr EUR/yr	Operation/yr EUR/yr	Specific costs EUR/molten tonne	Δ dust tonnes/yr	Δ SO_X tonnes/yr	Specific costs EUR/kgSO_2	Specific costs EUR/kg dust
ESP plus dry scrubber with $Ca(OH)_2$								
Float glass furnaces 500 TPD with filter dust recycling	3904240	500000	376000	4.8	-78	-153	0.51	10.2
Float glass furnaces 700 TPD with filter dust recycling	4700000	603200	488000	4.27	-104	-203	0.48	9.55
Float glass furnaces 900 TPD with filter dust recycling	5460000	700700	575000	3.88	-130	-254	0.45	8.93
Float glass furnaces 500 TPD all filter dust disposal	3904240	500000	688000	6.51	-78	-153	0.69	13.87
Float glass furnaces 700 TPD all filter dust disposal	4700000	603200	896000	5.87	-104	-203	0.66	13.12
Float glass furnaces 900 TPD all filter dust disposal	5460000	700700	1080000	5.44	-130	-254	0.63	12.5
Float glass furnaces 700 TPD all filter dust disposal and 1.5x more absorbent	4700000	603200	1146000	6.81	-104	-308	0.73	14.56
Container glass 300 TPD with filter dust recycling (oil)	2380000	310000	185000	4.52	-25.6	-86.7	0.84	16.5
Container glass 450 TPD with filter dust recycling (gas)	3170000	415000	237000	3.96	-38	-59	0.8	15.43
Container glass 600 TPD with filter dust recycling (oil)	3400000	443250	341000	3.58	-60	-170	0.58	11.4
Container glass 133 TPD with filter dust recycling (oil), installed in 2007	3065000	404000	166000	11.74	-25	-77	0.99	19.9
Container glass 435 TPD with filter dust recycling (gas), installed in 2007	3850000	506000	317000	5.2	-71	-98	0.54	10.75
Container glass 740 TPD with filter dust recycling (gas), installed in 2007	4850000	632600	440000	3.96	-98	-135	0.51	10.24
Container glass 200 TPD all filter dust disposal	2200000	288000	201000	6.7	-18.7	-40	1.19	23.8
Container glass 300 TPD all filter dust disposal (oil)	2380000	311400	379000	6.31	-30.8	-86.7	0.98	19.63
Container glass 450 TPD all filter disposal	3170000	415000	370000	4.77	-38	-59	0.95	19.1
Container glass 600 TPD all filter dust disposal (oil)	3400000	443250	673000	5.1	-60	-170	0.81	16.24
Container glass 560 TPD all filter dust disposal (gas), installed in 2007 - 2008	4650000	605500	580000	5.8	-59	-103	0.93	18.3

APC methods and applications(1) (2)	**Total investment EUR**	**Investment/yr EUR/yr**	**Operation/yr EUR/yr**	**Specific costs EUR/molten tonne**	**Δ dust tonnes/yr**	**Δ SO_X tonnes/yr**	**Specific costs EUR/kgSO_2**	**Specific costs EUR/kg dust**
ESP plus dry scrubber with $Ca(OH)_2$								
Container glass 560 TPD all filter dust disposal (oil), installed in 2007 - 2008	4650000	605500	897000	7.36	-67	-233	0.95	19.1
Container glass 133 TPD all filter dust disposal (oil) installed in 2007 - 2008	3065000	403000	322000	14.96	-27	-76	1.16	23.3
Container glass 435 TPD all filter dust disposal (gas) installed in 2007 - 2008 installed	3850000	505000	534500	6.55	-71	-98	0.68	13.7
Container glass 740 TPD all filter dust disposal (gas) installed in 2007 - 2008 installed	4850000	632600	743000	5.1	-98	-135	0.66	13.2
Container glass 1275 TPD all filter dust disposal (gas) installed in 2007 - 2008	7000000	933500	1194000	4.57	-178	-245	0.56	11.2
Tableware furnace 35 TPD all filter dust disposal	1190000	156500	57000	16.7	-4.63	-4.8	2.2	43.9
Tableware furnace 35 TPD with all filter dust recycling	1119000	156000	43500	15.65	-4.63	-4.8	2.05	41.1
Tableware furnace 180 TPD all filter dust disposal	1960000	256000	247000	7.66	-22.7	-56.2	0.99	19.73
ESP plus dry scrubber with $NaHCO_3$								
Float glass furnace 700 TPD, gas-fired, all filter dust disposal	4719500	605920	1370000	7.75	-104	-414	0.79	15.9
Float glass furnace 700 TPD, gas-fired, all filter dust recycling	4719500	605920	515000	4.39	-104	-414	0.49	9.81
Container glass 300 TPD, oil-fired, all filter dust disposal, 67 %SO_2 absorption	2400000	312800	600000	8.33	-30.8	-232	1.07	21.5
Container glass 300 TPD, oil-fired, all filter dust disposal, 50 %SO_2 absorption	2400000	312800	491000	7.38	-30.8	-173	1.02	20.36

1. TPD =tonnes per day
2. Emission data used for the calculation are the following:
    - dust: typical values between 10 and 20 mg/Nm^3. Optimised values between 5 and 10 mg/Nm^3
    - SO_2: typical removal efficiency with $Ca(OH)_2$ between 25 and 33 %.

Table 4.9: Estimated costs for air pollution control systems with electrostatic precipitators plus dry scrubbing, applied to the flue-gases of glass melting furnaces
[94, Beerkens - APC Evaluation 2008]

4.4.1.3 Bag filters

Description

Fabric filter systems are used for many applications within the glass industry, due to their high efficiency in controlling the fine particulate matter. Their use in container glass flue-gas filtration is now much more common, due to the use of modern and reliable fabrics and control systems. However, due to their potential to blind in certain circumstances, they are not the preferred choice in all applications. In many cases there are technical solutions to these difficulties, but there may be an associated cost.

The basic principle of fabric filtration is to select a fabric membrane which is permeable to gas but which will retain the dust. Initially, dust is deposited both on the surface fibres and within the depth of the fabric, but as the surface layer builds up, it itself becomes the dominating filter medium. As the dust cake thickens, the resistance to gas flow increases, and periodic cleaning of the filter media is necessary to control the pressure drop over the filter. The direction of gas flow can be either from the inside of the bag to the outside, or from the outside of the bag to the inside (see Figure 4.3).

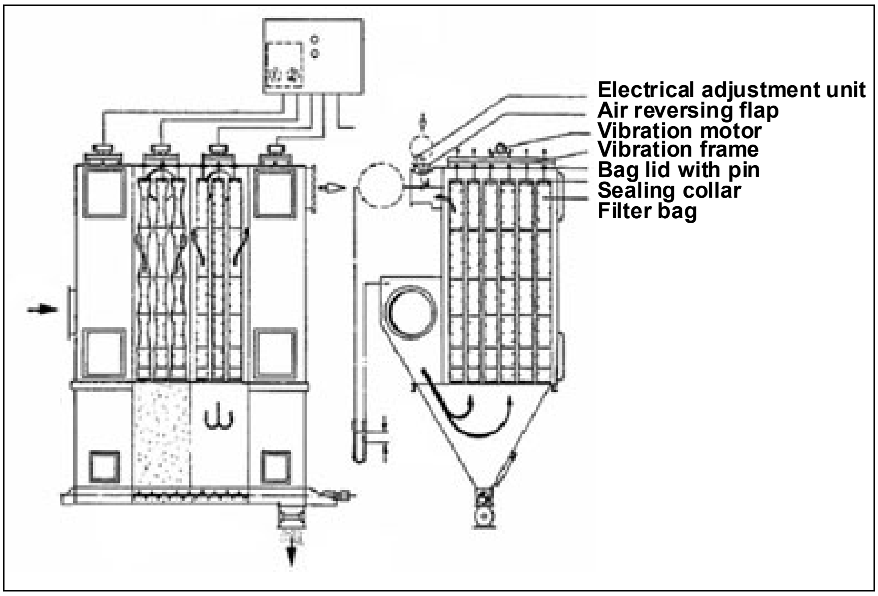


Figure 4.3: Bag (fabric) filter scheme
[70, VDI 3469-1 2007]

The most common cleaning methods of a bag filter include reverse airflow, mechanical shaking, vibration and compressed air pulsing. Often a combination of these methods is used. The normal cleaning mechanisms do not result in the fabric returning to its pristine condition. It is not beneficial to over clean the fabric because the particles deposited within the depth of the fabric help to reduce the pore size between the fibres, thus enabling high efficiencies to be achieved.

Fabric filters are designed on the basis of anticipated filtration velocity which is defined as the maximum acceptable gas velocity flowing through a unit area of fabric (expressed in m/s). Filtration velocities generally lie in the range of 0.01 to 0.06 m/s according to the application, the filter type and the cloth. The filter design must optimise the balance between pressure drop (operating cost) and size (capital cost). If the filtration velocity is too high then the pressure drop will be high and the particles will penetrate and blind the fabric. If the filtration velocity is too low the filter will be efficient but very expensive.

Because of the tendency of particles present in the waste gas downstream of glass tank furnaces to adhere to the filter material, cleaning of precipitated particles from the filter material may sometimes be difficult. Achieving satisfactory continuous operation can be assisted by the tendency of the particles to agglomerate, by continuously recycling a partial stream of particles cleaned off the filter material to the dirty gas stream. The use of hydrated lime in gas scrubbing enhances this effect.

Fabric material selection must take into account the composition of the gases, the nature and particle size of the dust, the method of cleaning to be employed, the required efficiency and the economics. The gas temperature must also be considered, together with the method of gas cooling, if any, and the resultant water vapour and acid dew point. Characteristics of the fabric to be considered include maximum operating temperature, chemical resistance, fibre form and type of yarn, fabric weave, fabric finish, abrasion and flex resistance, strength, collecting efficiency, cloth finishes and cloth permeability.

Achieved environmental benefits

Bag filters are highly efficient dust collection devices and a collection efficiency of 95 – 99 % would be expected if fuel has less than 1 % of sulphur therefore not requiring a large amount of alkaline reagent for the removal of acid gases.

Particulate emissions of between 0.5 and 5 mg/Nm^3 can be achieved and levels below 5 mg/Nm^3 could be expected in many applications. This generally equates to significantly less than 0.008 kg per tonne of glass melted and less than 0.02 kg/t glass in some specific cases, such as borosilicate glasses or modified soda-lime glasses. The necessity of achieving such low levels can be important if dust released from the process contains a significant amount of metals (approaching or exceeding typical emission limit values) and the low range of this can be expected in this case.

In the mineral wool sector, in particular for stone wool cupola furnaces, it is reported that the application of bag filters on existing installations achieve concentrations of below 10 mg/Nm^3 for dust emissions only in about 60 % of the cases.

It should be noted that in cases of discontinuous measurements, the uncertainty of the standard methods (see EN 13284-1: 2003) is of the same order of magnitude as the measured value; therefore, the low concentration data reported should be evaluated cautiously.

If a scrubbing stage is incorporated with the technique, a solid waste stream is generated that must either be recycled to the furnace or disposed of. The scrubbing phase will usually result in lower overall acid gas emissions (see Sections 4.4.3 and 4.4.4.2). If the dust is recycled, some of the acid gases will be re-emitted. However, a dynamic equilibrium will form where, generally, the uptake in the glass will be higher, some raw material levels may be reduced, and the overall emissions will be less. For some gaseous pollutants and specific circumstances, the efficiency of dry scrubbing can be higher with bag filters than ESPs, because further absorption can take place on the filter cake, which is on the bags, or during recycling of part of the dust, within mechanisms found in modern bag filtration systems.

Cross-media effects

The use of bag filters involves consumption of electricity for pressurised air and for the fans and control systems, corresponding to less than 1 % of the energy consumption of the furnace. The indirect CO_2 emissions related to the use of electricity will depend on the source of production at the generation plant. The estimated emissions for a 500 tonnes/day float glass furnace are about 2500 tonnes CO_2/year (approximately 2.5 - 3 % of glass furnace CO_2 annual emissions). For a container glass furnace of 300 tonnes/day, the indirect CO_2 emissions are about 1000 - 1050 tonnes CO_2/year equivalent to about 2.5 to 3 % of the annual glass furnace CO_2 emissions (from combustion and from raw materials).

For tableware furnaces, the indirect CO_2 emissions are about 200 - 250 tonnes/year, for a capacity of 30 - 40 tonnes/day and 600 tonnes/year for larger furnaces of 180 - 200 tonnes/day (about 3 % of the total CO_2 emissions of the furnace).

Additional indirect emissions are associated with the production of alkaline reagents used for the scrubbing process (sodium bicarbonate, sodium carbonate, calcium hydroxide). Values are estimated in the range of 60 - 200 tonnes CO_2/year for container glass furnaces with a capacity of 200 - 600 tonnes/day (<0.5 % of the total CO_2 emissions of the furnace), and up to 300 - 600 tonnes CO_2/year for large float glass furnaces of 500 - 900 tonnes/day capacity (about 0.5 % of the total CO_2 emissions of the furnace).

Production of solid waste can be a major cross-media effect when dust recycling is not possible and external disposal is necessary. A summary of costs and cross-media effects for air pollution control systems applied to melting glass furnaces is shown in Table 4.40.

Operational data

It is essential to maintain the waste gas temperature within the correct range for a bag filter system. The gas must be maintained above the dew point of any condensable species present (e.g. H_2SO_4 or water) and below the upper temperature limit of the filter medium. If the temperature is too low condensation occurs, which can cause bag blinding and/or chemical attack of the fabric material. If the temperature is too high, the filter material can be damaged requiring expensive replacement. Conventional filter fabrics usually have a maximum operating temperature of between 130 and 220 °C and in general, the higher the operating temperature, the higher the cost. In most glass processes, the waste gas temperature is between 450 and 800 °C. Therefore, the gas must be cooled before the filter by dilution, quenching or by a heat exchanger.

If the flue-gases are likely to contain acidic species (in particular oil-fired furnaces), then it is considered necessary to install a scrubbing stage upstream of the filter, to prevent acid condensation which would damage certain bag materials and the filter housing. For flue-gases containing boron, the scrubbing stage helps precipitate volatile boron species and may make the dust easier to collect without blockages.

Although fabric filters are sensitive materials, the technology has improved and modern filters are now suitably robust. Proper control systems exist which allow a good control of the temperature in order to avoid bag fabric damage giving overall good reliability. A well developed technical procedure, combined with a reliable continuous electronic control system, is required to prevent avoidable damage to the filter fabric.

Modern bag filter systems contain over 1000 bags. Damage to a small number of bags does not normally significantly effect filtration efficiency. Continuous dust monitoring systems on the stack effectively identify any potential problem.

A summary of the main advantages and disadvantages associated with the use of bag filters is shown in Table 4.10.

Advantages

- very high collection efficiencies
- collection of product in dry condition
- lower capital cost for simpler applications
- effective capture of metals
- in general, improved removal efficiency of acid gaseous species, e.g. hydrogen fluoride, selenium and boron compounds.

Disadvantages

- a solid waste stream is generated that is not always possible to recycle
- increased energy consumption due to higher pressure drop (CO_2 and other indirect emissions from electricity production)
- gas cooling often required
- fabric conditioning sometimes required
- expensive fabrics sometimes required
- dew point problems leading to blinding of fabric filters and filter housing
- cleaning air (reverse flow) sometimes requires heating
- some dusts very difficult to dislodge causing pressure drop to exceed the design value
- outlet flue-gas temperature too low for SCR application, requiring waste gases reheating, with an increase of energy consumption of about 5 – 10 %.

Table 4.10: Main advantages and disadvantages of bag filters

Applicability

In principle, fabric filters can be applied to all types of furnaces within the glass industry, and to both new and existing furnaces. However, in many of the sectors it has not often been the technique of choice due to relatively high maintenance requirements and the potential for the fabric to blind, resulting in the costly replacement of the filter medium. In addition, it is more technically feasible to join multiple furnaces to an ESP rather than a bag filter, which can be advantageous in terms of both economic cost and space where space is limited.

In modern systems, most of these problems have been overcome and there are many examples of bag filters operating well in container glass plants, borosilicate glass plants and one float glass plant. The addition of a scrubbing stage and low fuel sulphur levels reduces the tendency of the bags to blind.

Filter blockages due to fabric blinding have been a particular concern in fossil fuel-fired glass wool furnaces (and some other boron containing glasses), because of the sticky nature of the fine particulate matter, which without a dry scrubbing stage makes it difficult to avoid blockages. The furnaces are usually gas-fired with very low concentrations of acid species, and therefore, with a well maintained electrostatic precipitator a scrubbing stage may not be considered necessary. This significantly reduces capital and operating costs and makes dust recycling much easier. However, the use of a scrubbing stage favours the absorption and condensation of volatile species, e.g. boron and selenium compounds.

A further concern with bag filters is that most fossil fuel-fired furnaces require sensitive pressure control, and the presence of a fabric filter with a high pressure drop could make this more difficult. Modern materials and control systems have reduced this problem.

Bag filters have gained wide acceptance within a number of the sectors of the glass industry. The technique is widely used in conjunction with electric furnaces, stone wool cupolas, frit furnaces and furnaces for high temperature insulation wools (HTIW). In many smaller fossil fuel-fired furnaces, bag filters have been chosen as the technique to operate with scrubbing systems which are installed to reduce acid gas emissions. Furthermore, the lower capital costs of bag filters compared with electrostatic precipitators can be very attractive, offsetting the expenses associated with higher maintenance and the risk of bag blinding.

The application of bag filter systems does not represent the best option when the use of SCR is foreseen, due to the generally low operating temperatures, which are not suitable for the operational conditions of the catalyst.

Economics

In general, investment costs are lower for a bag filter system than for ESPs but running costs can be higher. However, for large gas volumes, the specific costs of bag filters combined with a dry scrubbing stage are comparable or even higher than for an ESP plus a scrubber system. This is mainly the case for float glass furnaces or for situations where several container glass furnaces are connected to a single air pollution control system.

The major factors affecting bag filter costs are:

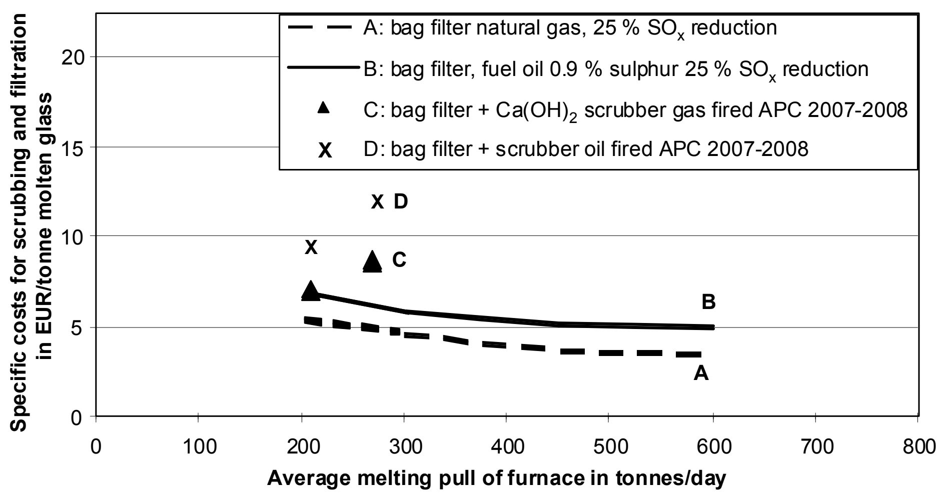
- waste gas volume
- filter surface area (depending on requested efficiency)
- fabric material (glass fibre, polyamide, polyimide, etc)
- waste gas conditioning to the filter operating temperature
- if acid gas scrubbing is required, efficiency of the scrubber and scrubbing agent (i.e hydrated lime, sodium bicarbonate, sodium carbonate)
- plant characteristics (space availability, layout, required site preparation, etc)
- the local, specific costs for energy, electricity, water and manpower
- dust disposal costs (if not possible to recycle).

Cost estimations have been made in a reference study for different furnace capacities and SOx removal efficiency. Data are based on the calculation methodology presented in Section 8.1, which takes into account an emission concentration for dust in the range of <5 - 10 mg/Nm^3 and a standard removal efficiency of SO_2 between 25 and 33 %, unless stated otherwise. The main estimated cost data are the following:

- the calculated specific costs for a bag filter and scrubber combination applied to a 500 tonnes/day float glass furnace are about EUR 7 per tonne molten glass (without filter dust recycling), compared to the costs of about EUR 6.5 per tonne for the ESP plus the dry scrubber. The operational costs are higher for bag filters than for ESPs. The typical investment costs for the same size float glass furnace are equivalent to EUR 2.7 million and annual operational costs are about EUR 0.9 million. The indirect CO_2 and NO_x emissions, related to the use of electric energy and production of alkaline reagent, are higher compared to an ESP
- for a single container glass furnace, with a smaller flue-gas volume, the specific costs are somewhat lower for the bag filter system compared to the ESP. For instance, for a gas-fired container glass furnace producing 300 tonnes/day molten glass, typical costs without filter dust recycling are EUR 4.5 - 6 per tonne molten glass and with filter dust recycling EUR 3.9 - 4.5 per tonne molten glass. In exceptional cases, the costs may increase by 25 % (for instance for relatively large APC systems, to be able to operate at maximum furnace pull). The lower ends of the given ranges of the cost data are based on air pollution control equipment installed before 2005. Capital costs for filter systems, however, increased in 2007 – 2008 (see Table 4.12)
- for glass production levels of 200 - 300 tonnes/day molten glass, specific costs for dry scrubbing in combination with a bag filter are EUR 5 - 6.5 per tonne molten glass in the case of oil-firing and complete filter dust recycling and about EUR 4.5 - 6 per tonne molten glass for gas-fired furnaces and recycling of filter dust, based on capital cost data for equipment installed after 2006. These costs will increase for gas-fired furnaces (flue-gas: 600 - 800 mg SO_2/Nm^3) by about EUR 1 EUR per tonne molten glass in the case of complete filter dust disposal (EUR 400 per tonne) and will increase by EUR 2 per tonne molten glass for oil-fired furnaces (1800 mg SO_2/Nm^3), assuming a removal efficiency of 25 - 30 % SO_x by dry scrubbing and complete filter dust disposal to landfill

- investment costs of bag filters plus dry scrubbers are typically EUR 1.2 - 1.5 million for small furnaces (200 tonnes/day), and up to EUR 2 million for larger container glass furnaces of 300 - 350 tonnes/day
- for a production range of 200 - 600 tonnes/day molten glass, operational costs with filter dust recycling range from EUR 170000 to EUR 345000 per year, and when disposal of the filter dust is required, between EUR 220000 and 490000 per year. In the case of filter dust disposal, the specific costs will be higher for oil-fired furnaces compared to gas-fired glass furnaces due to higher amounts of filter dust production (the cost increase can be an additional EUR 1.65 per tonne glass).

Figure 4.4 shows some estimated cost data for bag filters plus dry scrubbers applied to container glass furnaces.



Notes: 1 Glass furnaces, assuming complete filter dust disposal and 25 % SO_x removal
2 Filter dust disposal at EUR 400/tonne

Figure 4.4: Specific estimated costs for dry scrubbers in combination with bag filters for container glass furnaces, assuming a complete filter dust disposal and 25 % SO_X removal
[94, Beerkens - APC Evaluation 2008]

The specific costs for oil fired furnaces (see Figure 4.4), assuming the same percentage of SO_2 emissions reduction, appear to be 30 - 35 % higher than for gas-fired furnaces, mainly because of the higher disposal costs for the sulphate filter dust and increased costs of hydrated lime (due to the higher SO_2 concentration levels in the flue-gases of oil-fired glass furnaces). These costs increased in 2007, due to higher capital (investment) costs for the installation (filter, scrubber and piping), as shown in Figure 4.4 for installations C and D. Typical costs for smaller glass production sites range from EUR 6 to 10 per tonne molten glass, but sometimes even higher costs can be expected. Installations with a production above 400 - 500 tonnes/day molten glass have costs between EUR 3.5 and 5 per tonne molten glass. These costs refer to cases with complete disposal to landfill of collected filter dust and gas firing furnaces. The specific costs will increase by EUR 1 - 1.5 per tonne molten glass in the case of filter dust disposal and fuel oil-firing. Table 4.12 shows a summary of the estimated investment and operational costs for different size installations in the container, float, tableware glass and continuous filament glass fibre sectors, applying bag filters plus different options of scrubbing systems.

Examples of actual cost data, for two installations producing special glass under different operating conditions are reported in Table 4.11.

	Special glass Installation N. 1	**Special glass Installation N. 2**
Type of furnace	Electric melting	Oxy-fired
Fuel	-	Natural gas
Furnace capacity	86 t/day	50 t/day
Actual pull rate	80 t/day	40 t/day
Electric boosting	-	yes
Type of glass	Borosilicate, white	Borosilicate
Cullet	70 %	60 %
Specific energy consumption	4.18 GJ/t glass (average of two furnaces)	6.72 GJ/t glass
Temperature before filter	80 °C	105 °C
Type of sorbent	$Ca(OH)_2$	$Ca(OH)_2$
Amount of sorbent	3 kg/h	15 kg/h
Re-use of filter dust in the batch formulation	0 %	0 %
Energy consumption for filtration system, including ventilator	20 kWh/h	34 kWh/h
Associated emission levels (AELs)	**Half-hour average values**	**Half-hour average values**
mg/Nm^3, dry gas	Dust: 1.0 (1) SO_X: <5	Dust: 0.3 SO_X: 5.6
kg/t glass	Dust: 0.0013 (1) SO_X: <0.01	Dust: 0.0027 SO_X: 0.054
Investment costs (2)	EUR 440000	EUR 1.5 million
Duration of amortisation	10 yrs	15 yrs
Operating costs	EUR 50000/yr	EUR 83109/yr
Annual amortisation costs	EUR 58520/yr	EUR 126000/yr
Total annual costs	EUR 108520/yr	EUR 209109/yr
Estimated costs per tonne of glass	EUR 3.71/t glass	EUR 14.32/t glass

1. The emission levels represent the average value of two furnaces.
2. Cost data refer to the filtration and dry scrubbing system.

Table 4.11: Examples of actual costs of bag filters applied to the special glass sector in two installations
[75, Germany-HVG Glass Industry report 2007]

Driving force for implementation

The accomplishment of the legal emission limits is the most important driving force.
An additional factor in the driving force for the installation of a bag filter system combined with dry or semi-dry scrubbing might be the reduction of metal emissions (Pb, Se, etc) and/or gaseous emissions (SO_2, HCl, HF, etc). When metals are associated to the dust emissions, bag filters can be a good solution. For volatile metals such as selenium and arsenic, the lower operating temperatures of bag filters promote good capture of the metals.

Example plants

For container glass, more than 16 plants were equipped with bag filters in 2005 and there were many more in other glass sectors.

References to literature

[tm32 Beerkens][33, Beerkens 1999] [64, FEVE 2007] [70, VDI 3469-1 2007] [94, Beerkens - APC Evaluation 2008] [86, Austrian container glass plants 2007] [110, Austria, Domestic glass plants 2007]

APC methods and applications (1) (2) (3)	Investment EUR	Investment/yr EUR/yr	Operation/yr EUR yr (1)	Specific costs EUR/molten tonne	Δdust tonnes/yr	ΔSO_X tonnes/yr	Specific costs EUR/kg SO_2	Specific costs EUR/kg dust
Bag filter plus dry scrubber								
Float glass 500 TPD all filter dust disposal	2670000	344300	930000	6.98	-80	-159	0.72	14.42
Container glass 200 TPD with filter dust recycling	1211000	158600	168000	4.63	-17.2	-19.9	0.9	17.93
Container glass 300 TPD with filter dust recycling	1435500	188400	234000	3.86	-20.3	-26.5	0.98	19.57
Container glass 450 TPD with filter dust recycling	1588300	208000	268000	2.9	-35.3	-43.4	0.64	12.72
Container glass 600 TPD with filter dust recycling	1895000	249000	344000	2.7	-43.3	-53.3	0.64	12.9
Container glass 210 TPD with filter dust recycling - Installation 2007 (gas-fired)	1960000	260300	191000	5.89	-25	-29	0.85	17
Container glass 210 TPD with filter dust recycling - installation 2007 (oil-fired)	1960000	260300	227400	6.36	-28	-87	0.76	15.11
Container glass 270 TPD with filter dust recycling - installation 2008 (oil-fired)	3036000	406500	365000	7.83	-47	-146	0.71	14.21
Container glass 290 TPD with filter dust recycling - installation 2005 (gas-fired)	1860000	247000	235000	4.55	-28.5	-33	0.8	16
Container glass 200 TPD all filter dust disposal	1211000	158600	220000	5.2	-16	-19.1	1	20.04
Container glass 300 TPD all filter dust disposal	1435500	188400	298000	4.44	-20.5	-23.6	1.04	20.78
Container glass 450 TPD all filter dust disposal	1588900	208000	380000	3.6	-35	-41	0.79	15.74
Container glass 600 TPD all filter dust disposal	1895000	249000	488000	3.37	-45.5	-52.6	0.77	15.3
Container glass 210 TPD all filter dust disposal installation 2007	1960000	260300	271000	6.93	-25	-29	1	20.1
Container glass 290 TPD all filter dust disposal installation 2005 (gas)	1860000	247000	326000	5.41	-28.5	-33	0.95	19
Container glass 290 TPD all filter dust disposal installation 2005 (oil-fired)	1860000	247000	526000	7.3	-32	-99	1.16	23.14
Tableware furnace 30 TPD with filter dust recycling	771000	99600	64500	12.85	-5.32	-3.25	1.49	30
Tableware furnace 30 TPD all filter dust disposal	771000	99600	77200	13.84	-5.32	-3.25	1.61	32.2
Tableware furnace 180 TPD with filter dust recycling	900000	115000	174000	4.36	-8	-4.3	1.77	35.5
Tableware furnace 200 TPD with filter dust recycling	905200	120000	155000	3.76	-11.4	-6.1	1.17	23.5
Tableware furnace with E-boosting borosilicate glass 150 TPD	1150000	154000	141000	5.4	-68	--	--	--

APC methods and applications (1) (2) (3)	Investment EUR	Investment/yr EUR/yr	Operation/yr EUR yr (1)	Specific costs EUR/molten tonne	Δdust tonnes/yr	ΔSO_X tonnes/yr	Specific costs EUR/kg SO_2	Specific costs EUR/kg dust
E-glass furnaces oxygen-fired 100 TPD, with all filter dust disposal (estimated)	1224000	160000	281000	11	-34	-39	0.61	12.3
Bag filter plus semi-dry scrubber								
Float glass 500 TPD without filter dust disposal, gas-fired to 400 mg SO_X/Nm^3	4500000	586000	700420	7.05	-68.3	-285	0.78	15.58
Float glass 500 TPD without filter dust disposal, oil-fired to 750 mg SO_X/Nm^3	4500000	586000	756860	7.36	-82.6	-655	0.58	11.65
Float glass 900 TPD without filter dust disposal, gas-fired	7345000	963270	947000	5.82	-122	-508	0.65	12.96
Float glass 500 TPD all filter dust disposal at, gas-fired	4500000	586000	1165000	9.59	-69.4	-290	1.04	20.88
Float glass 500 TPD all filter dust disposal, oil-fired	4500000	586000	1793000	13.03	-83.8	-665	1.02	20.3
Float glass 900 TPD all filter dust disposal gas fired	7345000	963270	1774000	8.33	-121	-508	0.93	18.58
Container glass furnace 350 TPD without filter dust disposal, gas-fired	2304500	300400	377000	5.3	-23.2	-100.7	1.2	24.02
Container glass furnace 350 TPD all filter dust disposal, gas-fired	2304500	300400	535000	6.54	-23.2	-100.7	1.48	29.62

1. The costs for filter dust disposal are assumed to be EUR 400/tonne.
2. TPD = tonnes per day.
3. Emission data used for the calculation are the following:
   - dust: typical values between 10 and 20 mg/Nm3 for ESP with optimised values between 5 and 10 mg/Nm^3
   - SO_2 typical removal efficiency with $Ca(OH)_2$ between 25 and 33 %.

Table 4.12: Costs for air pollution control systems with bag filters plus scrubbing, applied to the flue-gases of glass melting furnaces [94, Beerkens - APC Evaluation 2008]

4.4.1.4 Mechanical collectors

The term mechanical collectors is used to describe techniques which use mechanical forces (gravity, inertia, centrifugal) to separate the dust from the gas stream, for example:

- cyclones - spinning motion imparted to gas, and dust separated by centrifugal force
- gravity settlers - gas enters a large chamber reducing gas velocity and causing dust to settle out
- baffle chambers - baffles cause gas to change direction and dust to settle out
- louvers - banks of small baffles split and change the direction of gas flow causing dust to settle out.

These techniques have poor collection efficiencies for small particles, in particular with diameters smaller than 10 µm, and due to the low particle size of most dusts encountered in the glass industry, they are rarely used. The exception to this is the cyclone, which can be found in some applications, particularly as a pretreatment stage for other techniques. The operating principles and main advantages and disadvantages are summarised below. However, because they are not considered an effective technique for furnace emissions, cyclones are not described in detail.

The cyclone is an inertial gas cleaning device. Dust becomes separated from the gas stream when the direction of gas flow is changed and the dust continues in the original direction by virtue of its inertia and is then deposited on a collection surface. There are two types of cyclones; reverse flow and straight through. Reverse flow cyclones are the most common, and consist of a cylindrical shell with a conical base, a dust collection hopper and air inlets and outlets. There are two main types of reverse flow cyclones; tangential and axial. These classifications arise from the geometry of the air inlet.

The inlet gas stream is channelled into a vortex and centripetal forces sustain the circular motion. Particles above a critical size are thrown from the inlet spiral into a wider circular path and are deposited on the cyclone wall. The airflow carries the dust to the collection hopper, and at the base of the cone the gas flow reverses and clean gas passes back along the centre of the cyclone in the outlet spiral.

In general, the efficiency of a cyclone increases for corresponding increases in: density of particulate material, inlet velocity, cyclone length, number of gas revolutions, ratio of body diameter to outlet diameter, particle diameter, amount of dust, and smoothness of the cyclone wall. Efficiency decreases with increases in: gas viscosity, gas density, temperature, cyclone diameter, gas outlet diameter, inlet gas duct width, and inlet area.

Cyclones are widely used in many industries and are particularly suitable for collecting particles with diameters greater than 10 µm. Depending on design, medium/high efficiency cyclones give collection efficiencies of 45 – 90 % at 10 µm, and 5 – 30 % at 1 µm. They are frequently placed preceding more expensive technologies, in order to remove coarse material from the gas stream and hence reduce the dust burden entering the main abatement equipment.

A summary of the main advantages and disadvantages associated with the use of cyclones is shown in Table 4.13.

Advantages:
- low capital and operating costs (including maintenance)
- moderate pressure drop
- low space requirement, relative to other techniques
- capable of operation with high dust loading
- can be used with a wide range of gases and dusts
- can be operated at high temperatures and pressures
- manufacture possible in a wide range of materials.

Disadvantages:
- low collection efficiency on small particles
- light materials or needle-shaped materials difficult to remove
- plugging can result where dew points are encountered
- explosion relief for flammable materials is difficult
- potential problems with abrasive dusts.

Table 4.13: Main advantages and disadvantages of cyclones

4.4.1.5 High-temperature filter media

One of the problems with conventional bag filters is the need to maintain the waste gas temperature within the operating range of the filter material. When the temperature goes above the upper temperature limit, the filter has to be bypassed or the gas cooled, e.g. by dilution. Conventional filter materials have a temperature limit of 120 – 180 °C, with some materials up to 250 °C (glass fibre). The costs of the materials increase significantly for materials capable of operating above 180 °C. In some applications, high-temperature media have been used, but these filters are not normal bag filters and usually are similar to candle filter designs.

High-temperature filters have been used successfully for abating emissions from some stone wool cupolas and from a borosilicate glass furnace, but are no longer used due to either high costs or the plant having shut down. The most common high-temperature filters used in other industries are ceramic or high-temperature wool candles for the removal of dust. These filters are made of aluminium-silicate materials and can be applied to temperatures up to 1000 °C. A new type of filter is now available, which combines the technology of ceramic candles with embedded catalyst for the removal of NO_X. This is still considered an emerging technique, therefore it is discussed in Section (6).

A summary of the main advantages and disadvantages associated with the use of high-temperature filters is presented in Table 4.14.

Advantages:
- can be operated at high temperatures, up to 1000 °C
- in general, high resistance to acid gases
- high filtration efficiency; up to 99.9 %
- no need to reduce the flue-gas temperature with dilution air
- heat recovery systems can be positioned after the filter (cleaned gas) at high temperatures.

Disadvantages:
- rigid and expensive materials
- high costs for maintenance and damage repairs
- low chemical resistance to HF at high humidity and low temperatures.

Table 4.14: Main advantages and disadvantages of high-temperature filters

4.4.1.6 Wet scrubbers

Wet scrubbing systems can be used to control both gaseous and particulate emissions. Whilst the basic technology for both of these is similar, the design criteria for particulate or gas removal are very different. However, to keep down capital costs, wet scrubbing systems are often used to control mixed emissions of particulates and gases. The design is inevitably a compromise, but may represent BAT where separate control systems are prohibitively expensive. Wet scrubbing systems can also be prone to blockage by insoluble particles, and waste slurry is generated. The technique is described in more detail in Section 4.5.6.1.2 for mineral wool non-melting activities, particularly in the forming area applications and in Section 4.4.3.4 for acid gases (SO_X, HCl, HF, etc) removal applications.

In some applications venturi scrubbers may be considered. These systems have a high-pressure drop and consequently they have high power consumption and operating costs. Although good removal efficiencies can be achieved with venturi scrubbers, this technique is considered both technically and economically impracticable in most cases, due to the size of the glass processes. However, the removal of dust emissions by wet scrubbing may find application in some specialised operations, particularly if gaseous emissions also need to be removed.

For most glass furnaces, wet scrubbing is not likely to be a useful technique or the most optimum technique for cost-effective particulate matter abatement.

A summary of the main advantages and disadvantages associated with the use of wet scrubbers is presented in Table 4.15.

Advantages:

- simultaneous removal of particulate matter and gaseous pollutants
- smaller space requirement.

Disadvantages:

- generation of a waste water stream to be treated
- high efficiencies only with high-pressure drops and high energy consumption
- difficulties and high costs for recovering dust/sludge to re-use in the batch formulation.

Table 4.15: Main advantages and disadvantages of wet scrubbers

Economics

An estimation of the investement and operating costs related to the application of wet scrubbing systems to glass melting furnaces is summarised below:

- for an oxy-fired furnace of 100 - 150 tonnes/day producing E-glass, the investment is estimated at EUR 2.65 million, with annual operating costs of EUR 286400 and a specific cost ranging from EUR 14.4 to 21.5 per tonne melted glass, based on the cost for dust disposal ranging from EUR 100 to 400 per tonne of dust
- for a conventional air/gas furnace of 100 - 150 tonnes/day producing E-glass, the investment is estimated at EUR 2.96 million, with annual operating costs of EUR 300 and a specific cost ranging from EUR 15.7 to 20.5 per tonne melted glass, based on the cost for dust disposal ranging from EUR 100 to 400 per tonne of dust.

Example plants

A very limited number of wet scrubber applications are in operation in the glass industry, particularly in the domestic glass and continouos filament glass fibre sectors. They are:

- Bormioli Luigi, Parma, Italy - domestic glass (electric furnaces)
- PPG Industries Fibre Glass, Hoogezand, the Netherlands - continuous filament glass fibre.

References to literature
[94, Beerkens - APC Evaluation 2008]

4.4.1.7 Summary of considerations of techniques inSection 4.4.1

[115, EURIMA-ENTEC Costs evaluation 2008] [68, Domestic Glass Data update 2007

The reduction of particulate matter emissions from glass furnaces is somehow considered as a debatable issue from both a technical and an economic point of view. There are a number of factors that play a role when determining the BAT for dedusting at glass furnaces. The most important are:

- the environmental impact of the dust
- primary and secondary abatement techniques in relation to BAT
- the economy of scale and related cost considerations.

Environmental impact of the dust
The relevant aspects of dust emissions from an environmental point of view are the emissions of dust in general, the potential emissions of (heavy) metals and the emissions of fine particulate matter. Studies have been carried out to investigate the potential non-toxicity of dust emitted from soda-lime glass furnaces and to determine the theoretical contribution to background level concentrations of particulate matter in the surrounding areas of glass installations.
In soda-lime glasses, the main component of the dust is sodium sulphate (up to 95 %). Sodium sulphate is not considered harmful in itself, but as a solid it contributes to the emission of particulate matter. Such emissions are currently receiving increasing attention from environmental policy makers, particularly for particles with a diameter of less than 10 µm (PM_{10}) and less than 2.5 µm ($PM_{2.5}$), which is generally the case for emissions from glass furnaces.

Several species of metals may also be found in the particulate matter from glass furnaces. The main components of concern are selenium (Se), lead (Pb), chromium (Cr), copper (Cu), vanadium (V), nickel (Ni), antimony (Sb), arsenic (As), cadmium (Cd), zinc (Zn) and manganese (Mn). The emissions of these components strongly depend on the quantity and quality of recycled glass (cullet) used, whether or not fuel oil is used and the addition of metals to the batch formulation for colouring and/or decolouring the glass. Most of these components are predominantly bound in the particulate matter. However, especially for selenium, cadmium, lead and zinc, volatile emissions of these substances may also be significant. The absorption of gaseous metals may depend on the filtration temperature and the type of alkaline reagent selected for the scrubbing stage. In many cases, the main driving force for installing dedusting equipment has been the reduction of (heavy) metals emissions, either volatile or incorporated in the dust. The reduction of gaseous emissions (SO_2, HCl, HF, etc) has also been the driving force in many cases.

A final point of consideration is the potential condensation of gaseous components after the stack, which can occur especially in glasses which contain boron, where a portion of the gaseous boron compounds may pass through the dust abatement equipment and condense after being emitted to the atmosphere.

Primary and secondary abatement techniques in relation to BAT
The most well-established secondary abatement techniques in the glass industry are electrostatic precipitators and bag filters. Both techniques are used widely, although each with its respective possibilities and restrictions. By the end of 2005, approximately 40 % of the soda-lime glass furnaces in the EU and 100 % of the furnaces in some Member States were fitted with secondary abatement for dust. This process will be completed to almost 100 % of the furnaces in connection with the furnace rebuild, at the end of their lifetime.

On the other hand, the implementation of secondary measures involves substantial financial costs, and a certain degree of environmental cost. In general (for small container plants to large float plants), capital costs will be in the range of EUR 0.8 - 5.5 million with operating costs of EUR 44000 to 1 million per year. Investment costs as low as EUR 0.1 million are reported for particularly small furnaces in the mineral wool sector equipped with bag filters. Questions are raised as to whether secondary dedusting would be necessary in all cases, in particular for small furnaces producing high quality soda-lime glassware where the metal content of the emissions is very low. Clearly, the costs of primary measures are much lower than for secondary measures and no waste is produced or energy consumed. These are good reasons to prefer primary measures above secondary measures and to stimulate the development of primary measures.

The European glass industry has invested significantly in understanding the mechanism behind dust formation and the development of primary dust abatement techniques. At the time of writing (2009), a large number of plants were already equipped with secondary measures and only a small number of soda-lime plants had dust emissions below 100 mg/Nm^3 without the use of secondary abatement, while 100 - 200 mg/Nm^3 (around 0.3 kg/tonne glass) was currently considered the range generally achievable with primary measures. The relative benefit of further reductions in dust should be considered in the context of the protection of the environment as a whole.

The positive aspects of primary techniques are overshadowed in a technical sense by the much better performance of secondary abatement techniques (<30 mg/Nm^3 or 0.06 kg/tonne glass for existing installations, and <10 mg/Nm^3 or 0.02 kg/tonne glass for newer installations) and the lack of prospect of reaching such low values with primary measures in the near future.

The need to reduce emissions of fine particulate matter, acid components and (heavy) metals has made the application of secondary measures a well-established procedure within the glass industry, being so far the best option in terms of emissions to air.

In addition, the exclusive use of primary techniques for reducing dust emissions could limit the flexibility of the operational conditions of the furnace in terms of quality of the feed materials (low impurities: fluorides, chlorides, heavy metals), type of fuel (low sulphur and heavy metals), production changes (coloured or decoloured glasses).

Economy of scale and related cost considerations

The definition of “available technique” in the Directive 2008/1/EC requires a technique to be developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, and to be reasonably accessible. In general, secondary abatement techniques for dust in the glass industry are considered to be accessible, technically viable and, in the vast majority of cases, economically viable.

However, as for any secondary technique, the economy of scale is an important aspect. It means that for small furnaces, relative costs (costs per Nm^3 of flue-gas treated) are generally higher than for large furnaces. The costs depend on the application and particularly the volume of waste gas. Specific costs per tonne of melted glass may vary significantly depending on the type of glass produced and the size of the furnace. The economy of scale should be taken into account when determining BAT on a general level. Apart from the economy of scale, the overall cost considerations for dedusting should also include the environmental benefits: removal of fine particulate matter, metals (if present) and acid gas scrubbing (if present), and the drawbacks due to waste generation (if recycling is not possible), energy consumption and indirect emissions from the use of electric energy and alkaline reagents.

4.4.2 Nitrogen oxides (NO_X)

[88, FEVE Proposal Ch.4-NO_X 2007]

The term "nitrogen oxides (NO_X)" includes nitric oxide (NO) and nitrogen dioxide (NO_2) expressed as the NO_2 equivalent. Nitrous oxide (N_2O) is not a normal pollutant within the glass industry, and is not covered in the term "'NO_X". The three main sources of NO_X emissions from glass melting activities are raw materials, fuel and thermal NO_X. A fourth source, prompt NO_X (from the reaction of nitrogen by a complex route with short-lived hydrocarbon radicals) is relatively insignificant.

When nitrates are present in the batch materials, NO_X will be emitted as the materials melt. In general, the majority of the nitrogen component is emitted as NO_X and is not incorporated into the glass. For example, when sodium nitrate ($NaNO_3$) is melted, the sodium component is incorporated into the glass as Na_2O and the rest of the compound is released as gases (NO_X, $O_2$and N_2).

Fuel NO arises by from the oxidation of nitrogen and nitrogen compounds present in the fuel, but the overall contribution is low in comparison with thermal NO_X. With natural gas firing, fuel NO is effectively zero.

Due to the high temperatures in glass furnaces (up to 1650 °C and 2000 °C in the flame), the major source of NO_X is thermally generated NO_X, arising from the oxidation of nitrogen in the combustion atmosphere at temperatures above 1300 °C. The main sources of the nitrogen are combustion air, atomising air (in oil-fired furnaces), and air leakage into the furnace. The predominant species is NO (90 – 95 %) formed by the overall reaction $N_2 + O_2 \rightarrow 2NO$. Levels of NO_2 are very low, and most NO_2 detected in the emissions results from atmospheric oxidation of NO. The conditions in the furnace are such that nitrous oxide (N_2O) is not detected in the emissions.

In electrically heated furnaces, NO_X arises from batch material breakdown only. In stone wool cupolas there is an overall reducing atmosphere and NO_X emissions are generally very low. Emissions may arise if an afterburner system is installed. The purpose of such a system is to oxidise carbon monoxide and hydrogen sulphide.

In fossil fuel-fired furnaces, if all other factors are equal, thermal NO_X emissions are reduced if fuel consumption is reduced. Therefore, techniques that improve energy efficiency generally result in lower overall NO_X emissions expressed in kg NO_X/tonne of melted glass. However, the concentration of the emissions is not always reduced, particularly if waste gas volumes are also lower. The reduction in thermal NO_X is a result of a combination of factors but principally, lower temperatures and reduced combustion air levels. Techniques that reduce NO_X emissions but are primarily intended to reduce energy consumption are described in Section 4.8 and are not discussed here.

4.4.2.1 Combustion modifications

Description

The formation of thermal NO_X is determined by a series of chemical reactions and is qualitatively described by the formula shown below.

$$\boxed{NO_X = A \text{ x } \exp\left(-\frac{B}{T}\right) \text{x } N_2 \text{ x } (0_2)^{0.5} \text{ x } t}$$

Where A and B are rate constants (m^3/gmol-s), T is the flame temperature (K) and t is the residence time at temperature T (sec). Gases are given in concentrations (gmol/m^3)

Therefore, the main factors influencing NO_X formation are flame temperature, oxygen content in the reaction zone and the residence time in the high temperature zone of the flame. The primary control measures for NO_X seek to generate those conditions least favourable for NO_X formation, i.e. to avoid the simultaneous presence of nitrogen and oxygen at high temperatures. The main techniques to minimise thermal NO_X are summarised below.

a) Reduced air: fuel ratio

The leakage of air into the furnace, particularly around burner nozzles and through the batch material feeder can lead to increased NO_X levels. The burner block is relatively easy to seal and measures can be taken to avoid air ingress at the batch feed area. These measures are relatively cheap and quite effective. The NO_X reduction clearly depends on the starting level but can be up to 10 %.

Generally, furnaces operate with an excess of air of 5 – 10 % (e.g. 1 – 2 % excess oxygen) to ensure complete combustion. By reducing the air/fuel ratio to near stoichiometric levels, significant NO_X reductions can be achieved and the technique can also result in significant energy savings; although a slight excess of air is normally required in order to avoid significant losses of fining agent from the batch and to ensure the glass quality. To implement the technique effectively, it will be necessary to monitor the NO, CO and O_2 levels in the waste gas. If combustion is substoichiometric, carbon monoxide levels and refractory wear may increase, and the redox level of the glass may be altered thus affecting the glass quality.

The air levels in the furnace may be further reduced by using natural gas, high pressure or steam as an alternative to air for oil atomisation. This reduces oxygen levels and so reduces peak flame temperatures. Results with this technique have been mixed, with very little benefit seen in some applications.

This type of change must be implemented carefully and incrementally to avoid problems and to achieve the best results. In some cases (e.g. recuperative furnaces), if the stoichiometry of the furnace as a whole is considered, some burner positions may fire with excess fuel in the hottest parts of the furnace, and others with slightly excess air in cooler parts. Overall, the ratio will be close to stoichiometric.

b) Reduced combustion air temperature

The flame temperature can be lowered by reducing the combustion air preheat temperature. For example, the combustion air temperatures in recuperative furnaces are significantly lower than in regenerative furnaces, resulting in lower flame temperatures and lower NO_X concentrations. However, the lower preheat temperature results in a lower furnace efficiency (lower specific pull), lower fuel efficiency and thus higher fuel demand and potentially higher emissions (kg/tonne of glass) of NO_X, CO_2, oxides of sulphur, particulate, etc. Thus overall, this technique is unlikely to be of environmental or economic benefit.

c) Staged combustion

If the fuel and air/oxygen are injected at the same place in the burner, a flame is produced with a hot oxidising primary zone close to the port and a cooler secondary zone further away. The majority of the NO_X is produced in the hottest zone. Therefore, by reducing the proportion of either the air or the fuel injected at the burner, the maximum temperature and the NO_X formation are reduced. The remaining fuel or air is added later in the combustion zone. The application of this principle is the basis of staged combustion, in both cases air staging or fuel staging.

Air staging involves firing substoichiometrically and then adding the remaining air or oxygen into the furnace to complete combustion. There are several ways of achieving air or oxygen staging. First experiences by hot air staging have been problematic. The techniques of blowing air staging (BAS) and oxygen-enriched air staging (OEAS) have been developed in the US.

As of 2009, there is no available information regarding applications of this process, and it is thought that this process is not being used in Europe due to the cost of the process and the preference for other primary techniques.

Fuel staging is based on the following principle: a low impulse gas flame (around 10 % of the total energy) is developed in the port neck. This secondary flame will cover the root of the primary flame, reducing the oxygen content of the primary flame and its core temperature. Therefore, NO_X formation is reduced. This technique has been applied widely by the glass industry and is commonly used in most conventional furnaces. At the time of writing (2009), no further improvements were foreseen by using this method.

d) Flue-gas recirculation

Waste gas from the furnace can be re-injected into the flame to reduce the oxygen content and therefore the temperature and the NO_X formation efficiency. Difficulties have been encountered by applying this technique in the glass industry at full scale. An innovative application based on internal recirculation of the flue-gases, has been in operation since 2007 on a recuperative furnace producing special glass (lighting) at the Osram plant, Augsburg, Germany. The system applied is based on the use of special "Glass-FLOX®" technology burners with automatic recirculation of the waste gas. In this case, flue-gas recirculation takes place directly in the combustion chamber; the combusted gases are used to dilute the FLOX® flames. The application shows a reduction efficiency of NO_x emissions in the range of 46 - 59 % from the initial value. The best achieved performance reported shows a concentration value of 484 mg/Nm^3 of NO_x emissions, from a starting level of 1183 mg/Nm^3 when a conventional combustion system was applied.

e) Low NO_X burners

This is a term used to cover a range of proprietary or glass company burner systems designed to minimise NO_X formation. These systems can vary in principle and can incorporate a range of features, including some of those described above and others listed below. Systems for gas firing will differ in some ways from those for oil firing. The main features of low NO_X burner systems are:

- slower mixing of fuel and air to reduce peak flame temperatures (flame shaping)
- minimum injection velocities that allow complete combustion
- increased (radiation) emissivity of the flame, with optimisation of the heat transfer to the glass melt. Therefore, a lower temperature level can provide the required energy for melting
- different nozzles and nozzle designs enable to generate multiple fuel jets per burner; some jets are shielded from the air by other fuel jets, creating soot to improve heat transfer and cooling of the flame, with a consequent reduction of NO_X formation.

f) Fuel choice

The general experience within the glass industry is that gas-fired furnaces result in higher NO_X emissions than oil-fired furnaces. Statistical data for 2005 concerning container glass furnaces, indicate an average value of 1000 mg/Nm^3 with gas firing compared to 750 mg/Nm^3 with oil. The differences vary widely between furnace type and application but a variation of 25 – 40 % between gas-fired and oil-fired operating conditions is not uncommon. The main reason for this is that gas flames have a lower thermal emissivity than fuel oil flames, requiring higher flame temperatures to enable the same heat transfer to the glass melt and thus more favourable conditions for NO_X formation. However, as the industry has developed more experience with gas firing and furnace designs have changed, the difference in NO_X emissions and fuel requirements for the two fuels has reduced. In some applications (e.g. container glass), fuel efficiency and NO_X emissions of gas-fired furnaces are progressively approaching those associated with fuel oil firing, due to a suitable flame adjustment. However, a comparison between the energy performance obtained with fuel oil and natural gas depends strongly on the furnace design.

To some extent, mixed oil-gas firing maintains the advantages in terms of oil flame emissions while using a proportion of natural gas and is increasingly used in some sectors.

The nitrogen content of natural gas is generally negligible, but can vary from region to region, with a consequential effect on NO_X. For instance, the concentration of nitrogen in gas supplied in the UK can vary between 0.1 and 5.7 % around the country according to the national grid and this is also the case for other Member States, e.g. Portugal, Italy.
Nitrogen is also, at times, purposely added to natural gas to control its calorific value and Wobbe index, which needs to be maintained constant, for instance for safety reasons in household (domestic) applications. This practice occurs in the Netherlands on its natural gas supply net with 11 - 14 % nitrogen in the gas composition. The UK, for example, is likely to adopt this practice in the future to ensure that liquefied natural gas (LNG) imported into the UK conforms to the entry specification and likewise may be necessary for gas to be imported from various Norwegian gas fields. This source of nitrogen will have a particularly significant effect on NO_X emissions from oxy-fuel fired furnaces.

The choice between gas and fuel oil is very dependent on the prevailing economic conditions and energy polices of the Member States. It is also reliant on the fuel being available which will vary geographically and also seasonally depending on the security of supply issues.

Achieved environmental benefits
The indicative emissions reductions that can be achieved using these combustion modification techniques are given in the description for each technique.

The effects of these techniques are not cumulative, as they are generally different ways of achieving the same broad objectives. Therefore, a 10 % reduction arising from one technique cannot simply be added to 10 % from another technique.

The overall emission reductions for optimised combustion systems vary widely from less than 10 % to greater than 70 %. For a furnace where little or no work has been done using these techniques, reductions in NO_X emissions of 40 – 60 % could be expected in most applications.

The actual emission levels achievable with these techniques will vary considerably depending on the starting point, the age and design of the furnace, and particularly on the rigour with which they are applied and monitored. A great deal can be achieved with relatively simple measures if they are properly applied. During the last decade, the glass industry has made substantial progress in minimising the formation of NO_X emissions by means of combustion modifications and a great deal of resources have been devoted to the work.

See also data regarding an example installation presented in Section 4.5.1.

Cross-media effects
The main cross-media effect associated with the application of most of the described techniques is the emissions of carbon monoxide (CO), due to local substoichiometric combustion conditions in the furnace, with potential problems in the recuperators and regenerators where CO is generally oxidised to CO_2.

At times, the completion of combustion might take place in the upper part of the regenerators, causing a temperature increase, which generates higher levels of SO_X emissions, due to the volatilisation/decomposition phenomena of the sulphates deposited on the surface of the regenerators.

Local reducing conditions may also be responsible for an increased evaporation from the glass melt, with higher levels of particulate emissions. Moreover, an early decomposition of sulphates used in the batch with a consequent loss of efficiency of the fining process and higher levels of SO_X emissions can occur.

The fuel switch from natural gas to oil for improving the emissivity of the flame and for decreasing NO_X emissions would lead to a significant increase of SO_X emissions, associated with the sulphur content of the fuel oil.

Operational data

End-fired regenerative furnaces generally give lower NO_X emissions than cross-fired regenerative furnaces (see Section 4.2) and the techniques described in this section are generally more successful for end-fired furnaces. Emission levels of 700 – 1100 mg/Nm^3 and 0.9 - 2 kg/tonne of glass have been achieved for cross-fired furnaces. For end-fired furnaces concentration values of 550 - 800 mg/Nm^3 and less than 1.5 kg/tonne of glass have been achieved. A limited number of figures have been reported below these levels, for certain applications.

Results on recuperative furnaces are more varied, but this may be due to the more variable use of these furnaces. Results comparable to (or sometimes lower than for) regenerative furnaces have been achieved with container glass and continuous filament glass fibre recuperative furnaces.

In Table 4.16 below, a summary of the best performance levels achieved with the application of primary measures in the container glass sector is presented, based on the mid 90 % (i.e.5 - 95 % of the values) data collection reported in Table 3.11,Section 3.3.2.2.

Data shown in Table 4.16 refer to different types of furnace and glass products, and to measurement conditions which are not homogeneous and standardised, therefore the reported values should be regarded as short-term achieved emission levels.

Glass container	**Range of the best achieved short-term emission levels**	
	mg/Nm^3 dry, 8 % O_2	kg/melted tonne
Type of fuel		
Gas	600	0.72
Fuel oil	520	0.65
Mixed gas + fuel oil	540	0.83

Table 4.16: NO_X short-term emission levels achieved for certain applications in the container glass sector with the use of primary techniques

The application of primary techniques to the glass frits sector is not expected to obtain the same results as for the other glass sectors, due to the peculiar characteristics of the small size furnaces which normally operate in oxidising conditions (excess air for combustion, oxygen enrichment) and with a number of batch formulations which contain significant amounts of nitrates (see Section 3.10.2.2). Typical NO_X values for the sector are around 1600 mg/Nm^3 referred to 15 % oxygen, equivalent to 15 kg/tonne frit.

A summary of the main advantages and disadvantages associated with the application of combustion modifications is shown in Table 4.17.

Advantages:

- low relative costs
- substantial reductions in NO_X emissions are achievable for most types of furnaces
- applicable to new and existing furnaces
- these techniques can often result in significant energy savings
- the lower furnace temperatures and energy use also result in lower overall emissions.

Disadvantages:

- substantial expertise required to obtain the best results
- modified furnace design may be required to obtain the best results
- care must be taken to avoid glass quality problems due to redox changes
- CO levels must be controlled to avoid refractory damage
- the more reducing atmosphere can encourage SO_2 emissions.

Table 4.17: Main advantages and disadvantages of combustion modifications

Applicability

In principle (and subject to the limitations stated above), these techniques are applicable to all conventional fossil fuel fired furnaces. Most of the techniques can be applied to both existing and new furnaces. However, the benefits of some techniques (e.g. low NO_X burners) may only be fully realised when combined with the optimum furnace design and geometry, which can only be achieved for a new furnace.

The success achieved with these techniques may also depend on the degree of operator expertise and scientific resource. To optimise the systems requires a sustained period of gradual experimentation and monitoring and a high degree of technical expertise and experience. For those operators that do not possess these resources, specialist consultants offer services for furnace combustion modifications and optimisation. This development work of course adds to the costs of the techniques.

The degree to which these techniques can be applied will also vary depending on product and process requirements. For example, in some domestic glass production, the product quality constraints demand a highly oxidised, very clear glass. This involves higher residence times, higher temperatures, and the use of oxidising agents, all of which contribute to higher NO_X emissions and limit the use of some of the techniques described above. This example is discussed further in Section 4.4.2.2 below.

The tendency of all glass sectors is to continuously improve the process by extending the use of these techniques when possible, try to determine the emission levels that could be expected in the future with primary techniques.

Economics

Costs comprise the purchase of adjustable burners, oxygen sensors (for cross-fired furnaces, more oxygen sensors and a more complex control system are required compared to end-port fired regenerative furnaces), a control unit for air-fuel ratio, maintenance, and manpower to modify and check burner settings.
Burner exchanges and changes in burner blocks will typically cost EUR 50000 to 100000 for end-port fired furnaces and up to EUR 300000 to 400000 for cross-fired furnaces.

The estimated costs for an oxygen sensor system are typically between EUR 20000 and 25000 for end-port firing, and EUR 60000 and 125000 for cross-fired furnaces.

In the case of furnace design changes, extra investment costs for the refractory materials and steel construction have to be taken into account and this may amount to EUR 2 million for float glass furnaces and EUR 700000 for end-port fired container glass furnaces.

The costs of combustion modifications are relatively low and can sometimes be offset by lower operating costs from energy savings. The costs for burners represent replacement costs (not the additional costs) and for a new furnace, the extra costs would be very low. Air staged combustion systems can be substantially more expensive.

These primary techniques combined with formulation optimisation are, in general, much cheaper than secondary abatement techniques. Comparative costs are discussed in Section 4.4.2.9.

The improvement and implementation of primary measures for the reduction of NO_x emissions is based on the principle that actions taken to avoid the formation of NO_x have, in general, a better overall environmental impact than end-of-pipe techniques, including a lower economic impact and a potential for energy savings with consequential reduction of other pollutants, e.g. CO_2. In any case, the application of primary techniques would be beneficial even when the use of a secondary measure is foreseen, since it will reduce the initial levels of NO_x before treatment.

Example plants
In 2005 in the container glass sector, more than 76 furnaces were applying primary techniques. Other glass sectors are also successfully applying one or more of these techniques. Many furnaces in Europe and US apply adjustable burners and oxygen sensors to control the combustion process (air-fuel ratio). This applies to the container glass, float glass and special glass sectors.

Reference literature
[tm32 Beerkens][33, Beerkens 1999] [64, FEVE 2007] [94, Beerkens - APC Evaluation 2008] [88, FEVE Proposal Ch.4-NO_X 2007], [117, GWI, VDI-Berichte Nr. 1988 2007], [118, CTCV Data for BREF revision 2007]

4.4.2.2 Batch formulation

Nitrates are used in glass manufacture as oxidising agents. By far, the most common nitrate used is sodium nitrate, but in some special glass applications, potassium or barium nitrate are also used. Sodium nitrate is often used in conjunction with fining agents that require oxidation (e.g. As_2O_3, Sb_2O_3, CeO_2) and thus takes indirectly part in the fining process although, in most applications, sodium sulphate would be the preferred fining agent. During the melting process the nitrates dissociate to form NO, NO_2, N_2, and O_2. The O_2 is used to oxidise the melt (particularly iron Fe^{2+} to Fe^{3+}) to give a very clear glass, and to oxidise any organic components of the batch materials.

The use of nitrates varies widely between the different sectors of the glass industry. They are rarely used in flat glass or container glass, except to produce some very high quality, very colourless products or highly coloured glass, e.g. grey or bronze glass. Nitrates are used in the domestic glass sector for some high quality products, which require a high optical clarity and so low Fe^{2+} levels. Nitrates are widely used in the special glass sector for TV (cathode ray tubes), borosilicate, ceramic and optical glasses.
Electric furnaces producing very oxidised glasses or where raw materials containing organic compounds are melted (e.g. glass wool waste) may also require nitrates as oxidising agents.

In glass wool production, nitrates are often used to compensate the oxygen consumption during burning of the organic material contained in the batch composition, particularly when high levels of recycled glass are added to the formulation. In frits production, nitrates are in the batch of many of the products in order to obtain the required characteristics. In all, an estimated 7 - 9 % of EU glass production involves the use of significant quantities of nitrates.

Typical quantities of around 0.5 – 1 % nitrate are introduced, i.e. 5 – 10 kg $NaNO_3$ per tonne of glass. For some processes, e.g. TV glass or frits, this can be up to 4 % or even higher. During melting, the main gases emitted are NO and O_2 with only low levels of N_2 and NO_2. For 1 % of nitrate introduced in the batch, the maximum NO_X emission is 5.4 kg/tonne of glass. This value is equivalent to approximately 2200 mg/Nm^3 at 8 % O_2, e.g. for a typical domestic glass furnace. The actual NO_X emissions from nitrates vary from 30 to 80 % of this maximum, with a typical value under industrial conditions of around 50 – 65 % (although the full range of values are frequently found).

The amount of NO emitted from nitrate depends on the heating rate, the redox state of the batch and the effect of the reducing gases (reducing flames) contacting the batch blanket which contains nitrates.

Effective alternatives to nitrates are limited by environmental and economic considerations. For example, sulphates can be used but the required quantity is much higher, more than three times, and SO_2 is emitted. Arsenic oxides can also be used, but these are being phased out wherever practicable for environmental reasons. Cerium oxide can be used in some cases but is many times more expensive than sodium nitrate. Some process modifications can also reduce the nitrate requirement, but these are generally prohibitive due to quality considerations, energy requirements, throughput restrictions or thermal NO_X generation.

In conclusion, the current opinion within the industry is that nitrate levels can be reduced by experimentation to the minimum commensurate with product and melting requirements, but due to economic and environmental reasons an effective alternative is still not currently available (as of 2009).

In many Member States, the legislation has allowed a doubling of the normal NO_X emissions limit for glasses requiring nitrate addition. This approach is not generally considered to be commensurate with the objectives of Directive 2008/1/EC. It makes no allowance for the wide variation in nitrate addition levels and provides little incentive to minimise nitrate usage. Furthermore, for processes adding only small amounts of nitrate, the doubling of the emission limit can mask high thermal NO_X emissions and could reduce the incentive to optimise firing conditions

The addition of nitrates cannot be considered as an isolated feature of the melting process. In general, glasses that require nitrate also have other specific constraints linked to their use. For example, the melting process for soda-lime glass, tableware or luxury packaging differs from container glass production not only by the use of nitrates, but also by: residence time (at least 50 % longer), by the requirement for much more oxidising conditions in the melt and in the furnace, and by higher glass temperatures (between 50 and 100 °C higher). All of these issues contribute to higher NO_X emissions per unit of glass production and can be up to two to three times higher than in container glass end-port fired regenerative furnaces.
The costs of the methods for reducing nitrate addition and the emission levels that can be achieved are very difficult to quantify; they depend greatly on the starting point and are very case specific.

4.4.2.3 Special furnace designs

The concern over NO_X emissions has led some furnace designers to propose recuperative type furnaces that integrate various features intended to permit lower flame temperatures and therefore lower NO_X levels. The best known of this type of furnace is the LoNO$_X$ ® melter. Another available design is the Flex® melter, which was originally intended to be used in discontinuous applications but so far, most of the furnaces built are operated continuously. The Flex® melter is understood to have comparable NO_X emissions to the LoNO$_X$ ® melter. A brief description of the Flex® melter is given in Section 2.3.7, but only the LoNO$_X$ ® melter is discussed in detail here.

Also the design of regenerative type furnaces can be modified with the aim of reducing NO_x emissions. However, detailed information about these applications is not available. In general, the important parameters concerning furnace design with respect to NO_X formation/limitation are the following:

- type of burners
- number of burners in operation
- angles of burners
- angle of burner port
- size of burner port (which determines the air velocity entering the combustion chamber)
- distance between the burner/burner port and the melt
- height and size of the combustion chamber (in general, increased sizes are associated with lower NO_X emissions).

Description

The $LoNO_X^®$ melter uses a combination of shallow bath refining and raw material preheating to achieve reduced NO_X levels, potentially without the penalty of reduced thermal performance.

Combustion air preheating is recuperative and two-stage raw material preheating is used to compensate for the reduction in combustion air preheating compared to a regenerative furnace. The waste gases from the main burners are passed over the raw materials entering the furnace, in an extensive premelting zone, before entering the recuperators. Upon exiting the recuperators, the waste gases are passed through an external cullet preheater, before finally leaving the system.

The shallow bath refiner forces the important critical current path close to the surface of the glass bath, thereby reducing the temperature differential between it and the furnace superstructure. The furnace can be operated at lower temperatures than a comparable conventional furnace.

The $LoNO_X^®$ melter is basically long and narrow and is divided into three parts. The first part is used to preheat, and then pre-melt the batch and cullet. Following this is the refining area, where the glass bath depth is reduced to 400 mm (or less). A deep refiner completes the tank.

The heating is provided by gas or oil burners in the melting zone and, mainly, in the refining area. The waste gases are exhausted over the top of the batch and cullet in the first part of the furnace, with consequent material preheating. The furnace is divided by internal walls to ensure that the raw materials entering the furnace are not directly heated by radiation from the hotter part of the furnace. Therefore, a high temperature differential is maintained between the raw materials and the gases and efficient heat transfer is achieved.
A small amount of electric boosting may be provided to assist the maintenance of convection currents in the preheating area and to avoid relatively low temperatures below the batch blanket. This effect is aided by bubblers installed near the end of the melting zone.

The external cullet preheater is positioned after the recuperator and is an important part of the $LoNO_X^®$ melter. It is a direct heating system, where the hot waste gases and the cullet to be heated are in contact with each other. The cullet and the waste gas flow countercurrently.
The cullet enters the tower construction at the top and slowly makes its way downwards to the exit; the waste gases enter at the bottom and are exhausted at the top. The preheater has internal louvre type vanes, which distribute the waste gases more evenly through the column of cullet. The cullet residence time in the preheater is around five hours. The waste gases enter the preheater at typically 500 °C and exit at typically 200 °C. The cullet preheat temperature is typically around 350 °C.

Achieved environmental benefits
Due to the lower combustion temperatures, quite low NO_X levels have been achieved. Emissions below 500 mg/Nm^3 are reported for the LoNO$_X$® melter, which equates to <1 kg NO_Xper tonne of glass melted. Lower emissions may be possible with increased operating experience and the application of combustion optimisation techniques.

The technique can achieve good energy efficiencies; figures of approximately 3.3 GJ/tonne of glass melted were reported for a cullet ratio of 90 - 95 % and an electrical boost of 3 %. This figure, although not corrected for primary energy, compares favourably to modern regenerative furnaces, although cullet levels as high as 90 - 95 % may be difficult to maintain due to the lack of post-consumer cullet and this will impact on the energy performance figures.

For normal operating conditions, specific energy consumption is similar to a comparable regenerative furnace.

Data concerning the performance of a LoNO$_X$® furnace producing 358 tonnes per day of container glass, with 80 % cullet in the batch composition are reported, showing an energy consumption of 4.0 GJ/tonne glass (including electric boosting) and measured NO_x emissions of 336 mg/Nm^3 at 8 % oxygen. [75, Germany-HVG Glass Industry report 2007]

Cross media effects
The LoNO$_X$® furnace is designed to operate with high levels of cullet, which could cause an increase in the emissions of metals and acid gaseous components (SO_x, HCl, HF) contained in the raw material.

Due to the low glass depths, an inherent feature of the design is that it is a long, narrow furnace, and the area of the furnace can be significantly greater than a conventional recuperative furnace design for a specified pull rate. This increases the space requirements, the capital cost, and the construction material to be used for the furnace and to be disposed of at the end of life.

As with all cullet preheating systems, there is the potential for emissions of organic species, including odorous substances and potentially dioxins/furans. Measurements have shown dioxin emissions to be below 0.1 ng/Nm^3 I-TEQ. These issues are discussed further in Section 4.8.

Operational data
The data submitted are included with the description.

Applicability
The technique of special furnace designs relies on significant preheating of the batch composition, which is difficult to achieve without high cullet levels. These furnaces are only really viable when high levels of cullet are used, i.e. greater than 70 %. Therefore, at the time of writing (2009) this implies that the technique is only applicable to the container glass sector and to those furnaces with >70 % cullet. The technique can only be applied at a full rebuild.
The dimensions of the tank (long and narrow) may also limit the applicability where there are space restrictions.

Economics
In 1998, it was estimated that for a 350 tonnes per day container glass furnace, the extra operating costs of this technique were negligible but the extra capital cost may be in the region of EUR 1.8 million. No other information is currently available.

Driving force for implementation
No data submitted.

Example plants
Wiegand & Söhne, Steinbach am Wald, Germany - Container Glass.

Reference literature

[Sorg LoNO$_X$][60, SORG 1999][tm19 5yrs LoNO$_X$][20, Ehrig et al. 1995]
[http://www.sorg.de/htm/sorg_technology/lonox_melter.htm]
[75, Germany-HVG Glass Industry report 2007] [tm6 NO$_X$Ind.duVerre][7, Ind.duVerre 1996],

4.4.2.4 The FENIX process

Description

The FENIX process is based on the combination of a number of primary measures for the optimisation of combustion of cross-fired regenerative float furnaces and of the reduction of energy consumption. In common with the combustion modification techniques described in Section 4.4.2.1, the optimisation of combustion for FENIX relates to:

- the reduction of excess air
- the suppression of hot spots thanks to the homogenisation of flame temperatures; and a controlled mixing of the fuel and combustion air, without giving rise to glass quality problems or carbon monoxide emissions.

The FENIX process also involves a complete modification of the combustion system and particularly the use of a new type of injectors. These injectors are under patent registration and are different depending on the type of energy used (gas, heavy oil or mixed energy) and are associated with new furnace designs including:

- overall dimensions (length, width, depth of glass), also depending on the pull rate
- design of burner ports
- regenerators (separate chambers).

The technology can be implemented on furnaces using gas, heavy oil, or the mixing of the two energies. Combustion control is provided by:

- minimising excess air thanks to a reduction of the air for atomisation of fuel oil, special designs of socket plates, elimination of cold air entrances and maintenance of furnaces
- reducing the fuel/air mixing rate in particular through the optimisation of the number, the types and the positions (angles) of injectors in the port.

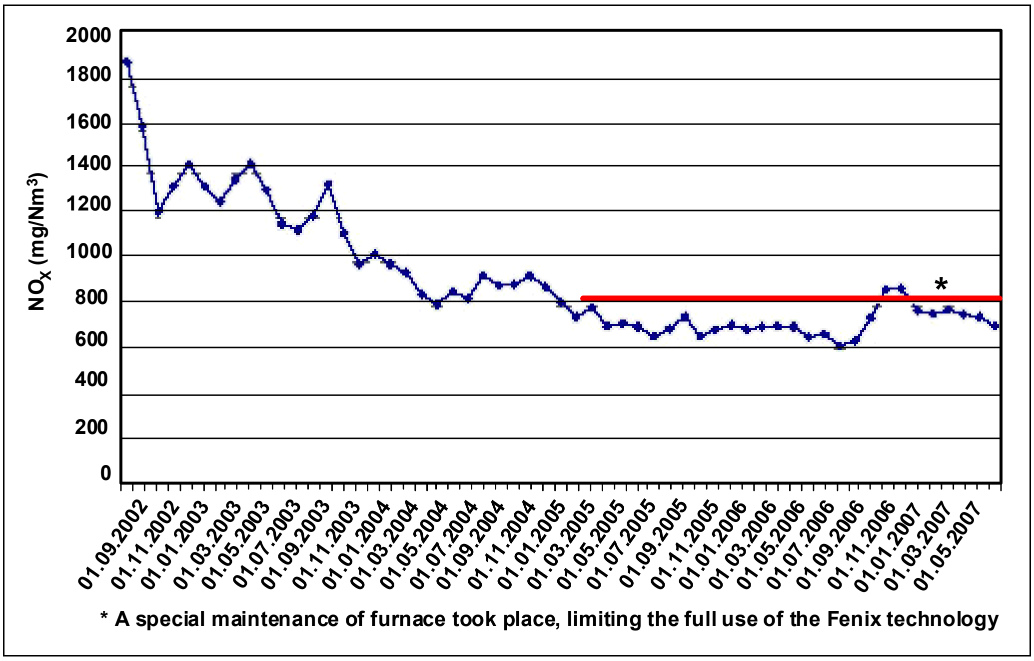
The technique also includes a review of the furnace control system and the installation of monitoring methods for certain furnace parameters. In particular, oxygen probes are installed at the top of the regenerator chambers to provide better control of excess air levels.

The main characteristics of the modifications to the combustion system are described in the patent application and are summarised below.

Temperature peaks are limited by the maintenance of the flame length while increasing the flame volume. The staging of combustion is achieved by controlling the supply of fuel and oxidant to stagger the contact and/or increase the flame volume. A 100 % oxygen flame may be used at the hottest level of the furnace. The staggering of the contact is also partly achieved by the use of an inert "buffer" gas on at least one injector. The inert gas can be CO_2 or recycled flue-gas and is injected between the main fuel and oxidant supplies. This pushes the development of the flame towards the centre of the furnace and promotes a wider, more even flame of greater volume.
The contact between the oxidant and the fuel can also be retarded by (a) secondary fuel injector(s) positioned in or close to the air inlet opening above the injectors of the main fuel supply. The technique can also include the use of air injectors or oxygen lances at various locations to maintain an oxidising atmosphere above the glass without overall excess air.
These devices can also be used to help control the combustion. A very important aspect of the technique is the design of the burner, details of which are considered confidential.

Achieved environmental benefits

The FENIX process allows the continuous stabilisation of NO_X emissions of between 700 and 800 mg/Nm^3. For example, NO_X emissions of the Stolberg plant, that runs a cross-fired float glass furnace (see Figure 4.5 below) have been stabilised below 800 mg/Nm^3 since February 2005, which correspond to a specific emission coefficient of less than 1.7 kg of NO_X per tonne of molten glass.



* A special maintenance of furnace took place, limiting the full use of the Fenix technology

Figure 4.5: NO_X emissions from FENIX process
[65, GEPVP-Proposals for GLS revision 2007]

Cross-media effects

At the time of writing this document (2009), the cross-media effects had not been evaluated.

Operational data

As reported in the glass BREF adopted in 2001, the first trial in the Aniche plant (France) had been carried out following the modifications to the combustion system as described in the patent application and had shown a performance of 510 - 580 mg/Nm^3 (1.25 kg of NO_X/tonne of molten glass) during a short period of tests. In 2008, this furnace is operating with 60 % gas and 40 % heavy oil and the NO_X emissions had been stabilised consistently at a higher value than the one which was achieved during tests, and are in the range of 700 - 800 mg/Nm^3.
In the mean time, the Fenix process had also been applied to other furnaces with the same range of emissions (between 700 and 800 mg/Nm^3) being achieved.

Applicability

The FENIX process requires careful application by a specialised team. It has been fully developed on at least nine furnaces of Saint-Gobain Glass in Europe. The technique can be available for float processes when directly integrated during the design and construction of the furnace.
Saint-Gobain Glass stated in 2001 that they were ready to grant a non-exclusive licence under the FENIX technology to other glassmakers, provided that an agreement could be reached on the conditions of such a licence. However, the application of this technique requires a previous study of the furnace to be carried out by the supplier; this necessity could make the application to other glassmakers very difficult because of confidentiality issues.

At the time of writing this document (2009), this technique has only been applied to cross-fired regenerative furnaces and, due to its specificities, it is improbable that it could be extended to other furnace technologies.

The trends of the first results obtained in the Aniche plant that had been reported inside the Glass BREF of 2001 were reproduced on other furnaces, using other fuels, allowing for the conclusion that the NO_X emission ranges of 700 - 800 mg/Nm^3 could be stabilised consistently.

The main issue concerning this technique is whether it can be considered available and accessible to all processes where it could be applicable. The implementation of the technique is a specialised and time-consuming process. Saint-Gobain have stated their readiness to license the technology, but (as for 2009) there still remains the question of whether the existing expertise is sufficient to permit the widespread implementation of the technique within the medium term.

Economics
The capital costs, including the furnace modifications (upper cost of refractories), the new burners and the improved control systems amount to approximately EUR 1.5 million for the application to an existing furnace operating with at least part of the energy supply as fuel oil. For a new plant or rebuild, the extra costs would be lower, at around EUR 1 million. Consideration would also have to be given to any licence fee and the time and expertise required to implement the technique.

Driving force for implementation
No data submitted

Example plants
Saint-Gobain Glass, Stolberg, Germany - float glass
Saint-Gobain Glass Herzogenrath, Germany - float glass
Saint-Gobain Glass, Chantereine, France - float glass
Saint-Gobain Glass, Aniche, France - float glass.

Reference literature
[tm24 FENIX][25, FENIX 1998] [65, GEPVP-Proposals for GLS revision 2007]
[tm36 FENIXpat] [38, FENIX 1998]

4.4.2.5 Oxy-fuel melting

Oxy-fuel melting involves the replacement of the combustion air with oxygen (>90 % purity). The technique can be used with either natural gas or oil as the fuel, although the use of gas is more common. The elimination of the majority of the nitrogen from the combustion atmosphere reduces the volume of the waste gases (composed mainly of CO_2 and water vapour) by 70 - 85 % depending on oxygen purity.
In general, oxy-fuel furnaces have the same basic design as recuperative melters, with multiple lateral burners and a single waste gas exhaust port. In the most modern furnaces, the geometry is optimised for oxy-fuel firing and NO_X minimisation. Furnaces designed for oxygen combustion do not currently utilise heat recovery systems to preheat the oxygen supply to the burners, due to safety concerns.

The technique potentially involves energy savings, because it is not necessary to heat the atmospheric nitrogen to the temperature of the flames.
Less gas has to be heated and therefore less energy is lost with the furnace waste gases. The potential energy savings depend greatly on the conventional furnace with which it is being compared.

In particular, the efficiency of the waste gas heat recovery system (recuperator, regenerator, etc) and the energy required to produce the oxygen must be taken into account. This complex issue is discussed later in this section.

The formation of thermal NO_X is greatly reduced because the main source of nitrogen in the furnace is very much lower, although some nitrogen is still present in the combustion atmosphere. This is derived from the residual nitrogen in the oxygen (VSA/VPSA 4 6 %, cryogenic <0.5 %), nitrogen in the fuel (natural gas 2 – 15 %), nitrogen from nitrate breakdown, and from any parasitic air. Due to the high flame temperatures any N_2 present is more readily converted to NO_X, and even low levels of N_2 can prove quite significant. It is therefore important to minimise air ingress into the furnace.

The furnace waste gas flow volume is 4 to 7 times lower compared to air-fired furnaces; their temperature can be very high (1200 – 1450) °C and will usually require cooling. Due to the high water content and concentration of corrosive species (e.g. chlorides and sulphates), cooling is usually by dilution with air. Following dilution, waste gas volumes are generally in the region of 30 – 100 % of conventional furnace waste gas volumes depending on the degree of dilution necessary.

Oxy-fuel melting requires different burner designs than those found in conventional air-gas firing. Since the introduction of the technique, the burner systems have undergone substantial development, from early modifications of existing designs for other oxy-fuel applications to the current, highly specialised low NO_X oxy-fuel burners developed specifically for glass making. These systems can feature some of the characteristics of other low NO_X high efficiency burners for conventional firing. Some of the important features of the main proprietary systems are summarised below:

- burners with long, wide luminous flames giving uniform heat transfer
- multiple oxygen injection per burner to stage the combustion process
- flat flames with wider coverage
- delayed mixing of fuel and oxygen to reduce peak flame temperatures in the oxygen rich zone
- no water cooling
- flame adjustability for momentum and shaping
- multi-fuel use.

The oxygen required for combustion can be supplied either by delivery to the site or by on-site production. Except for very small applications (e.g. some isolated frit furnaces), the amounts of oxygen required usually make it more economical to produce the oxygen on-site. However, if a site is situated close to an industrial oxygen pipeline it is usually more cost effective to obtain the oxygen directly from the pipeline. There are two main techniques for producing oxygen on-site, cryogenically or via an absorber system. The oxygen plant is usually owned and operated by the supplier who makes a charge for the oxygen supplied, although some operators will chose to have complete ownership of the oxygen plant. On-site oxygen plants are always provided with backup storage of liquid oxygen.Oxygen is produced cryogenically by compressing air and passing it through a purification unit to remove dust, water, carbon dioxide and trace contaminants.
The purified air is then cooled and passed through a low-temperature distillation column where the separation takes place. The separated gases can be warmed in heat exchangers to provide gaseous oxygen and nitrogen and, if required, liquid oxygen can be taken from the colder parts of the system.

The absorption process usually takes one of two forms; Vacuum Swing Absorption (VSA) or Vacuum Pressure Swing Absorption (VPSA). Both of these are non-cryogenic systems and the separation takes place around ambient temperatures.

The technique is usually much cheaper than receiving cryogenic oxygen by tracks, but has limited capacity compared to the cryogenic system and is usually chosen for medium level oxygen demands.

Most sites supplying only one or two glass furnaces would opt for this technique. For multiple furnaces or for furnaces with high O_2 demand (e.g. float glass), a cryogenic system may be preferred. The choice depends mainly on economic factors, which can be influenced by local conditions.

Compressed air enters the bottom of one of two absorber vessels filled with zeolite, which absorbs most of the nitrogen. The oxygen is withdrawn from the top of the vessel until the zeolite becomes saturated with nitrogen. The air stream is then directed to the second vessel whilst the nitrogen in the first vessel is discharged to the air. In the vacuum system, the nitrogen is removed by vacuum and in the pressure system, it is vented under pressure. The vacuum system usually gives the highest efficiencies.

The technique of partial oxy-fuel heating has been in use in glass making for many years. Two different techniques have been tested: oxygen lancing which was an additional injection of O_2 in a conventional air-fuel furnace in order to improve the heat transfer; or the addition of a pure oxy-fuel burner. The technique was used mainly to solve glass quality and furnace pull problems by positioning very hot flames accurately on the melt surface in order to increase temperature gradients and consequently to enhance the convective currents inside the melt. This also reduced the flow of waste gas feeding the same energy to the system. The technique was often used to extend the operating life of a furnace that was showing signs of deterioration or regenerator problems. The technique is still used in these ways today but the use is less common due to the problems of potentially increased NO_X emissions arising from the high temperatures. "Zero-port oxygen burners" are also used, for instance on float glass furnaces at the end of the furnace campaign to improve the melting of the batch blanket.

Achieved environmental benefits

It should be noted that concentrations of pollutants in the case of oxy-fired furnaces may show much higher values than those related to air-fuel furnaces, due to the reduced flue-gas volume. Correction of emission concentrations to 8 % oxygen is not meaningful for oxy-fired furnaces, since the oxygen content of the flue-gases includes both the possible excess of oxygen supplied for the combustion and the air entering the furnace and waste gas system. In these cases, the use of emission factors (kg/tonne glass) is more appropriate.

This principle should apply even when a combination of flue-gases from different furnaces using diverse combustion techniques (oxy-fuel, enrichment with oxygen, air-fuel) is conveyed to a single stack, which is often the case for glass frits production installations, in order to avoid an incorrect estimation of the emissions.

The main environmental benefit of oxy-firing combustion is a significant potential reduction of NO_x emissions (in terms of emission factors) with respect to an equivalent air-fuel fired furnace without other primary or secondary abatement techniques, and which would generally be over 70 %. This figure clearly depends on the point of comparison and can be higher than 95 % and lower than 60 %. In the glass frits sector, the reported NO_x reduction efficiency achieved with oxy-fuel fired furnaces is in the range of 20 - 45 %, due to the peculiar configuration and operating conditions of the melting furnaces (slight negative pressure) that allow parasite air to enter the furnace. Specific emission values of around 0.5 kg NO_x/tonne glass and, in specific cases, emissions as low as 0.23 kg/tonne glass are achieved with the application of oxy-fuel firing.

Apart from the burner choice, the achievable levels depend significantly on the type of natural gas supplied to the combustion system which might contain high percentages of nitrogen, and other parameters reported in the section concerning the operational data, presented below.

Oxy-fuel firing might also help to reduce overall emissions of volatile materials from the furnace (particulates, fluorides, chlorides etc) due to reduced gas flow over the melt and, in some cases, reduced turbulence, in spite of the high concentration of water vapour in the furnace atmosphere which stimulates the evaporation of alkali or boron.

Particulate emissions in soda-lime glass can be reduced by 10 - 30 % from the starting emission levels (air-fuel), although this is not seen in all applications. Particulate emissions are most effectively reduced for glasses containing boron (up to 50 %), in particular for alkali-borate glasses. In the US, the motivation for conversion to oxy-fuel melting has, in several cases, been particulate reduction rather than NO_X reduction. In cases where the adoption of oxy-firing results in a reduction in fuel usage, this will also lead to lower SO_2, in terms of emission factors when oil is used to fire the furnaces. However, SO_X emissions can be increased if the sulphur retention in the glass decreases due to the modified equilibrium between the glass melt and the combustion gases. Direct emissions of CO_2 are also reduced in proportion to any energy savings though the indirect CO_2 emissions corresponding to the electrical energy required to produce the oxygen should also be taken into account.

Cross-media effects.

The main cross-media effect of oxy-fuel combustion is represented by the emissions generated upstream at the power generation plant for the electrical energy used for oxygen production. Oxygen production requires about 0.375 kWh/Nm^3 and, according to primary energy sources, the related emissions will offset to a greater or lesser extent the potential NO_x, CO_2 and energy reductions obtained with the application of oxy-fuel firing for glass melting. In particular, the reported cross-media effects are the following:

- NO_X emissions indirectly related to oxygen production are reported to represent up to 10 to 15 % of the reduction of NO_x direct emissions
- examples report an increase of CO_2 emissions ranging from 35 to 230 %, compared to the reduction of direct emissions obtained through energy savings
- on average, oxygen production by VSA requires approximately 1.44 MJ/Nm^3 which corresponds to about 7 % of the equivalent energy released by the complete combustion of fuel with 1 Nm^3 of oxygen. In addition, this value should be converted into primary energy according to the electrical conversion efficiency at the power plant (i.e. up to ~20 % primary energy for a 33 % conversion efficiency)
- SO_X, dust and other atmospheric emissions are associated with electricity generation.

In general, it can be said that if the energy savings from oxy-fuel melting outweigh the costs of the oxygen production, then the reduced emissions will significantly outweigh the emissions associated with the oxygen production.

In recuperative furnaces without additional energy recovery measures (waste heat boiler or cullet preheating), the average energy saving will be about 25 – 35 %, including the energy consumption for oxygen production. For large regenerative furnaces this value is in the range of 0 – 15 %. For highly efficient regenerative furnaces, this figure can be negative.

As for all abatement measures that require the use of energy, the environmental benefits observed at site level are partially eroded when the overall figures are taken into account.

Some examples concerning the evaluation of cross-media effects of oxy-fuel combustion applied to glass furnaces are presented below (data reported are calculated on the basis of the methodology indicated in Section 8.1):

- for a container glass furnace of 225 tonnes/day, the direct decrease of NO_x emissions is 80 tonnes/year and the NOx associated with oxygen production is 11 tonnes/year, thus net reduction is equivalent to 69 tonnes/year. The decrease of CO_2 release from the furnace is equivalent to 1942 tonnes/year, but oxygen production causes indirect CO_2 emissions for 4444 tonnes/year. Besides, emissions of SO_2 released from the average power plant amount to 30 tonnes/year
- for a continuous filament glass fibre melting furnace, the direct NO_x emissions reduction is 80 tonnes/year, but the indirect increase of NO_x emissions (power plant) is almost 9 tonnes/year. The emissions of CO_2 from the furnace decrease by 5390 tonnes/year, while the indirect CO_2 emissions increase by 3530 tonnes/year.

The specific indirect emissions estimated for different glass furnaces and for different abatement pollution control techniques are shown in Table 4.41.

Operational data

The latest versions of oxy-fuel burners combined with optimised furnace design and operation are reported to give NO_x emissions in the range of 0.3 – 0.8 kg NO_X/tonne melted glass in the container glass sector, which generally equates to 200 - 500 mg NO_x/Nm^3. No information is available for emissions from flat glass furnaces where oxy-fuel firing is applied.

In the glass frits sector, data reported show emission levels in the range of 8 - 12 kg NO_x/tonne of glass melted, to be compared with typical levels of around 15 kg/tonne glass when air-fuel furnaces are used. These values refer to productions whose formulation contains significant levels of nitrates and the requested operating conditions of the furnaces allow parasitic air to enter the combustion chamber.

NO_X emissions depend very strongly on the following factors:

- the production process of oxygen; oxygen produced by VSA or VPSA systems still contains a small percentage of nitrogen
- natural gas quality; in the EU, natural gas is often supplied with more than 10 % nitrogen
- the type of applied burners; stage combustion burners generally lead to lower NO_x values (<0.5 kg/tonne molten glass, in the container glass sector)
- the energy consumption of the furnace; this determines the volume flow of flue-gases per unit mass of glass melt and depends, among other things, on required glass quality, furnace size and cullet ratio in the batch
- the quality of the fuel; some types of fuel may contain low quantities of organically-bound nitrogen.

One of the most important issues related to this technique is the potential energy savings that can be achieved. As mentioned above, this can often be the deciding factor in the economic viability of the technique in a particular application. In considering the cost effectiveness of the technique, it must be compared not just with the furnace it replaces, but with all the available options and alternative abatement measures and taking into account the energy used for oxygen production.

Energy savings can be greater than 50 % when small, thermally inefficient furnaces are converted to oxy-fuel firing. For a medium-sized recuperative furnace with no specialised energy saving measures, standard levels of insulation, and using only internal cullet, the energy use with oxy-fuel melting would be in the region of 20 – 50 % lower. However, for large, energy efficient regenerative furnaces with optimised thermal performance, the savings can be close to zero or can even be negative and up to 5 %. In these cases, the savings in energy would not compensate for the cost of the oxygen.

Each case is unique and must be considered with regard to its individual circumstances. As a general rule, oxy-fuel fired furnaces should be very well insulated and sealed in order to avoid problems with corrosion and attack of the refractory superstructure by vapours from the glass melt.

The main issue that could improve the economics of oxy-fuel melting is the recovery of heat from the waste gases. The high temperature of the waste gases improves the potential for heat recovery, but there are also a number of difficulties. The waste gases require cooling prior to any waste gas treatment in order to reach the operating temperature of the abatement equipment and to ensure that any particulate matter that will derive from volatile materials has been condensed.
The nature of the waste gases from many furnaces limits the use of direct heat exchangers due to problems of fouling by condensed particulates and corrosion. These problems are increased by high waste gas concentrations associated with oxy-fuel firing.
A particular problem exists in glasses which contain boron, where the gases have to be cooled quickly to prevent the formation of sticky solids which are corrosive and readily cause fouling in ducting and abatement equipment such as electrostatic precipitators. For these reasons, cooling tends to be carried out by dilution with air, although heat recovery should be the best option.

For the above reasons, the energy saving measures available for conventional furnaces (e.g. waste heat boilers, high-efficiency burners, and cullet preheating) have not been as widely applied for oxy-fuel furnaces. There is some experience with these techniques and at the time of writing (2009) it is understood that there are at least two furnaces fitted with waste heat boilers and very few oxy-fired furnaces apply cullet or batch preheating. A new technique for batch and cullet preheating, especially designed for oxy-fuel fired furnaces, which allows to operate at much higher flue-gas temperatures, is expected to be tested in the near future in the US. Some development work has been done on preheating gas and oxygen supplies, but this has not been developed at full scale and cannot be considered available. More details are given in the Emerging techniques, (Section 6).

However, as experience grows, more of these measures may be used in conjunction with oxy-fuel firing. There are no fundamental reasons why most of these techniques could not be used with oxy-fuel firing, but there are important technical issues that must be addressed and would take time to resolve (e.g. possible deterioration of refractory materials, colour changes in glass melt, foaming, etc).

Oxy-fuel melting involves higher flame temperatures which in some applications can lead to higher pull rates per square meter of furnace size (up to 25 % increase). This is particularly important where there is a desire to increase the capacity of a furnace but where space is not available to accommodate a conventional furnace of the desired size. This situation is aided further by the absence of the preheating system. In some applications, the technique can also lead to better process control and improved glass quality. This is particularly so for some special glass processes that require high melting temperatures. However, the higher levels of oxygen and water vapour may affect the glass chemistry for some glass types, requiring changes to the batch composition.

There is concern about the higher refractory wear and therefore shorter furnace lifetimes. In some cases, it may also lead to a higher level of glass defects (e.g. due to crown dripping). Reduced campaign lengths can have a very important financial impact on a plant particularly for larger furnaces such as in float glass. Experience to date (2009) varies from application to application from poor to very promising. A great deal of work has been done in this area and the problem can be reduced greatly. Some borosilicate producers report extended furnace lifetimes and, in some applications, lower crown temperatures have been experienced following conversion. It has been proven that, in order to avoid sodium silicate formation and dripping when a silica crown is used, the temperature of the crown should be maintained all the time at a sufficiently high temperature (above 1460 – 1470 ºC).

Under these conditions, a soda-lime container glass furnace with silica crown was still operating in 2009 after 14 years (O-I Europe, Leerdam, Netherlands in operation since 1994).

The new high emissivity burner systems are much more effective at transferring heat into the glass. Combined with careful design of the furnace, careful burner positioning and higher quality refractories, these burners make it easier to maintain operation within the thermal resistance limit of the refractories.
The use of higher quality refractory materials can add to the capital cost of the furnace and there remain concerns that they may not be sufficiently resistant in all applications. In soda-lime glass, the high vapour pressure of water can cause high NaOH vapour pressures, which can contribute to refractory wear, particularly above the glass level.
The technique of oxy-fuel melting is under constant development and furnaces designed using the latest techniques are likely to have greater campaign lengths than the earlier furnaces. In some applications problems with batch foaming have been reported. This can cause quality problems and reduce the efficiency and stability of heating. In glass wool manufacturing, the high oxygen levels in the furnace can make it easier to recycle wastes containing organic materials without the use of nitrates.

The high concentration of water vapour in the atmosphere of the furnace created by oxy-fuel promotes gas release from the melt with a potential improvement in fining (fewer seeds) but also much more foaming.

The effect of the furnace atmosphere on foam stability is still not fully understood and is a topic for further investigations. Although, oxygen-fired furnaces are considered proven technology, some possibilities remain for the optimisation of furnace geometry, crown height, burner location and height above the melt, positioning of exhaust ports which might improve energy efficiency and accordingly a reduction of CO_2 emissions and energy costs. Other possibilities for recovering heat from the low volume flow, but very hot flue-gases, are batch preheating or natural gas preheating and other options for the use of the energy recovered which could be developed. The high concentration of CO_2 in the flue-gas could potentially facilitate its capture.

A summary of the main advantages and disadvantages associated with the application of oxy-fuel melting is shown in Table 4.18.

Advantages

- low values of NO_X emissions can be achieved (0.2 - 0.8 kg/tonne of melted glass for soda-lime container glass)
- capital costs for furnaces are usually significantly lower
- in some applications, the technique is cost neutral or results in savings
- substantial reductions in energy consumption are possible in some applications (particularly where a recuperative furnace is replaced)
- potentially lower emissions of volatile substances and dust, expressed in mass flow, where waste gas volumes are reduced. This can lead to lower capital costs for abatement equipment
- potentially improved production/m^2 and improved process control
- glass quality may improve
- may facilitate the capture of CO_2, due to the high concentration in the flue-gases.

Disadvantages

- if substantial energy savings are not realised, the technique can be very expensive, especially for large soda-lime furnaces
- the cost effectiveness varies greatly between applications and must be assessed individually
- there have been problems with refractory wear leading to shorter furnace lifetimes, which have not been fully resolved
- the generation of oxygen requires electrical energy (from around 7 % of furnace consumption up to 20 % expressed in primary energy)
- the technique is essentially a primary measure in that it reduces NO_X formation, but does nothing to reduce NO_X from non-thermal sources e.g. batch nitrates
- the technique is most effectively installed at a furnace rebuild
- the storage, generation and use of oxygen have inherent risks and appropriate safety considerations are necessary
- oxygen generation can give rise to noise that must be controlled
- extra SO_x emissions can arise because the sulphur retention in the glass can decrease
- when high glass quality is required, the use of this technique may be restricted, due to a potential deterioration of refractory materials in the furnace.

Table 4.18: Main advantages and disadvantages of oxy-fuel melting

Data concerning the emission levels achieved with the use of oxy-fuel melting for installations producing container and special glass as examples, are presented in Table 4.19.

	Container glass (1)	**Special glass**	**Special glass**	**Special glass (2)**
Fuel	Natural gas	Natural gas	Natural gas	Natural gas
Total melting capacity	650 t/day	50 t/day	50 t/day	40 t/day
Actual pull rate	502 t/day	40 t/day	50 t/day	40 t/day
Electric boosting	-	yes	Yes	yes
Type of glass	Brown, green	Borosilicate	Borosilicate, containers	Glass ceramics
Cullet	66 % (average value)	60 %	40 %	50 %
Specific energy consumption	4.20 GJ/t glass (average value)	6.72 GJ/t glass	10.37 GJ/t glass	3.55 GJ/t glass
Associated emission levels (AELs)	0.23 kg/t glass	1.42 kg/t glass	6.67 kg/t glass (3)	5.59 kg/t glass

1. The installation consists of two furnaces.
2. The installation is equipped with a heat-recovery system, installed before a bag filter.
3. The value has been calculated, based on the information provided (mass flow, flue-gas volume, melted glass, measured emissions concentration)

Table 4.19: NO_X emission levels associated with the use of oxy-fuel melting in example installations

[75, Germany-HVG Glass Industry report 2007]

Applicability

Although the principle of 100 % oxy-fuel melting is well established, particularly in the continuous filament glass fibre and special glass sectors, its use in the glass industry as a whole has been limited by a number of factors. The technique is still considered associated with potentially high financial risk for larger capacity furnaces of >500 tonnes/day. A few issues still require further investigations, such as the choice of optimum refractory for the superstructure of the furnace, the prevention and stabilisation of foam formation and the heat recovery from the flue-gases.

In general, it is beneficial to delay installation until the next furnace rebuild to maximise potential benefits and to avoid any anticipated operating problems. In principle, oxy-gas burners could be installed in many processes without waiting until a cold repair. Hot installation may lead to energy savings and to an increased pull rate. However, it is unlikely to result in lower NO_X emissions and may actually increase NO_X levels; also there is a danger of accelerated refractory wear.

In 1998 it was estimated that 5 – 10 % of the world's glass production was made with oxy-fuel melting. Estimations made by the French oxygen producer Air Liquide, indicate that of the total glass production made by oxy-fuel, 25 % is produced in Europe and 56 % in North America. Since then, these figures have been changing with different trends between the sectors.

Worldwide there are at least 200 industrial oxygen-fired glass furnaces. Especially in the continuous filament glass fibre sector and special glass sector, oxy-fuel firing is widely applied. There are three oxy-fired float glass furnaces in the world (US) and about 40 to 50 oxy-fired container glass furnaces.

There are also several examples of oxy-fuel melters operating successfully in the mineral wool, special glass and frits sectors.
The application of oxy-fuel combustion has encountered more problems in the domestic glass production sector, due to severe foaming that can affect the higher quality requirements for this type of glass. However, some installations are successfully operating with oxy-fired furnaces.

Concerning the flat glass sector, the main barrier to the application of oxy-fuel combustion is represented by the high costs for oxygen and special refractory material required for the furnace. In Europe, at the time of writing (2009), one oxy-fired furnace was operating in the flat glass sector (cast glass), and one application was planned to start in the near future in France. Eight furnaces are operating for the production of container glass representing 3.2 % of the total European production of the sector (in Germany, the Netherlands, France and Italy). In the production of continuous filament glass fibre, 43 % of the melting furnaces operating in Europe are oxy-fired. In glass frits production, 15 % of the furnaces apply oxy-fuel melting. A significant number of European furnaces in the mineral wool, domestic and special glass production (in particular for borosilicate glass tubes) are oxy-fired.

Economics

The financial aspects of oxy-fuel melting can vary greatly between the different sectors and from case to case. The costs are very difficult to predict, but some indicative figures are given in Section 4.4.2.9 where a comparison of NO_X abatement technique costs is given. The main factors affecting costs are:

- the capital cost compared to the most likely alternative
- the possible energy savings that can be achieved (very dependent on furnace size and design)
- the prevailing cost of oxygen for the installation
- the potential effect on campaign length and the financial risk that entails.

An important factor in the capital cost is that oxy-fuel furnaces do not have a conventional combustion air preheat system and so the capital cost is generally lower than for a regenerative or recuperative furnace of comparable pull rate. This is most evident for new plants where the total cost of the preheating system is saved. The most advanced oxy-fuel burners are generally more expensive than advanced low NO_X burners and the costs of the oxygen control system are quite substantial. However, for most furnaces, the extra costs of the oxy-fuel burners and control systems are significantly lower than the savings for the preheating system.

Concerns over the effect of the technique on refractory life may lead to the use of more expensive materials for the furnace crown. If necessary, this extra cost could reduce the capital advantage significantly. Comparative costs have been calculated for oxy-fired furnaces with high duty silica crown (EUR 300000 - 400000 in extra costs) and for crowns constructed of fused cast materials (AZS or alumina). These fused cast materials may increase the costs for the crown of a float glass furnace by EUR 4 - 5 million.

The elimination of air preheaters and consequent capital savings is not only the case in the most common glass sectors (container, continuous filament glass fibre, special glass, etc) but also in the frits industry where the use of air preheating with recuperative heat exchangers is well established and applied to the majority of furnaces.

For regenerative furnaces, the regenerator systems can date back to the first furnace built in that position, and they will be repaired, upgraded or replaced as necessary with each furnace rebuild. Therefore, although there is a significant savings it may not be as great as for a new plant. With recuperative furnaces, the recuperator is usually replaced with each furnace rebuild, but the supporting framework may be re-used if the furnace design and position are largely unchanged. The capital savings for new plants may vary significantly among different installations. In general, savings in the region of 20 % for recuperative furnaces and 30 - 40 % for regenerative furnaces have been reported.
If the supplier operates the oxygen plant, the capital cost is generally included in the oxygen charge and is not considered separately.
The housing of the oxygen facility is usually provided by the glass company, but the cost is quite low. If the glass company chooses to operate the oxygen plant independently, the capital cost may be up to 10 % of the furnace cost. If the nitrogen by-product from oxygen generation can be used or sold, then it may contribute to reducing the overall costs.

Several documents in the glass industry literature quote the costs of oxy-fuel firing as greater than or equal to SCR. However, this has not always been reflected in practice with some operators reporting cost-neutral conversions or in some cases savings on operating costs. Most of the positive results are from conversions of smaller non-regenerative furnaces, with relatively high specific energy consumption.

Excluding concerns over refractory life, in most applications, the determining factor regarding the cost effectiveness of oxy-fuel firing will be the difference between the energy savings and the costs and the cross media effects of oxygen compared to the costs and the cross-media effects of alternative NO_X abatement techniques. This is case specific and while for many smaller furnaces the balance will be beneficial, for larger furnaces the savings are generally lower and the financial balance will depend much more on the specific circumstances and other factors (particularly the annualised capital cost) will become more important. The prevailing energy and particularly the oxygen costs (both of which are subject to variation) are also clearly important.

In Figure 4.6 below, the total difference in specific melting costs comparing oxygen-gas fired furnaces with conventional glass furnaces is shown. Estimated data concerning regenerative furnaces for float and container glass and large tableware, and recuperative furnaces for small tableware and continuous filament glass fibre are reported. (See Section 8.1 for the methodology and assumed costs used for the comparative study).

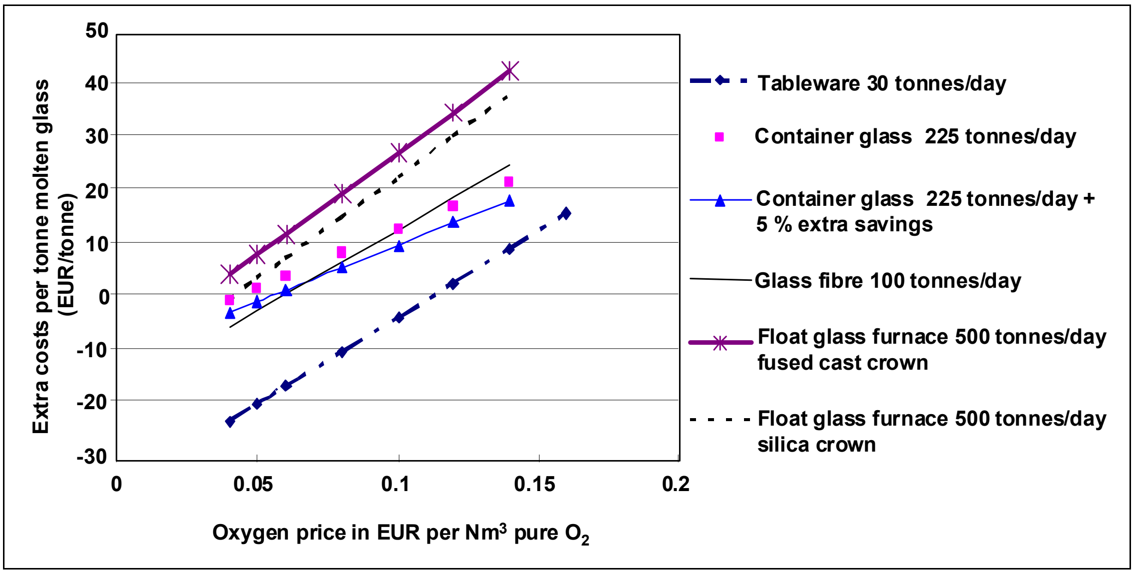


Figure 4.6: Difference in specific melting costs after conversion from conventional furnaces to oxygen-firing for different glass production installations (container, float, continuous filament glass fibre and tableware)

[94, Beerkens - APC Evaluation 2008]

In Germany, as of 2007, the current average costs for oxygen production were quoted to be in the range of EUR 0.04/m^3 and EUR 0.07/m^3, depending on the type of generation system used (cryogenic, VSA/VPSA) and the volume produced, and a final price at delivery point is reported between EUR 0.046 and 0.11 per m^3. The electricity needed for the production of oxygen is between 0.4 and 1 kWh/m^3, with a typical cost in the range of EUR 0.05 - 0.065 per kWh. [75, Germany-HVG Glass Industry report 2007].The price of oxygen may vary significantly up to a factor of two or more, depending on the amount of oxygen use in the installation.

Specific costs related to the application of oxy-fuel melting have been estimated for different types of glass and furnace capacity. The achievable levels assumed for the calculation have been the following:

- float glass: 1.5 - 2 kg NO_X per tonne of melted glass
- container glass: 0.5 - 0.9 kg NO_X per tonne of melted glass
- special glass (no nitrates in the batch): 1 - 1.5 kg NO_X per tonne of melted glass.

The results obtained are reported below:

- for container glass, the estimated costs for furnaces of different capacities (200 tonnes/day and 450 tonne/day), when comparing an end-port regenerative type furnace to an oxy-fired furnace, show a decrease in investment costs of between EUR 2 million for a small furnace and EUR 4.7 million for the larger furnace, with annual operating costs that increase by EUR 450000 per year and EUR 1.5 million per year, respectively. The specific cost increase per tonne of melted glass is equivalent to EUR 3/tonne glass for the small furnace and EUR 5 - 5.25/tonne glass for the larger capacity furnace. The cost of NO_x removal is estimated at EUR 3.4 - 4 per kg NO_x for the small furnace and EUR 5.5 - 6 per kg NO_x for the one of larger capacity
- for float glass, the costs estimation for the application of oxy-fuel combustion to a float glass furnace with a capacity of 500 tonnes/day shows a decrease in investment costs equivalent to EUR 7.5 million in the case of a silica crown for the furnace, reduced to EUR 3.5 million when fused cast material (AZS or alumina) is used for the crown. The operating costs would increase by EUR 2.7 million per year, including costs for CO_2 allowances to comply with the Emission Trading Scheme (ETS) Directive 2003/87/EC, and calculated on the basis of a cost for oxygen equivalent to EUR 0.06 per m^3.

The specific costs would increase by EUR 6.8 per tonne glass up to EUR 11.4 per tonne glass, depending on the type of material used for the furnace crown. A lower price for the oxygen would significantly reduce the cost increase per tonne of melted glass. For a price of EUR 0.045 per m^3, the specific cost increase would be in the range of EUR 1.1 and 5.6 per tonne glass. The estimation for the float glass furnace results in a cost for NO_x removal of between EUR 3 and 5 per kg NO_x removed

- for tableware, the extra investment costs estimated for a furnace of 30 tonnes/day are equivalent to EUR 500000, due to the high quality refractory material required for this type of glass. A decrease in operational costs is expected if the oxygen price is below EUR 0.12/m^3. For an existing furnace of 70 tonnes/day, the conversion from regenerative configuration to oxy-fired resulted in a reduction of the investment costs equivalent to EUR 2.25 million. Operating costs increased by EUR 600000 per year, equivalent to an increase of EUR 12 - 13/tonne of glass, based on an oxygen price of EUR 0.10 per m^3.
- for continuous filament glass fibre, for a furnace of 100 - 120 tonnes/day, the increase of investment costs related to the conversion from a recuperative type furnace to oxy-fuel combustion has been estimated at EUR 1.5 million, with a reduction of operating costs equivalent to EUR 250000 per year, taking into account a price for oxygen of EUR 0.10 per m^3. In this case, the specific costs per tonne of glass melted will increase by EUR 6 per tonne and the cost of NO_x removal is equivalent to EUR 3 - 3.25 per kg NO_x
- for glass wool, the application of oxy-fuel combustion to a melting furnace of 125 tonnes/day, shows specific costs of about EUR 100 per tonne of glass. The estimation is based on the price for oxygen at the delivery point equivalent to EUR 0.1 per m^3 and a cost of electricity of EUR 0.091 per kWh including taxes. Above this furnace capacity, the application of fuel-air combustion appears to have a lower specific cost.

Examples of actual cost data are reported in Table 4.20 for installations producing different glass types under diverse operating conditions.

	Container glass[1]	Special glass[2]	Special glass[3]
Fuel	Natural gas	Natural gas	Natural gas
Furnace capacity	650 t/day	50 t/day	50 t/day
Actual pull rate	502 t/day	40 t/day	50 t/day
Electric boosting	-	yes	Yes
Type of glass	Brown/green	Borosilicate	Borosilicate
Cullet	66 % (average value)	60 %	40 %
Specific energy consumption	4.20 GJ/t glass (average value)	6.72 GJ/t glass	10.37 GJ/t glass
Associated emission levels (AELs)	0.23 kg/t glass	1.42 kg/t glass	6.67 kg/t glass
Oxygen production	On-site, cryogenic	Delivered, cryogenic	On-site, cryogenic
Electric energy cost	EUR 0.05/kWh	EUR 0.065/kWh	350 °C
Delivery cost of oxygen	EUR 0.046/m^3	EUR 0.11/m^3	EUR 0.065/m^3
Natural gas price	EUR 0.0193/kWh	EUR 0.025/kWh	EUR 0.025/kWh
Specific costs for oxy-fuel melting	EUR 9.97/t glass (average value)		~ EUR 23/t glass
Total investment costs including amortisation of entire plant	EUR 34.2/t glass	EUR 93.46/t glass	EUR 90.73/t glass
Interest rate	6 %	-	-
Service life	12 years	-	-
Estimated cost for a comparable conventional regenerative furnace	EUR 40.2/t glass	EUR 120.13/t glass	EUR 142.36/t glass
Estimated difference	- 15 %	- 22 %	- 36 %

1. The installation is equipped with two furnaces. A heat-recovery system is installed before the bag filter. Values for cullet usage and energy consumption are the mean average of the two furnaces.
2. The fuel decreases from 555 m^3/t glass (conventional furnace) to 196.2 m^3/t glass (oxy-fuel melting). Costs are estimated based on verbal communication from the site management.
3. Costs are estimated based on available information. Costs associated with the use of electric boosting are not included in the calculation.

Table 4.20: Examples of estimated costs of oxy-fuel melting applied to the container and special glass sectors.
[75, Germany-HVG Glass Industry report 2007]

Driving force for implementation

Oxy-fuel melting is a primary technique that is applied to reduce NO_x emissions and, in some specific cases, other atmospheric emissions (particulate). The application of oxy-fuel melting to some sectors of the glass industry (special glass, continuous filament glass fibre, mineral wool) is regarded as a good technical and economic option for the melting process. The reduction of energy consumption with consequently lower CO_2 emissions may be the driving force for the application of oxy-fuel melting to furnaces in these sectors.

In the glass frit sector, the NOx removal efficiency associated with oxy-fuel combustion is about 20 - 45 %. Therefore, for this sector the technique is mainly considered a good alternative for the melting process.

Example plants

Pilkington-LOF, Toledo, Ohio, US - float glass
Ardagh Glass, Moerdijk, the Netherlands - container glass
O-I Europe, Leerdam, the Netherlands - container glass
O-I Europe, Schiedam, the Netherlands - container glass
Vetrobalsamo, Sesto San Giovanni, Italy - container glass
PPG Industries, Hoogezand, theNetherlands - continuous filament glass fibre
PPG Fiber Glass, Wigan, UK - continuous filament glass fibre
OCV Reinforcements - Vado Ligure, Italy - continuous filament glass fibre

Gerresheimer Pisa, Pisa, Italy - borosilicate glass tubes
Schott Glas, Mainz, Germany - special glass
Philips Lighting, France, Poland, Netherlands - lighting glass
Owens Corning Building Products (UK) Ltd, Cwmbran, UK - glass wool
James Kent Ltd, Stoke-on-Trent, UK - frit
Saint Gobain Desjonqueres, Mers, France - container glass
Orrefors Kosta Boda, Sweden - <5tonnes/day crystal glass
Verrerie de La Rochère, France - 17 tonnes/day soda-lime
St George Crystal, US - 32 tonnes/day lead crystal
Nachtmann, Germany - 9 tonnes/day lead crystal.

Reference literature
[4, EPA 1994] [7, Ind.duVerre 1996] [tm29 Infomil] [30, Infomil 1998] [tm8 S23.03] [9, S2 3.03 1996] [tm32 Beerkens] [private communication BOC] [33, Beerkens 1999] [tm17 Ercole] [18, Ercole 1998] [tm45 Illy] [46, Illy et al. 1998] [19, CPIV 1998] [75, Germany-HVG Glass Industry report 2007] [78, DUTCH oxi-firing furnaces 2007] [79, TNO OxyFiring2005ATIVFinal 2005] [88, FEVE Proposal Ch.4-NOx 2007] [91, ITC - C071304 2007] [92, ITC - C071603 2007] [94, Beerkens - APC Evaluation 2008] [79, TNO Oxy-firing 2005, ATIV Final 2005] [98, ANFFECC Position of the Frit Sector 2005] [99, ITC-C080186 2008] [e.g. tm3 EPA, tm6 NO_X Ind.duVerre] [115, EURIMA-ENTEC Costs evaluation 2008]

4.4.2.5.1 Overall conclusions for NO_X reduction using oxy-fuel

[94, Beerkens - APC Evaluation 2008]

Due to the complexity of the issues surrounding this technique, it is considered useful to have a conclusion.

Oxy-fuel melting can be a very effective technique for NO_X abatement and, with some exceptions, the technique can be considered to be technically proven. In principle, oxy-fuel melting can be considered as applicable to the glass industry as a whole, but the problems of the implementation should not be underestimated.

Oxy-fuel fired furnaces are applied successfully to container glass production, several kinds of special glass (flat panel, soda-lime-silica lighting glass, borosilicate lighting glass), float glass, glass fibre, continuous filament glass fibre and insulation wool [94, Beerkens - APC Evaluation 2008]. The efficiency for NO_X emissions removal associated with the application of oxy-fuel combustion to the glass frits industry is significantly lower than for other glass sectors. Available data show a reduction of between 20 and 45 % from typical values with air-fuel furnaces [99, ITC-C080186 2008].

There are still some important unanswered questions concerning the effect on the lifetime of furnace refractory materials. Refractory suppliers have been developing new materials, such as improved silica and MgO-Al_2O_3 materials, as an alternative to AZS or alumina materials. However, there is still a degree of financial risk associated with the technique.
[109, Schep, A decade of oxy-fuel 2003]

Initially (1990 - 1995), the lifetime of oxy-fuel fired glass furnaces was expected to be shorter than that of traditional fuel-air fired furnaces. However, in the European container glass sector, there are at least a few oxygen fired furnaces with the same lifetime. The design of the furnace, the quality of materials (especially crown) and a very tight sealing of the superstructure are important factors to determine the furnace lifetime.
The economic competitiveness of the technique depends mainly on the potential for energy savings and on the relative costs of alternative techniques for achieving comparable NO_X emission levels.

In many applications that require small to medium sized furnaces, significant energy savings can be realised, which makes the technique more competitive. Indeed in some applications (particularly furnaces producing <50 tonnes per day) the energy savings alone may be sufficient motivation to install the technique. Larger conventional furnaces tend to be inherently more energy efficient and the potential reductions in energy consumption are much less, which increases the overall cost of the technique. In a number of applications the savings are unlikely to outweigh the costs and the technique may not represent the most cost-effective way of achieving NO_X reductions. On the other hand, larger furnaces require high quantities of oxygen, with are normally associated with a better price per m^3.

The improvements in the performance of other NO_X abatement techniques (particularly primary techniques), combined with the advances in furnace energy efficiency are eroding the competitiveness of oxy-fuel melting. However, in applications where these developments have not been so great or where other factors limit their application (e.g. glass wool, continuous filament glass fibre and special glass), oxy-fuel melting is potentially a very attractive technique.

The relative merits of oxy-fuel melting vary greatly from case to case and the decision to implement the technique can be strongly affected by other factors, for example, if an increase in pull rate is required without an increase in the size of the furnace, an improvement of the quality of glass is needed, or if the plant is located close to a cheap source of oxygen. The economics can be affected to such a degree by site-specific factors that each case must be considered on its individual circumstances.

Oxy-fuel melting should be considered as one effective NO_X abatement measure that, depending on the site-specific issues, might represent the most appropriate approach. It should, however, be recognised as one of the main techniques in determining BAT Associated Emission Levels (BAT-AELs) in the glass industry.

Nonetheless, the use of oxy-fuel combustion brings with it certain considerations concerning the potential cross-media effects that need to be taken into account, such as the environmental impact associated with the production of oxygen [99, ITC-C080186 2008].

For a comparison of estimated costs and cross-media effects of oxy-fuel firing with other techniques Table 4.27, Table 4.29 and Table 4.42.

4.4.2.6 Chemical Reduction by Fuel (CRF)

Chemical Reduction by Fuel (CRF) describes those techniques where fuel is added to the waste gas stream to chemically reduce NO_X to N_2 through a series of reactions. The fuel does not burn but pyrolyses to form radicals which react with the components of the flue-gas to form H_2O and N_2. The two main techniques that have been developed for use in the glass industry are the 3R process and the reburn process. Both of these techniques are currently restricted to regenerative furnaces. The 3R process has been fully developed for application within the industry but at the time of writing (2009), the reburn process has not yet demonstrated its industrial applicability in the glass industry.

The principal reaction pathway for the techniques based on the reduction by fuel is summarised below:
$CH_4 \rightarrow CH$
$CH + NO \rightarrow HCN$
$HCN + OH \rightarrow NH_2$
$NH_2 + NO \rightarrow N_2$

During the first stage of the process hydrocarbon radicals (CH_X) are formed mainly by thermal decomposition in the zone where the fuel (generally natural gas) is injected.

The radicals react with NO_X formed in the furnace to form other nitrogen species such as HCN and NH_3. Once formed, these species rapidly react with other primary NO molecules to form molecular nitrogen (N_2). After allowing the reburn fuel to mix and react with the combustion gases, burnout air is injected to complete combustion of the reburn fuel. In the burnout zone, any remaining reduced nitrogen species are completely converted to molecular nitrogen (N_2) or back to NO.

4.4.2.6.1 The 3R process

Description

The basis of the 3R process is the addition of a hydrocarbon fuel (e.g. natural gas or oil) in a controlled manner to the waste gas stream at the regenerator entrance. This fuel does not burn but dissociates and acts to chemically reduce the NO_X formed in the furnace. The technology is designed for use in regenerative furnaces, where the regenerator provides the necessary conditions of temperature, turbulent mixing and residence time for the reactions to proceed. The process name “3R” relates to reaction and reduction in regenerators.

There are two main stages involved in the 3R process, $deNO_X$ and burnout. In the $deNO_X$ stage there are two principle mechanisms; the first involving the reaction between 3R fuel radicals and NO. The radicals (CH_x) are formed very quickly as the fuel enters the regenerator. The main reactions occurring at this stage are:

$CH_4 + OH/O/O_2 \rightarrow CH_x + H_2O$
$CH_4 \rightarrow CH_x$
$CH_x + NO \rightarrow H_xCN + O$
$CH_x + NO \rightarrow H_xCNO + H$

These reactions are very rapid and take place mainly in the upper regenerator chamber. They account for around 25 % of the NO_X reduction.

The second mechanism occurs as the waste gases pass down through the regenerator checkerwork, where the residence time is relatively long. The CO and H_2 (formed from primary and 3R fuels) have adequate time at a high enough temperature to reduce the majority of the remaining NO to N_2. This reaction takes place throughout the regenerator system, but predominantly in the checkerwork and accounts for the majority of the NO_X reduction achieved by 3R. The main reactions are:

$CO + NO \rightarrow \frac{1}{2} N_2 + CO_2$
$H_2 + NO \rightarrow \frac{1}{2}N_2 + H_2O$

The second stage of the process involves the burnout of reduced species, mainly unreacted CO and H_2. These species are oxidised by the controlled supply of air into the flue-gases below the regenerator. The main reactions are given below.

$CO + \frac{1}{2} O_2 \rightarrow CO_2$
$CO + OH \rightarrow CO_2 + H$
$CO + HO_2 \rightarrow CO_2 + OH$

Achieved environmental benefits

Depending on the installation, the emission levels achieved with the application of 3R are in the range of 1.0 – 1.5 kg/tonne of glass melted. An overall NO_X reduction of between 70 – 85 % and NO_x emission concentration levels down to 500 mg/Nm^3 (dry, 8 % O_2) can be achieved, according to data reported by the 3R technology supplier.

Cross–media effects

The main drawbacks with 3R are that the use of hydrocarbon fuels to achieve the necessary NO_X reduction involves an inherent cost and leads to an increase in CO_2 emissions. This means it is attractive to combine 3R with more conventional primary NO_X reduction measures in order to reduce the 3R fuel requirement.

If a waste heat boiler is installed, most of the energy in the 3R fuel can be recovered and the overall CO_2 increase will be minimal. The use of 3R does not necessarily imply that a waste heat boiler would be cost effective overall, but where one is already installed (or intended to be installed) 3R results in a beneficial increase in the furnace load range over which the boiler can be utilised. Overall this may lead to substantial savings in the site energy requirements and the use of other energy sources (e.g. fossil fuel boilers) can be reduced. An important limitation to the amount of energy that can be recovered is often given by the lack of demand for steam within the installation. Depending on the specific application, these energy savings mean that the 3R process could give rise to significant cost savings (one 1997 example quoted around EUR 600000/year).

With no waste heat recovery on the plant, the extra fuel required is generally around 7 % of the melting energy. This would result in increased CO_2 emissions of 25 – 35 kg per tonne of glass melted or 4 – 6 tonnes per tonne of NO_X abated. The estimated increase of emissions does not include the extra indirect emissions of CO_2 (100 - 150 tonnes/year) and NO_x associated with the use of additional electric energy needed for the increased capacity of the fans (additional waste gas volume).

In practice, the precise fuel requirement to achieve the desired NO_X reduction may vary depending on the specific conditions of the furnace.

Although 3R is sometimes considered a primary technique because of its relative simplicity, it should be regarded as a secondary techniques such as SCR and SNCR in that it does not prevent formation and not only reduces thermal NO_X, but also NO_X from other sources, such as raw materials.

Damage to regenerators may occur if the 3R process is not properly applied and operated. Reducing flue-gases may lead to an increased corrosion resulting from condensation and deposition phenomena, depending on the type of refractory material used for the regenerator.

Operational data

The degree of NO_X reduction achieved with 3R depends mainly on the amount of extra fuel added and can be tailored to meet various emission standards. For applications to air-fuel fired float glass furnaces the achieved NOx concentrations could be of below 500 mg/Nm^3 at 8 % O_2 dry volume. However, the application should be carefully controlled, in particular when some type of refractory material is used.

The main aspects of 3R technique are reported below:

- the temperature window for injection of fuel is typically >1300 - 1400 ºC in hot exhaust gases entering the regenerators
- regarding conversion efficiency, depending on the amount of available oxygen, eventually all hydrocarbons are converted into CO_2 and H_2O vapour
- typical NO_x emission reductions are, in general, in the range of 70 - 85 % from the initial values, but lower reduction rates are also reported in relation to lower amounts of injected hydrocarbons
- regarding the use of hydrocarbons, the quantity of extra fuel needed for the 3R process is about 7 - 10 % of the total amount used for combustion to provide energy to the melting furnace, but 8 % is the typical value. For a 500 tonnes/day float glass furnace, the additional fuel consumption is typically between 350 and 375 Nm^3 natural gas/hour. For a 300 tonnes/day container glass furnace, the extra fuel is 125 - 150 Nm^3 natural gas/hour

- in terms of specific energy consumption, the increase due to the application of 3R is estimated to be about 0.5 GJ/tonne float glass and 0.36 GJ/tonne container glass
- additional aspects related with application of 3R concern the refractory materials in the regenerator which may not be resistant towards reducing gases (CO, hydrocarbons and soot) or salt deposits with reducing characteristics or high alkali metals concentrations. For the application of 3R technique some refractory materials must be avoided, in order to prevent potential damages in the regenerator and reduced lifetimes.

A summary of the main advantages and disadvantages associated with the use of the 3R technique is shown in Table 4.21.

Advantages
can achieve substantial NO_X reductions
applicable to most types of regenerative furnaces
no major changes to plant design or operation
low capital costs
can be applied without the need for a furnace shut down
no chemical reagents required
increased fuel usage can, in some cases, be compensated by waste heat recovery
can be considered as proven and available technology
reduces NO_X from all sources
Disadvantages
increased fuel usage (generally 7 %, but can, in some cases, be reduced with waste heat recovery)
increased CO_2 emissions (20 – 30 kg/t glass melted, but can, in some cases, be reduced with waste heat recovery)
concern over effect on regenerator refractory material in some applications
not applicable to non-regenerative furnaces

Table 4.21: The main advantages and disadvantages of the 3R technique

Applicability
The technique, as for 2009, is considered applicable only to regenerative furnaces, but it can be implemented to both new and existing plants and to furnaces firing on either oil or natural gas.

The 3R process is mainly applied in the float glass industry, with very few applications in other sectors.

There is a concern that the reducing atmosphere created in the regenerators could damage some types of refractory materials, particularly if higher temperatures are also experienced. Most experience with the technique has been gained with float glass furnaces, which tend to use high quality refractory materials in the regenerators. The likelihood of refractory damage is greater with lower quality refractories (e.g. those containing Ca, Fe and Cr) which are found in some container glass plants. This is very case specific but the replacement of existing refractories with materials of higher thermal and chemical resistance could involve substantial costs.

The developers of the technique anticipate that regenerator modifications will not be necessary in the vast majority of cases.

Economics
A summary of the costs and related achieved removal of NOx emissions for a number of 3R applications is shown inSectioon 4.4.2.9, Table 4.28 and Table 4.29.
The typical investment costs range from EUR 200000 to 350000, depending on the number of burner ports and the size of the furnace.

The operational costs consist mainly of the extra costs for fuel (often natural gas) injected at the top of the regenerator chambers; therefore, they strongly depend on the fuel price. An additional cost consists of the licence fees to be paid for the use of the technology. The license fee formula is quite complex, but over the lifetime of the licence, this typically equates to about EUR 0.5 per tonne of glass melted.

Estimated cost data, based on presumedly achieved emission levels equivalent to <500 mg/Nm^3 NO_X, associated with the application of the 3R process to float glass include:

- the investment costs which vary with the size of the furnace, from about EUR 310000 (500 tonnes/day) to EUR 360000 (900 tonnes/day)
- operating costs range from EUR 1.06 million up to EUR 1.3 million per year, which are for extra natural gas and the 3R licence
- based on natural gas prices in 2007, the application of the 3R process results in a specific cost of EUR 6 to 6.25 per tonne melted glass for a float glass furnace of 500 tonnes/day, and about EUR 5.5 per tonne melted glass for a 650 tonne/day furnace. The costs per kg NO_x emissions reduction is EUR 1.4 - 1.8 per kg NO_x removed. For float glass furnaces, the annual NO_x emission reduction is typically 700 - 1000 tonnes NO_x/year, depending on the furnace size and initial NO_x emissions. Cost data do not include heat recovery by waste heat boilers.

Estimated costs for the application of the 3R process to container glass furnaces are the following:

- the investment costs range from EUR 185000 (200 tonnes/day) to EUR 280000 (600 tonnes/day)
- typical operational costs are EUR 300000 per year for a 200 tonnes/day furnace capacity up to EUR 780000 per year for a 600 tonnes/day furnace capacity. This results in EUR 4 - 4.5/tonne molten glass for small and medium size container glass furnaces and EUR 3.75/tonne molten glass for very large furnaces.
- the costs calculated per kg of NO_x emissions reduction are about EUR 2.5 per kg NO_x removed. For smaller container glass furnaces (200 - 300 tonnes/day) the achievable emissions reduction is about 125 - 150 tonnes/year of NO_x emissions, and for a 600 tonnes/day furnace, more than 300 tonnes/year of NO_x emissions can be reduced
- cost data do not include heat recovery by waste heat boilers.

The rising cost of fuel, and penalties associated with the increased CO_2 emission are likely to affect the use of 3R in the future.

Driving force for implementation

To accomplish the legal limits and benefit from the low investment costs are the main driving forces for using this technique.

Example plants

In 2007, there were at least 14 furnaces with 3R equipment installed.

Installations are mainly in the float glass sector and very few in other sectors.

Container glass sector:

- not known. Tests have been done successfully at United Glass in St. Helens (this plant is not producing anymore)

Float glass sector:

- Pilkington, G, Weiherhammer, Germany
- Pilkington, G, Gladbeck, Germany
- Pilkington, St. Helens, UK,float glass - three furnaces
- Pilkington, Finland
- Pilkington, Sweden
- Pilkington, Marghera-Venice, Italy
- Pilkington, US, two float glass furnaces
- Interpane, France,
- Guardian, Luxembourg.

Special glass sector:

- Samsung Corning, Korea (TV glass)

Reference literature
[tm39 3R-update] [40, Shulver et al. 1997] [65, GEPVP-Proposals for GLS revision 2007] [85, Spanish BAT Glass Guide 2007] [94, Beerkens - APC Evaluation 2008]

4.4.2.6.2 Reburning

Description
Reburning is a combustion modification technology used to remove NO_X from combustion products by using fuel as a reducing agent. It can be used to control emissions from virtually any continuous emissions source, and is not fuel specific although natural gas is generally used.

The technique was originally applied to large boiler plants in the early 1980s. Reburning technology has been successfully demonstrated on utility boilers, typically achieving NO_X removal efficiencies of between 50 - 65 % at a moderate cost per tonne of NO_X abated.

These achievements led to consideration of reburning for use in the glass industry. Glass furnaces appeared to be good candidates for a successful installation of reburning because of their large post-melter cavities (furnace flues and regenerator crown), and characteristics such as hot combustion gases and high initial NO_X concentrations.

A schematic of the process is shown in the Figure 4.7. The reburning process can be conceptually divided into three zones, the primary zone, the reburning zone and the burnout zone. In the primary zone the fuel and air are fired through the existing burners on the furnace at normal or reduced primary fuel stoichiometry. The level of the NO_X exiting the zone is the input to the reburning process. In the reburning zone, the reburning fuel is injected downstream of the primary zone to create a fuel-rich NO_X reduction zone. Depending upon the primary stoichiometry, the amount of fuel required is 5 - 20 % of the primary fuel. In the burnout zone, air is added to produce overall fuel-lean conditions and to oxidise all unburned species.

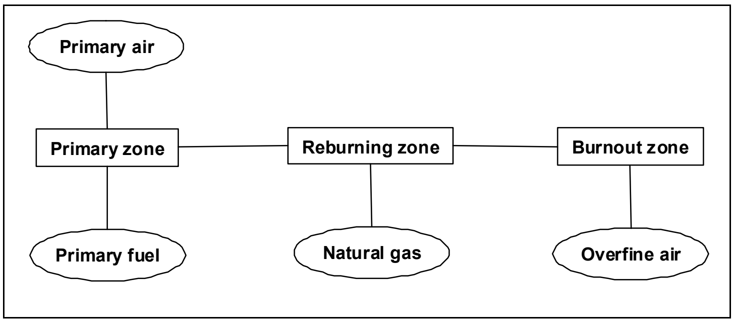


Figure 4.7: Reburn process overview

For the application of reburn to glass furnaces, it is expected that the reburn fuel will be injected at the back end of the melter or just downstream of the melter to minimise impacts on the heat distribution above the melt. For glass furnaces with a sufficient gas residence time between the reburn fuel injection point and the heat recovery device (i.e. regenerator or recuperator), the burnout air would be injected just upstream of the heat recovery device.

This technique was tested in 1996 on a 350 tonnes/day container glass furnace located in Antioch (US, California). At the time of writing (2008) there are no examples of its long-term use at full scale.

A demonstration was made on a float glass furnace in 1999. Tests were conducted to assess the technique. However, due to higher energy consumption and a tangible risk of damage to refractories the process has been stopped. At the time of writing (2009), there is no industrial application of the reburning technique in the glass sector.

More recent data are not available, at the time of writing, since the technique is not currently applied to glass furnaces; therefore, it will not be discussed further.

References to literature
[tm53 Gas Reburning] [54, Koppang et al. 1999] [tm54 Gas Reburning2] [55, Koppang et al. 1999] [tm55 Field Test] [56, Gaz de France 1996] [tm56 GazdeFrance] [57, CPIV 1998] [65, GEPVP-Proposals for GLS revision 2007] [85, Spanish BAT Glass Guide 2007]

4.4.2.7 Selective catalytic reduction (SCR)

Description
SCR involves reacting NO_X with ammonia in a catalytic bed at the appropriate temperature. Several catalysts are available, each operating over a slightly different temperature window. The most common catalysts are vanadium and titanium oxides (usually TiO_2 and V_2O_5) impregnated onto a metallic or a ceramic substrate. Zeolite molecular sieves can also be used, with the reaction taking place in the microscopic porous structure. The performance of zeolites can be optimised by adding metals such as platinum or palladium to the structure. Whichever catalyst is used, it is important to maintain the correct operating temperature, usually 200 - 500 °C with the optimum 300 - 450 °C.

The catalyst units used in the glass industry are modular honeycomb structures, although granular or plate forms are used in other industries. The size of the unit depends on the volume of waste gas being treated and the desired NO_X reduction. The modular structure allows easy section replacement, or the addition of further catalyst. Catalyst lifetimes depend on many factors but particularly waste gas composition and plant design. Most suppliers will guarantee a lifetime of three years or more, and in most industrial applications 5 to 6 years could be expected without significant deterioration of activity.

Systems are normally designed to achieve NO_X emissions <500 mg/Nm^3 with removal efficiency of >80 %, although typical long-term removal efficiencies are maintained between 70 and 80 %. In theory, the NO_X reduction efficiency increases with the NH_3:NO_X molar ratio, but this is usually kept as close as possible to 1:1 to minimise ammonia slippage. The NO_X reacts with the NH_3 according to the overall reactions given below. These reactions normally take place at around 950 °C (SNCR), but the presence of the catalyst lowers the temperature by absorbing the NH_3 which reacts with the NO from the gas phase. The ammonia is injected upstream of the catalyst either as liquid NH_3 or as an aqueous solution. Urea has been used in some applications but is not favoured by the glass industry.

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$
$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12\ H_2O$
$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6\ H_2O$

Several undesirable reactions can also take place:

$2NH_3 + 2O_2 \rightarrow N_2O + 3H_2O$
$2SO_2 + O_2 \rightarrow 2SO_3$
$SO_3 + NH_3 + H_2O \rightarrow NH_4.HSO_4$

With SCR the production of N_2O is very low and is not usually a problem. The formation of SO_3 and the subsequent reaction to ammonium bisulphate (NH_4HSO_4) can be a problem, particularly with high sulphur fuels. The ammonium bisulphate can poison the catalyst and cause fouling and corrosion of the equipment. Some dusts containing alkali metals (e.g. MgO, CaO, Na_2O, K_2O) or heavy metals might also act as catalyst poisons.

Although high dust systems exist, with glass processes, it is necessary to install a dust removal unit before the SCR unit. This unit must reduce the dust concentration to 10 – 15 mg/Nm^3, and is almost always an electrostatic precipitator (2 or 3 stage). The low operating temperatures of bag filters would require the waste gas to be reheated to the reaction temperature for the catalyst, which would add greatly to the operating costs and would generally be considered prohibitively expensive. It is also necessary to blow air through the catalyst bed (about every 2 hours) to prevent blinding and blockages by the remaining fine dust. The use of the ESP means that in many cases an acid gas scrubbing system must also be installed upstream of the ESP.

Achieved environmental benefits
The NO_X emission levels achieved will depend mainly on the inlet concentration and on the amount of catalyst and ammonia used. The level of ammonia is usually kept below the ratio 1.1:1 to limit the potential for ammonia breakthrough. In general, NO_X reductions down to <500 mg/Nm^3 are quoted for most applications. Some applications within the glass industry, e.g. special glass, have high unabated NO_X emissions (>4000 mg/Nm^3) and theoretically a 90 % reduction would give a concentration of below 500 mg/Nm^3. In theory, given a sufficient amount of catalyst, very low emission levels are possible but in practice there are many limiting factors which restrict performance.

Without a high degree of primary NO_X abatement measures, more typical glass furnace emissions would be in the range of 1200 - 2000 mg/Nm^3, and an 80 – 90 % reduction would give values ranging from below 200 - 500 mg/m^3 and 0.5 – 1.0 kg/tonne melted glass, for the container glass sector and 1 – 1.5 kg/tonne for flat glass. If combined with the primary measures described in Section 4.4.2.1, very low figures could be anticipated but in this case, the overall costs and cross-media effects would need to be taken into account, in particular per tonne of NO_X abated.

The actual values reported for container and flat glass applications are in the range of 400 – 950 mg/Nm^3, with removal efficiencies in the range of 70 - 80 %, depending on the initial concentration of NO_x. These figures are associated with an ammonia slippage of 8 - 20 mg/Nm^3.

Cross-media effects
The main cross-media effects associated with the application of the SCR technique are the potential emissions of ammonia, the use of electric energy and production of solid waste at the end of life of the catalyst.

The use of ammonia is associated not only with the slippage of unreacted solution but also with environmental and legal safety requirements for ammonia production, transport, storage and use. The operation of transferring ammonia from the container used for delivery to the storage represents a source of fugitive emissions.

Ammonia slippage from the SCR system into the waste gases is normally below 30 mg/Nm^3. A concentration of 30 mg/Nm^3 has been reported in the case of an SCR application on a float glass plant with a NO_x starting level of 2400 mg/Nm^3 and a removal efficiency of 71 %.

Ammonia emissions of 20 mg/Nm^3 have been reported for a special glass furnace with a starting concentration of 5278 mg/Nm^3 and a reduction efficiency of 80 %.
Normally an additional catalyst layer can reduce the ammonia slippage and increase the possibility to lower NO_x emissions (total NO_x removal >80 %).

The consumption of ammonia plus electricity (for extra fan capacity and pressurised air to clean the catalyst modules and to atomise the ammonia solution in the flue-gas) are associated with indirect emissions. The estimation made for the SCR technique applied to float glass furnaces results in 1.8 - 2.5 tonnes per year of indirect $NO_{x,}$ emissions and 800 to 1500 tonnes CO_2 per year, depending on the size of the float glass furnace. Indirect NO_x emissions represent only 0.3 to 0.5 % of the amount of NO_x reduced by SCR (600 - 1300 tonnes/year for 500 - 600 tonnes/day float glass melting furnaces) and the indirect CO_2 emissions are almost 1 % of the CO_2 emissions of the glass furnace.

Waste material is produced when the catalyst must be renewed after its lifetime. Typical catalyst lifetimes are 4 - 5 years (>5 years have been reported for container glass) and the volume of waste produced can be 20 m^3 for a float glass furnace of 700 tonnes per day.

Operational data

In most applications within the glass industry, SCR is used to maintain compliance with the applicable local legislation, which is usually not lower than 500 mg/Nm^3. Therefore, subject to the limitations discussed in this section for glass processes, NO_X emissions levels of <500 mg/Nm^3 (<800 mg/Nm^3 for high inlet concentration) can be achieved using SCR. Current operational data are affected by existing legislation concerning both NO_x and residual ammonia emissions. In some industries, figures of <200 mg/Nm^3 have been achieved, and it is not unreasonable to expect that figures around these levels could be achieved in some cases in the glass industry. However, it should be emphasised that at the time of writing (2009) these lower figures have not been achieved in practice in the glass industry and both the technical and economic implications should be considered. Most existing applications of the technique within the glass industry have achieved reductions in the range of 70 – 80 % but 80 – 95 % could potentially be achieved, particularly with a new installation, by means of larger catalyst volumes (e.g. second layer of catalyst modules).

Container glass and flat glass furnaces at the moment of the reported information (2005 - 2006) were obtaining their best values of between 460 - 500 mg/Nm^3 with this technique.

Data concerning example installations producing container, flat and special glass, where the SCR technique is used in combination with an ESP and a dry scrubbing stage, are shown in Table 4.22.

	Container glass[(1)]	**Flat glass**[(2)]	**Special glass** [(3)]
Fuel	Natural gas	Natural gas	Natural gas/light fuel oil
Type of furnace	End-fired (four furnaces)	Float	Cross-fired regenerative
Total pull rate	640 t/day	600 t/day	170 t/day
SCR installation	two-layer honeycomb catalyst	Honeycomb catalyst	10 m^3 volume honeycomb catalyst
Reducing agent	Ammonia solution 25 %	Ammonia solution 25 %	Ammonia solution 25 %
Consumption of reducing agent	145 l/h	Not available	Not available
NO_X reduction	75 %	71 %	82 %
Associated emission levels (AELs)	**Half-hour average values**	**Half-hour average values**	**Half-hour average values**
NO_X			
(Nmg/Nm^3, dry gas at 8 % $O_{2)}$	456	700	950
kg/t glass	0.97 [(4)]	1.12	6.05
NO_X removal efficiency	75 %	71 %	82 %
Ammonia slip (mg/Nm^3, dry gas at 8 % O_2)	19.5	<30	20
1. The installation consists of four furnaces. 2. The installation is equipped with continuous monitoring of NO_X, NH_3 and other parameters. 3. The installation is equipped with a heat recovery system. Batch formulation contains nitrates. 4. The value has been calculated, based on the information provided (mass flow, flue-gas volume, melted glass, emissions concentration).			

Table 4.22: NO_X emission levels associated with the use of the SCR technique in example installations
[75, Germany-HVG Glass Industry report 2007] [84, Italy-Report 2007]

The NH_3 reagent is injected under pressure into the flue-gas upstream of the catalyst bed and either liquid ammonia or an aqueous solution (usually 25 %) can be used. Liquid NH_3 is a hazardous substance and there are important cost and safety issues associated with its storage and use, including neighbourhood awareness. Most glass processes do not use these types of chemicals and operators prefer to use an aqueous solution, which also requires careful storage and handling. Site-specific issues, in particular the proximity of housing and sensitive environments must be taken into account.

The SCR operating temperature should be above 330 °C to avoid formation of ammonium bisulphate (NH_4•HSO_4). This condensation/deposition product can foul the catalyst surfaces and the SCR installation and will lead to poor performance.

When these phenomena do not occur, the lifetime of the catalyst should be at least 4 - 5 years for most glass furnaces and flue-gas characteristics, but much longer periods have been claimed.

The typical volume of catalyst needed for a float glass furnace of 700 tonnes/day molten glass (90000 Nm^3/h flue-gas volume) is 20 m^3 (one layer). Normally, it is estimated that 0.008 m^3 of catalyst is used per tonne of NO_x emissions reduction, and a volume of 20 m^3 used for a period of 4 - 5 years will reduce the total NO_x emissions by about 2500 - 3000 tonnes over the period.

The use of a double layer catalyst will improve the removal efficiency of NO_x and lower ammonia slippage. With one layer, the NO_x reduction is about 75 - 80 %, for a certain ammonia dosing level. A higher ammonia dosing rate used with a single layer catalyst (1 - 1.3 metres in height) will increase ammonia slippage to values that may become unacceptable.

A summary of the main advantages and disadvantages associated with the application of the SCR technique is shown in Table 4.23.

Advantages:

- very high NO_x reduction efficiency
- reduces NO_x from all sources in the furnace, not only thermal NO_x
- may form part of an integrated air pollution control system
- several examples within the glass industry for different glass sectors
- performance guarantees often available from suppliers

Disadvantages:

- technical issues still to be resolved in some applications (e.g. some glasses which contain boron)
- ammonia is consumed and emitted and the cross-media effects from ammonia production and storage must be considered
- energy is consumed by the system
- must be installed with dust abatement and acid gas scrubbing, low dust and SO_2 levels are required
- relatively high capital cost particularly for small plants
- high space requirement
- relative cost benefit under erosion by developments of other cheaper techniques
- concerns persist over catalyst lifetimes
- the operating temperature limits the possibilities for heat recovery
- gas cooling may be required for recuperative furnaces.

Table 4.23: Main advantages and disadvantages of the SCR technique

Applicability

In principle, SCR can be applied to most new and existing processes in the glass industry. However, there are a number of issues that severely limit the applicability of the technique in certain cases.

High levels of SO_2 in the flue-gas can result in ammonium bisulphate formation causing a poisoning of the catalyst and corrosion. This is potentially also true for gas-fired furnaces with high sulphate levels. In order to avoid this problem, the flue-gas temperature must be maintained above 330 °C. One of the key aspects of the costs of SCR is the catalyst lifetime, which could be significantly reduced if poisoning occurs.

SCR has been used in the power industry to treat gases with high SO_2 concentrations, and the problem has been solved by the use of efficient flue-gas desulphurisation techniques upstream of the equipment. The SO_2 removal efficiency of gas scrubbing systems currently used within the glass industry is unlikely to be adequate for SCR. More efficient SO_2 removal would add substantially to the costs and would make it difficult to recycle the collected material to the furnace, thus creating a further waste stream. Further information is given in Section 4.4.3.

However, successful experience has been reported with the use of SCR on oil-fired furnaces. This might suggest that the use of fuel oil is no longer a limiting factor for the implementation of SCR; however, this aspect needs to be investigated thoroughly.

SCR requires a lot of space, particularly if the scrubbing and filter units are not already installed. On some existing plants where space is limited, this could add substantially to the cost of the technique or, in some cases, make it prohibitively expensive.

Another important factor influencing the applicability of SCR is the temperature of the flue-gases. It is not generally practicable to use SCR in combination with a bag filter system because the low operating temperature, in the range of 180 – 200 ºC, would usually make it necessary to reheat the waste gas. The cost of reheating the gas to around 400 °C is generally prohibitively expensive, with an increase of energy consumption in the range of 5 – 10 %.

Even in the case of ESP filtration, the temperature window might become too low due to large variations of production (e.g. production of very thin float glass), negatively affecting the efficiency of the SCR system.

SCR also requires very low dust levels (preferably <10 mgN/m^3) and if the existing ESP is not adequate, it will require upgrading or replacement.

Apart from the limits of applicability described above, for the glass industry the overriding consideration for SCR is the cost compared with other techniques (see Section 4.4.2.9). In Table 4.40 the costs associated with the various techniques for NO_X reduction are shown. SCR is a relatively expensive technique compared to primary measures. All of these techniques have developed substantially in recent years, and in many applications where unabated emissions were below 2500 mg/Nm^3 (i.e. where nitrates are not added or very high temperatures are required) SCR was not generally considered by the glass industry to be the most cost-effective technique for NO_x emissions reduction, but the evolution of energy costs can make this technique attractive compared to other options (e.g. chemical reduction by fuel, or some oxy-fuel firing applications where inlet concentrations are very high).

Some tests are being carried out at the time of writing (2009) in a glass furnace using ceramic filters with an embedded catalyst (the CerCat flue-gas treatment system) that can resist temperatures of around 400 ºC. However, this technique is still considered as emerging since only test trials have been carried out in the glass industry and the first application will be installed in the near future. More information is given in Section ().
The SCR technique has been proven for certain glasses which contain high levels of boron (pharmaceutical borosilicate tubes), but has never been tried for glass wool or continuous filament glass fibre. The potential problem for these processes is the presence of volatile boron compounds, particularly boric acid, in the waste gases. These materials may condense to form salts or acidic materials down to 60 °C and, at the temperatures of SCR, are likely to be present in significant quantities. These materials could seriously affect the performance of the catalyst and would be difficult to remove by soot blowing.

The application of SCR to installations producing domestic glass with high levels of potassium in the batch composition could be problematic due to a potential poisoning effect of the alkaline component on the catalyst.

Economics
The cost of SCR depends mainly on the size of the plant (the waste gas volume to be treated) and the desired NO_X reduction efficiency. In general, the technique is considered to have high investment costs and moderately high operating costs. Also, because SCR is an integrated three stage abatement system, the cost of the technique depends greatly on whether the cost of the ESP and waste gas scrubber are included or not. In some cases, it could be argued that without the installation of SCR, the furnace might not require the dedusting equipment; in most cases it may be argued as an essential requirement.

The existing cost information is not always easy to interpret and is quite case specific. The information available at the time of writing (2009) is summarised below.

Most SCR applications in the glass industry are installed at float glass furnaces, and only a limited number are applied to container glass furnaces. Table 4.28 shows a summary of typical cost levels (investment, operating and specific costs per tonne of melted glass and per kg NO_X emission reduction) for a number of float glass furnaces, container glass furnaces and the estimated costs for hypothetical application of SCR tableware furnaces.

Prices considered in the study do not include the required previous installations of desulphuration and dedusting equipment. The applied methodology and the assumed hypothesis are reported in Section 8.1.

Additional information regarding costs for the application of SCR to different glass furnaces are given below. The associated emission levels used for estimating the costs related to the application of SCR to the glass furnaces are in the range of 400 - 500 mg/Nm^3 NO_X.

Estimated costs for SCR application to Float glass furnaces

- typical investment costs comprise the catalyst, catalyst housing, a fan or the increased fan capacity to overcome the pressure drop over the catalyst (about 10 mbar), extra ducts, ammonia solution storage, NO_x monitoring and the safety measures for site preparation
- the total investment cost is about EUR 1.9 up to 3.1 million; the higher figure is related to a 900 tonnes/day float glass production. The investment costs may differ from site to site depending on the total length of the ducts, flue-gas volume and safety measures to be taken
- the operational costs are mainly constituted of ammonia solution (or urea), electricity, maintenance and catalyst. The given costs refer to SCR with one catalyst layer and cat-modules of a height of about 1.2 - 1.4 metres
- the NO_x emissions are reduced down to concentration levels of 450 - 500 mg/Nm^3 from starting levels of 1800 - 2000 mg/Nm^3 for a natural gas fired furnace and 1400 mg/Nm^3 for an oil-fired float glass furnace without SCR. Based on these assumptions, the annual operating costs for float glass furnaces range from about EUR 331000 (500 tonnes/day) to EUR 450000 (900 tonnes/day). Ammonia consumption (and costs) will increase for higher NO_x concetrations in the unabated flue-gases. Examples presented in Table 4.28 show some differences due to diverse situations of NO_x levels in the uncleaned flue-gases or other site-specific conditions
- the typical additional production costs for float glass are about EUR 2.5/tonne molten glass. For smaller float glass production capacities (<600 tonnes/day) and gas firing, these might be as high as EUR 3/tonne glass
- the costs per kg NO_x emissions reduction by the application of SCR to float glass furnaces is about EUR 0.7 - 0.9 per kg NO_x removed.

Estimated costs for SCR application to container glass furnaces

- the typical investment costs for a furnace of 200 tonnes/day capacity would be about EUR 840000 and the operational costs are about EUR 75000 - 80000.
- for a larger container glass furnace of 450 tonnes/day, the investment costs are about EUR 1.27 million and the operational costs are about EUR 136000 per year, with an emissions reduction of about 200 - 250 tonnes NO_x per year. The specific costs would be about EUR 1.75 - 2 per tonne molten glass
- container glass furnaces generally have a much lower flue-gas volume compared to larger float glass furnaces and lower specific energy consumption. The associated costs of SCR application per tonne of molten glass are lower compared to float glass furnaces, but per kg NO_x emissions reduction the costs are higher: from EUR 1.3 - 1.7 per kg NO_x removed, depending on the container glass furnace size. The specific costs increase with lower glass melt capacity
- an example of the SCR application to the container glass sector referring to a production capacity of 640 tonnes/day, indicates an annual cost for ammonia solution (25 % in volume) of EUR 106000 per year, based on a consumption of 110 litres/h of ammonia at a cost of EUR 110 per m^3. The two-layer honeycomb catalyst used in the system corresponds to a cost increase of EUR 2 per tonne glass. The specific NO_x emissions after treatment are 0.68 kg NO_2/tonne glass, with a removal efficiency of 78 %.

Estimated costs for the application of SCR to tableware glass furnaces

No specific information is available concerning the application of SCR to installations in the domestic glass sector. By extrapolation, the investment and operational costs for SCR installation in the container glass sector have been used to investigate the theoretical costs of SCR application to tableware glass furnaces of different production capacities

- for a recuperative tableware furnace producing about 35 tonnes/day molten glass the application of SCR will costs about EUR 0.5 million (including site preparation, extra fan capacity, ammonia solution storage), while the operational costs are estimated to be up to EUR 40000 per year. The specific costs per tonne of molten glass are estimated to be EUR 8 per tonne molten glass. The NO_x emissions reduction would be about 20 - 25 tonnes per year, and the specific costs would be EUR 4 - 4.5 per kg NOx removed
- for a larger regenerative tableware furnace, the investment costs are about EUR 750000 to 800000 and operational costs EUR 80000 per year, with specific costs of almost EUR 5 per tonne molten glass and EUR 1.4 per kg NO_x emission reduction (see Table 4.28).

The addition of an extra layer of catalyst modules will normally increase the cost of SCR application by about EUR 0.6 to 0.8 per tonne molten glass and generate a further decrease of 100 mg NO_x/Nm^3. Extra costs would be about EUR 2.2 per any additional kg NO_x emissions reduction, including the extra costs for the catalyst plus extra electricity costs for the improved capacity of the fan.

In the special glass sector, SCR has only been applied in Europe for NO_x emissions reduction from CRT glass (TV glass) at five furnaces located in Germany, but these furnaces were shut down between 2002 and 2006 because of market reasons. At the time of writing (2009), SCR is still applied in the special glass sector to reduce NO_x emissions from a few regenerative furnaces (borosilicate glass production) connected to one single SCR plant. Typical costs for applications in the special glass sector are estimated to be about 2.5 - 3 EUR/tonne molten glass. Investment costs for the application of SCR to an installation consisting of approximately 4 x 200 tonnes/day furnaces, including ammonia solution storage in sealed tanks, catalyst, piping, a NO_x analyser, control equipment and laboratory equipment are estimated to be about EUR 2 million.

Examples of actual cost data are reported in Table 4.24 for installations producing container, flat and special glass.

	Container glass	**Flat glass**	**Special glass**
Fuel	Natural gas	Natural gas	Natural gas/light fuel oil
Total production capacity	640 t/day	600 t/day	220 t/day
Associated emission levels (AELs)	456 mg/Nm^3 0.97 kg/t glass	700 mg/Nm^3 1.12 kg/t glass	950 mg/Nm^3 6.05 kg/t glass
Emission control system	SCR + ESP + dry scrubbing with $Ca(OH)_2$	SCR + ESP + dry scrubbing with $Ca(OH)_2$	SCR + ESP + dry scrubbing with $Ca(OH)_2$
Investment costs for SCR, including ammonia storage	EUR 2.35 million	-	EUR 1.5 million
Investment costs for ESP + dry scrubbing	EUR 3.95 million	-	EUR 2.8 million
Total investment costs	EUR 6.3 million	EUR 5.0 million	EUR 4.3 million
Duration of amortisation	13 years	-	10 years
Annual amortisation costs for SCR + ESP and dry scrubber	EUR 312550/year + UR 525350/year	-	EUR 199500/year + EUR 372400/year
Specific investment costs for catalyst	EUR 2.00/t glass	-	EUR 9.34/t glass
Cost for ammonia supply	EUR 106000/year	-	-
Specific investment costs for emission control system	EUR 5.61/t glass	EUR 4.5/t glass	EUR 19.77/t glass

Table 4.24: NO_X emission levels associated with the use of SCR technique for example installations producing container, flat and special glass
[75, Germany-HVG Glass Industry report 2007] [84, Italy-Report 2007]

Driving force for implementation
The main driving force is to comply with legal emission limit values

Example plants
Table 4.25 shows a list of plants operating with the SCR technique.

Plant name and location	**Gas volume Nm^3/hour**	**Inlet mg/Nm^3**	**Outlet mg/Nm^3**	**Reduction (%)**	**NH_3 mg/Nm^3**
Schott-Ruhrglas, Mitterteich, Germany (special glass)	60000	5000	1500	70	<20
Euroglas SA, Homburg, France (float glass)	55000	2000	500	75	<5
AGC Flat Glass Europe, Cuneo, Italy (float glass)	70000	2400	700	71	<30
Ardagh, Bad Münder, Germany (container glass)	60000	1300	<460	>70	<14
Quinn glass, Ince, UK (container glass)	50000	1100	<500	55	<30

Table 4.25: Plants operating with the SCR technique and operating parameters

In 2007, a total of seven SCR techniques were in operation in the flat glass sector, including:

- Euroglas SA, Homburg, France (float glass)
- Euroglas SA, G.Osterwedding, Germany (float glass)
- AGC Flat Glass Europe, Cuneo, Italy (float glass)
- AGC Flat Glass Europe, France (float glass)
- AGC Flat Glass Europe, Roux, Belgium (flat glass)
- Interpane VitrageFrance S.à.r.l. Seinbouse (float glass), starting in 2007 with SCR
- AGC Flat Glass, Boussois, France.

A few more applications are planned for 2008 - 2009.

Reference literature
[tm32 Beerkens] [33, Beerkens 1999] [tm47 French Submission] [47, ANFFECC 1999] [tm6 NO_X Ind.duVerre] [7, Ind.duVerre 1996] [65, GEPVP-Proposals for GLS revision 2007] [64, FEVE 2007] [88, FEVE Proposal Ch.4-NOx 2007] [75, Germany-HVG Glass Industry report 2007] [94, Beerkens - APC Evaluation 2008] [84, Italy-ENEA Report 2007] [Schmalhorst, E.; Ernas, T.; Jeschke, R.: Experience with an SCR DeNOx plant for container glass furnaces. Glastech. Ber. Glass Sci. Technol. 70 (1997) no. 11 pp. 354-358].

4.4.2.8 Selective non-catalytic reduction (SNCR)

Description
In the Selective Non-Catalytic Reduction process (SNCR), also known as thermal $DeNO_X$, the oxides of nitrogen in the flue-gas are reduced to nitrogen by reaction with ammonia or urea at high temperature. In the glass industry, mainly ammonia and aqueous ammonia (typical 25 mass % aqueous solution) are used with some applications applying urea. The chemical reactions involved are the same as those for SCR described in Section 4.4.2.7 above. However, the reactions take place at higher temperatures without the need for a catalyst. The operating temperature is within the range of 900 – 1050 °C, but the optimum temperature is around 950 °C for ammonia and 1000 ºC for urea.

In some applications it has been suggested that the addition of hydrogen to the waste gas can assist the reaction at lower temperatures, but this type of application is not reported within the glass industry. In SNCR, the ammonia is injected closer to the furnace than in SCR, and usually involves a carrier gas. The efficiency of the technique depends on a range of factors, the main ones are:

- temperature
- initial NO_X concentration
- uniform reagent and flue-gas mixing
- ammonia to NO_X ratio; and
- reaction time (1-2 seconds required) in the temperature window 900 - 1050 °C.

In particular, it is important to ensure the correct temperature range since NH_3 injection below 900 ºC leads to ammonia slippage and reduced efficiency, and above1050 °C further NO_X may be formed. It is also essential to ensure that the reagent is uniformly distributed in the flue-gas. In achieving the correct temperature, the positioning of the ammonia injectors is critical, but the zone with the correct temperature may not be accessible or may change with operating conditions (e.g. load changes). This change in location of the correct temperature zone can be catered for by the provision of further ammonia injectors, but this will add to the capital cost and will depend on the accessibility. Uniform distribution can be achieved by good ducting design and, if necessary, the use of baffle plates or other flow correction devices.

The technique suffers some of the same potential operating problems as SCR, i.e. ammonia slip, N_2O formation (higher with urea), and ammonium bisulphate formation. Ammonium bisulphate formation may be higher than in SCR because the operating temperature requires injection upstream of any filter and scrubbing system. There is no catalyst present but the ammonium bisulphate can cause caking problems.

Due to the difficulties encountered to achieve uniform mixing between the reagent and the flue-gases within the required temperature window, the application of SNCR to regenerative type furnaces is very limited.

Achieved environmental benefits

NO_X reductions in the range of 40 – 70 % are commonly quoted for SNCR although figures above 80 % have been reported in some applications.
The main influencing factor will be the degree to which the performance-dependant factors can be optimised. In a well-controlled process where the optimum conditions can be achieved, reductions of 50 – 75 % are possible.

Cross-media effects

Ammonia emissions are one of the main concerns and can be a limiting factor on the efficiency of the technique. In addition to the legal requirements for ammonia transport and storage, safety measures are needed to avoid ammonia leakage and exposure to NH_3 fugitive emissions during storage operations and before injection into the flue-gas stream.

Indirect emissions associated with energy consumption for electricity (pressurised air, ammonia production) are also to be taken into account. The use of energy for the application of SNCR is about 1700 kWh/tonne NO_x reduced, while the energy required to produce ammonia is estimated at about 80 kWh/kg NH_3. The contribution of indirect emissions (mainly CO_2) from electricity production is very small compared to the emissions from the glass furnace, below 0.35 % of the total emissions.

Operational data

The final emissions concentration will depend on the initial value of NO_x and so the best results will be obtained where the technique is combined with primary reduction measures. For example, an initial concentration of 1100 mg/Nm^3 could be reduced to between 275 and 770 mg/Nm^3, depending on the process conditions. A high initial concentration of 4000 mg/m^3 could be reduced to between 1000 and 2800 mg/Nm^3. The typical operational data associated with the application of SNCR are the following:

For SNCR with the use of ammonia solution

- ammonia slippage: <10 mg/Nm^3
- ammonia use: typically, about 0.75 kg NH_3 is required per kg NO_x removed (calculated as NO_2), assuming a removal efficiency of 50 %, with resulting emissions from 0.5 to 1 kg NO_x/tonne melted glass, for soda-lime container glass productions.

For SNCR with the use of urea

- ammonia slippage: 3 mg/Nm^3
- urea use: typically, about 1.4 kg urea per kg NO_x removed (calculated as NO_2), assuming a removal efficiency of up to 40 %, with resulting emissions of 2.6 kg/tonne glass (special glass, TV screens with nitrates in the batch).

A summary of the main advantages and disadvantages associated with the application of the SNCR technique is shown in Table 4.26.

Advantages:

- can achieve good NO_X reduction efficiencies if correct conditions exist
- low capital cost compared to some alternatives
- no catalyst required
- low energy requirements.

Disadvantages:

- ammonia injection within the correct temperature window is essential, but sometimes difficult or impracticable to achieve (particularly for regenerative furnaces)
- outside the operating temperature range, NH_3 or increased NO_X emissions can result
- uniform mixing is important and can be difficult to achieve
- ammonia is consumed and emitted, and the storage and handling of the material presents environmental and safety concerns
- concern over possible damage to regenerator refractory material.

Table 4.26: Main advantages and disadvantages of the SNCR technique

Applicability

In principle, the technique is applicable to all glass processes including new and existing plants. SNCR involves lower investment costs and requires less space than SCR, making it more attractive for processes where space is limited. Also the technique can be operated without gas scrubbing and dust removal equipment. If the correct process conditions exist, SNCR is easier to retrofit to existing plants than SCR. However, the technique also has certain factors that limit its applicability within the glass industry. The most important of these is whether the reagent can be introduced at a point in the waste gas system where the correct temperature can be maintained for an adequate reaction time. This is of particular relevance in existing plants and for regenerative furnaces.

In existing plants, the area where the correct temperature occurs may be difficult to access or may be in a position where the gas flow makes it difficult to achieve good mixing with the reagent. In many cases, these problems can be overcome or mitigated, but it can add significantly to the cost and can compromise the efficiency of NO_X reduction. In regenerative furnaces, the correct temperature range usually occurs within the regenerators, which makes it very difficult to inject the ammonia effectively. This problem can be addressed by using split regenerators and injecting the ammonia in the connection. Split regenerators can be included in the design of a new plant, but for existing processes, splitting the regenerators can involve substantial costs and can only be done at a rebuild. Even when split regenerators are used, it is difficult to maintain the temperature window for SNCR due to reversal of fire between the chambers that causes a cyclical temperature change, and pull rate changes in the furnace.

Based on the difficulties mentioned above, in general, the SNCR technique is easier to implement with recuperative furnaces than with regenerative furnaces. In practice, SNCR is very unlikely to be used in existing regenerative furnaces; the costs and associated difficulties will usually lead the operator to choose an alternative means of reducing NO_X emissions. In smaller recuperative furnaces, the relative costs of SNCR are quite high, and in many cases, industry are likely to favour other more cost-effective control measures, although this will depend on the required performance level.

In Europe, the SNCR technique is currently applied in the special glass sector. Previous applications in the container glass sector (Germany) and the flat glass sector (US) are no longer in operation.

Economics

The estimated costs associated with SNCR applications on different size furnaces are reported below and a comparison with other available techniques for NO_x removal is shown in Table 4.28, based on presumable achievable emission levels of between 450 and 500 mg/Nm^3 NO_X.

- for container glass, recuperative furnace, typical investment costs for furnace capacities between 200 - 350 tonnes/day are in the range of EUR 680000 - 900000. Operational costs have been determined at EUR 74000 per year for a 200 tonnes/day recuperative furnace, and up to EUR 97000 per year for a larger furnace of 350 tonnes/year. Specific costs are in the range of EUR 1.9 - 2.3 per tonne of glass, with the higher figure related to smaller furnaces (200 tonnes/day). The costs per kg NO_x removed are EUR 2.1 - 2.5 EUR per kg NO_x removed, which are higher than for SCR applications due to the lower conversion efficiency of ammonia in the SNCR process
- for special glass, oxy-fuel fired furnaces, specific costs are estimated in the range of EUR 3 - 4 per tonne of glass and EUR 1 per kg NO_x reduced. The relatively low cost per tonne of NO_x reduced is due to the high initial concentration levels in the flue-gases of the oxy-fuel fired furnaces
- for continuous filament glass fibre produced with a recuperative furnace, there is no knowledge of applications in this sector. An estimation of costs for a potential installation of SNCR to a furnace of 100 tonnes/day indicates a capital investment of EUR 600000 - 625000, with operational costs of EUR 65000 - 70000 per year. The use of SNCR would increase the specific costs of production by EUR 4 - 4.25 per tonne of glass. Table 4.28 shows a comparison of costs for $DeNO_x$ technologies, including four cases with SNCR. Some data are only estimated and do not refer to any existing installations.

Information presented by Lubitz G [Langzeiterfahrungen mit dem SNCR-$DeNO_X$-Prozess an einer rekuperativ beheizten Behälterglaswanne - Vortrag v. d. Fachausschuss VI d. DGG (Umweltschutz) am 10. März 2004 in Würzburg].

Driving force for implementation

Lower costs and less space requirements than for SCR application are the driving forces for the implementation of this technique.

Example plants

Schott Glas AG, Mainz, Germany, applied to five oxygen-fired furnaces (special glass production)
Osram, Augsburg Germany (lighting glass).

References to literature

[tm32 Beerkens] [33, Beerkens 1999] [94, Beerkens - APC Evaluation 2008] [75, Germany-HVG Glass Industry report 2007] Lubitz G [Langzeiterfahrungen mit dem SNCR-DeNOx-Prozess an einer rekuperativ beheizten Behälterglaswanne - Vortrag v. d. Fachausschuss VI d. DGG (Umweltschutz) am 10. März 2004 in Würzburg].

4.4.2.9 Comparison of NO_X abatement technique costs

[65, GEPVP-Proposals for GLS revision 2007], [94, Beerkens - APC Evaluation 2008] [Beerkens, R.G.C.; Van Limpt, J.A.C.: Analysis of energy consumption and energy saving measures for glass furnaces. 80th Glastechnische Tagung der Deutsche Glastechnische Gesellschaft Session 1 Dresden Germany (2006) 12.-14. June] [Beerkens, R.G.C.; van Limpt, J.A.C.: LowNOx combustion in regenerative glass Furnaces. 68th Glass Problems Conference, 16.-17. October 2007, Columbus OH].

This section compares the costs of the main NO_X abatement techniques described in this chapter.

The information presented here is based largely on a report, the methodology and assumptions of which are presented in Section 8.1. However, there is a wide range of issues specific to the installations that are impossible to include in a report of this type, for example:

- energy prices (particularly electricity)
- taxation
- material costs (e.g. lime, ammonia, etc)
- incentive schemes provided by Member States
- the details of negotiations between suppliers and process operators
- disposal costs for solid or liquid wastes
- installation infrastructure.

The costs of a particular technique may also vary widely between sectors, between glass types and between furnaces of different sizes. It is not possible within the scope of this document to cover all of the potential combinations of size and glass type. Also for certain parts of the glass industry, there is very little information available. Therefore, the information presented here can only be considered as a general indicative guide based on the information available and with a degree of interpretation and extrapolation.
A more detailed, in-depth study would require a great deal of time and further information to be made available. This is not considered possible within the scope of this work.

A comparison of cost data is presented in Table 4.27 and Table 4.28, where cases considered are for flat, container and domestic glass installations all of which produce soda-lime glass. Estimated data are tentatively proposed for a continuous filament glass fibre furnace and a special glass installation. These examples have been chosen because they represent the majority of glass production and because most of the information available is for furnaces of these types. The examples given are for various production ranges, but care should be taken in making direct comparisons with other types of glass production. For example, a 100 tonne per day container furnace operating on 48 % cullet will be significantly smaller than a 100 tonne per day continuous filament glass fibre furnace.

The information given below considers the following techniques for NO_x reduction:

1. Primary measures:
    - basic package of low-NO_x measures
    - extended package of low-NO_x measures
    - oxy-firing

2. Secondary measures:
    - SCR process
    - 3R process
    - SNCR process.

Every technique is studied for different glass sectors and different furnace sizes using the methodology and hypotheses shown in Section 8.1

Basic package of low - NO_X measures
These measures can be applied (in most cases) to existing furnaces and are most often used for regenerative furnace types. For recuperative furnaces, systems or burners such as FLOX burners can be applied with the scope of lowering NO_x emissions. Basically, the technique consists of the use of adjustable burners, with low fuel injection velocities or the splitting of the fuel jet into separate jets, equipped with variable burner angles, air tight sealing between the burner and burner block and control of the oxygen content in the exhaust gases to avoid unnecessary excess air. Such control systems need to be tuned and require oxygen sensors in the burner ports or on top of the regenerator, and the CO content in the exhaust gases should be checked from time to time to avoid incomplete combustion.

The air/fuel flow ratio is controlled by measuring the residual oxygen content in the hot exhaust gas directly downstream of the combustion space of the furnace or, in general, at the top of the regenerators.The main costs are those for the adjustable burners (plus some spare burners), burner refractory blocks, oxygen sensors, a combustion control system and extra manpower to maintain low NO_x combustion conditions and to check the exhaust gas composition on a regular basis.

Table 4.27 shows examples of costs (investment and operational) for a basic package of low-NO_x measures, applied without changing the furnace designs, for some furnaces in the float glass, container glass and tableware glass sectors.

Extended package of low NO_X measures
Extended measures applied to glass furnaces to avoid or reduce formation of nitrogen oxides (NO_x) include adaptations of the furnace design, in particular: increasing the height of the combustion space, enlarging the size of burner ports, changing the slopes of the burner ports and positions of the burners. The costs for these measures can vary significantly. Some examples are given for float glass, container glass and tableware glass furnaces. NO_x emission levels between 900 and 1100 mg/Nm^3, depending on fuel type, glass type and furnace type seem to be possible without adverse cross-media effects.
Data presented in Table 4.27 include costs for furnace design changes (assuming completely new furnaces) and the costs for combustion control, oxygen sensors and adjustable burners.

Oxy-fuel firing
The costs for oxy-fuel firing are compared to the melting costs using regenerative furnaces (for float glass and container glass) or recuperative furnaces (for tableware, continuous filament glass fibre and special glass). The melting costs include the costs for the furnace, regenerators, recuperators, energy, electricity, and oxygen. The difference in the melting costs between the conventional glass furnace and the oxy-fuel fired furnace are attributed to NO_x emissions reduction. However, in many cases, the decision to convert to oxy-fuel firing is not only taken because of targeted NO_x emission reductions, but also because of other reasons such as glass quality requirements, space limitations for regenerators or potential energy savings compared to recuperative furnaces.

The comparison of the melting costs depends very much on the oxygen prices that may be affected by many factors, such as access to an oxygen pipeline, the oxygen capacity demand (oxygen prices increase when lowering the demand), the local electricity price, and the contract conditions between the oxygen supplier and the glass company.

Thus, the cost evaluations are indicative and many (local) conditions may affect the differences in melting costs when comparing air-fired glass furnaces with oxygen-fired furnaces.

An energy balance modelling has been applied to estimate energy and oxygen consumption of glass furnaces for which practical data were not available.
In this analysis, the oxygen costs are assumed to be EUR 0.06 per Nm^3 of pure O_2 for container and float glass furnaces, and EUR 0.10 per Nm^3 for furnaces with smaller melting capacities such as those for continuous filament glass fibre, special and tableware glass melting processes.

Compared to regenerative furnaces, investment costs for the oxygen-fired furnaces are lower because no regenerators have to be constructed, but in some cases the refractory material of the furnace crown needs to be of higher quality. Calculations have been performed for oxygen-fired furnaces with a high-duty silica crown (low lime contents) which would account for EUR 300000 - 400000 extra costs, and for crowns constructed of fused cast materials (AZS or alumina). The use of fused cast materials for the crown of float glass furnaces may increase the costs by EUR 4 - 5 million.

Table 4.27 below, shows the costs of oxy-fired melting in the investigated cases compared to regenerative furnaces, in section (a) and to recuperative furnaces, in section (b).

(1)	Costs						Internal emissions	External emissions (indirect)		
Primary measures for NO_X emission reduction	**Investment**	**Investment per year**	**Operation per year**	**Specific costs**	**Δ NO_X**	**Specific cost**	**Δ CO_2 internal**	**Δ NO_X external**	**Δ SO_2 internal**	**Δ CO_2 external**
	EUR	**EUR/year**	**EUR/year**	**EUR/molten tonne**	**tonnes/year**	**EUR/kg NO_X**	**tonnes/year**	**tonnes/year**	**tonnes/year**	**tonnes/year**
Low NO_X basic										
Float glass 500 TPD gas-fired, to 1050 mg/Nm^3 NOx	660000	89600	64000	0.84	-337	0.45				
Float glass 500 TPD oil-fired, to 900 mg/Nm^3 NOx	1010000	137000	79000	1.14	-337	0.64				
Float glass 900 TPD gas-fired, to 1050 mg/Nm^3 NOx	810000	110100	81000	0.58	-555	0.35				
Container glass 200 TPD gas-fired, end-port fired	230000	31250	24000	0.59	-60.3	1.07				
Container glass 300 TPD gas-fired, end-port fired	285000	38700	26000	0.59	-60.3	1.07				
Container glass 450 TPD gas-fired, to 1050 - 1100 mg/Nm^3 NOx, end-port fired	330000	44850	31500	0.47	-90.5	0.84				
Container glass 450 TPD gas-fired, cross-fired	700000	95000	72500	1.02	-130	1.3				
Tableware 186 TPD basic plus primary measures	123000	16712	30711	0.7	-82.3	0.58				
Low-NO_X extended (increase crown height, larger burner ports, changes in design										
Float glass 700 TPD	2660000	361000	64000	2.33	-551	0.77				
Float glass 900 TPD gas-fired, to 900 mg/Nm^3 NOx	3810000	517660	81000	1.82	-906	0.66				
Container glass 200 TPD, to 750 mg/Nm^3 NOx	700000	95108	24000	1.63	-82	1.45				
Container glass 300 TPD	885000	120240	26000	1.34	-112	1.31				
Container glass 450 TPD	1080000	147000	31500	1.09	-168	1.06				
Tableware 150 TPD including additional electricity for boosting	1000000	135900	163500	8	-711	0.42				

a. Oxy-fuel firing extra costs/savings compared to regenerative furnaces										
Float glass 500 TPD, silica crown	-7500000	-1290000	2540000	6.83	-410	3.03	-6683	48		16900
Float glass 500 TPD, fused cast refractory crown	-3250000	-714000	2785000	11.35	-410	5.04	-6683	48		16900
Container glass 150 TPD, EUR 0.06/Nm^3 O_2, high-duty silica crown	-2051100	-276633	444700	3.07	-49.3	3.41	-1227	7.6		3027
Container glass 225 TPD, EUR 0.06/Nm^3 O_2, high-duty silica crown	-2740000	-369000	637990	3.27	-73.9	3.64	-1942	11.1		4444
Container glass 450 TPD, EUR 0.06/Nm^3 O_2, high-duty silica crown	-4743000	-639400	1490000	5.18	-147	5.76	-2097	21		8380
b. Oxy-fuel firing extra costs/savings compared to recuperative furnaces										
Tableware 30 TPD, EUR 0.06/Nm^3 O_2	500000	56406	-245400	-17.26	-19.2	-9.86	-2600	1.8		716
Tableware 30 TPD, EUR 0.08/Nm^3 O_2	500000	56406	-175000	-10.79	-19.2	-6.16	-2600	1.8		716
Tableware 30 TPD, EUR 0.10/Nm^3 O_2	500000	56406	-103660	-4.32	-19.2	-2.47	-2600	1.8		716
Tableware 30 TPD, EUR 0.12/Nm^3 O_2	500000	56406	-32754	2.16	-19.2	1.23	-2600	1.8		716
Tableware 30 TPD, EUR 0.14/Nm^3 O_2	500000	56406	38152	8.63	-19.2	4.93	-2600	1.8		716
Tableware 70 TPD, EUR 0.10/Nm^3 O_2	-2254000	-265972	582590	12.76	-40	7.97	-2449	5.2		2064
E-glass furnace 100 - 120 TPD EUR 0.08/Nm^3 O_2	1500000	117340	-248400	6.19	-80.3	3.1	-5387	8.86		3530

1. Unless otherwise specified, the achievable emission levels used for the calculation of cost data are the following:

- 1100 - 1400 mg/Nm^3 NO_X for primary low NO_X measures (basic, no design changes); 900 - 1100 mg/Nm^3 NO_X for primary low NO_X measures with design changes on float glass furnaces and 750 mg/Nm^3 NO_X on container glass furnaces
- 0.5 - 0.9 kg/t glass NO_X for oxy-fuel on container glass furnaces; 1.5 - 2 kg/t glass NO_X for float glass; 1 - 1.5 kg/t glass NO_X for special glass without nitrates.

Table 4.27: Investigated cases of costs for DeNO_X with primary measures.
[94, Beerkens - APC Evaluation 2008]

DeNO$_X$ (SCR, SNCR, 3R)	**Investment**	**Investment/year**	**Operation/year**	**Specific costs**	**Δ NO$_X$**	**Specific costs**
APC methods/applications	**EUR**	**EUR/year**	**EUR/year**	**EUR/tonne glass**	**tonnes/year**	**EUR/kg NO$_X$**
SCR process						
Float glass 500 TPD	2065000	270000	331500	3.29	-804	0.75
Float glass 650 TPD oil	2303000	301400	332000	2.67	-692	0.91
Float glass 650 TD gas fired	2303000	301400	370000	2.82	-946	0.71
Float glass 700 TPD	1880000	248000	283000	2.07	-708	0.75
Float glass 900 TPD	3112000	391000	450000	2.57	-1255	0.67
Container glass 200 TPD	840000	110000	77500	2.56	-110	1.7
Container glass 300 TPD	1036000	134700	98800	2.13	-159	1.47
Container glass 450 TPD	1270000	166300	135500	1.84	-228	1.32
Tableware furnace 35 TPD (hypothetical case)	490000	64200	38500	8.03	-23.6	4.34
Tableware furnace 100 TPD regenerative: from 1500 to 450 mg/Nm^3 NO$_X$ (hypothetical case)	758000	98300	80800	4.9	-130	1.38
3R process						
Float glass 500 TPD oil	307400	41800	1057000	6.02	-598	1.84
Float glass 500 TPD gas	307400	41800	1085000	6.17	-769	1.47
Float glass 650 TPD oil	360400	49000	1224338	5.37	-726	1.75
Float glass 650 TPD gas	360400	49000	1309662	5.52	-985	1.38
Container glass 200 TPD	185500	25200	303200	4.5	-127	2.6
Container glass 300 TPD	238500	32400	405350	4	-169	2.6
Container glass 600 TPD	281000	46800	779000	3.73	-330	2.48
SNCR process						
Container glass 200 TPD recuperative	684000	93000	73850	2.28	-65	2.56
Container glass 350 TPD recuperative	900000	122000	97000	1.88	-101	2.16
Special glass (estimated) - 5 oxygen-fired furnaces (total capacity 250 tonnes/day)	785000	107000	199000	3.34	-290	1.06
E-glass fibres, 100 TPD (fictive)	615000	83500	66930	4.12	-55.2	2.73

- Unless otherwise specified, the achievable emission levels used for the calculation of cost data are the following: 400 - 500 mg/Nm^3 NO$_X$ for SCR; 450 - 500 mg/Nm^3 NO$_X$ for SNCR and <500 mg/Nm^3 NO$_X$ for 3R

Table 4.28: Investigated cases of costs for DeNO$_X$ with SCR, SNCR and 3R
[94, Beerkens - APC Evaluation 2008]

SCR process

The costs for the application of SCR, without including gas preconditioning, are given to show costs for any application where the filter and scrubber are already fitted. However, there will clearly be costs associated with retrofitting. The capital and operating costs concerning the filter and scrubbing systems are given in Sections 4.4.1.2, 4.4.1.3, and in Table 4.40.

Most SCR applications in the glass industry are installed on float glass furnaces, and very few on container glass furnaces. The costs for float glass and container glass furnaces are presented here, together with the estimated costs for a hypothetical case of two tableware glass furnaces. Table 4.28 shows the investment, operating and specific costs, expressed per tonne of molten glass and per kg of NOx emission reduction for different size float glass, container glass and tableware glass furnaces.

3R process

The costs for 3R applications on float and container glass furnaces are given in Table 4.28 for different melting capacities and in the case of oil or gas firing. Data presented in the table refer only to regenerative type furnaces, since 3R can be applied only to this type of furnace. The costs will depend greatly on whether regenerator repairs are envisaged or not. This issue is discussed in Section 4.4.2.6.1.

SNCR process

The costs for SNCR applications are presented in Table 4.28 only for recuperative type furnaces, for which the technique could most likely be implemented. Costs are given for two different production capacities; 200 and 350 tonnes/day. An estimation of the costs for the application of SNCR to an installation producing special glass with five melting furnaces and a total capacity of 250 tonnes/day installed together with the hypothetical costs for a furnace producing E-glass for continuous filament glass fibre are presented in the table.

A summary of the extra costs associated with each DeNO$_X$ technology evaluated in the comparative study is reported in Table 4.29 below.

EUR/tonne of glass								
Type of furnace	**Production**	**SCR**	**3R**	**SNCR**	**Basic low-NOx measures**	**Extended low-NOx measures**	**Oxy-firing with silica crown**	**Oxy-firing with fused cast crown**
	Tonnes/day			(1)	(2)	(3)	(4)	(4)
Float	500	3.3	6 - 6.25		0.85 - 1.1		6.83 (0.06)	11.35 (0.06)
Float	700	2.6 - 2.9	5.25 - 5.6			2.33		
Float	900	2.6			0.58	1.82		
Container	150						3.07 (0.06)	5.28 (0.06)
Container	200 - 225	2.56	4.5	2.28	0.76	1.63	3.27 (0.06)	5.39 (0.06)
Container	300	2.13	4	1.88	0.59	1.34		
Container	450	1.84			0.47	1.09	5.18 (0.06)	7.16 (0.06
Container (cross-fired)	450		3.73		1.02	1.5 estimated		
Tableware (recuperative)	30 - 35	8					-4.32 (0.10)	
Tableware (regenerative)	70						12.76 (0.10)	
Tableware (regenerative)	100	4.9						
Tableware (regenerative)	150					8 (high elect. boost)		
Tableware (regenerative)	190				0.7			
Special glass (oxy-fired)	250			3.34				
Special glass (regenerative)	700			2.8				
E-glass	100			4.1			6.20 (0.08)	

1. Recuperative furnaces only.
2. Basic low-NOx measures: adjustable burners, oxygen sensors, air-fuel control.
3. Extended low-NOx measures: basic measures plus modifications of burner ports and combustion chamber.
4. The cost of oxygen is given in brackets (EUR/m^3)

Table 4.29: Additional costs for DeNO$_X$ techniques in EUR/tonne glass
[94, Beerkens - APC Evaluation 2008]

4.4.3 Sulphur oxides (SO$_X$)

[89, EURIMA Suggestions 2007]

The term sulphur oxides (SO$_X$) includes sulphur dioxide (SO$_2$) and sulphur trioxide (SO$_3$), expressed as the SO$_2$ equivalent. Sulphur dioxide is by far the most prevalent oxide of sulphur in the glass industry and most of the following discussion relates to this species. Below about 200 °C, SO$_3$ is usually in the form of an acid mist or vapour; therefore, sulphuric acid (H$_2$SO$_4$) is, in general, considered included by the term SO$_X$, since it represents a condensation product of SO$_3$. The two main sources of sulphur oxides emissions are the oxidation of sulphur in fuels and the decomposition/oxidation of sulphur compounds in batch materials.

The retention of sulphur compounds in the glass is usually low (<0.35 % as SO$_3$, in most industrial glasses) and in general, the majority of the sulphur entering the furnace is emitted to the atmosphere as SO$_X$. Some of the SO$_X$ in the waste gas stream will react with other species to produce sulphates, which condense to form dust.

The amount of sulphate in the dust varies depending on the glass type, but for most soda-lime glasses it is around 90 - 95 %, mainly sodium sulphate. This issue is discussed in more detail in Section 4.4.1.

In electrically-heated furnaces SO_2 emissions tend to be very low and arise only from raw material decomposition. In stone wool cupolas, there is an overall reducing atmosphere and sulphur from the raw materials and fuel is emitted mainly as SO_X and hydrogen sulphide (H_2S). In EU installations, the waste gases are usually treated in an afterburner system, which oxidises the H_2S to SO_2.

4.4.3.1 Fuel selection

Description

In oil-fired processes, the main source of SO_X is the oxidation of sulphur in the fuel. The amount of SO_X derived from the batch materials varies depending on the glass type but in general, wherever fuel oil is burned, the SO_X emissions from the fuel outweigh those from the batch materials. The most obvious way to reduce SO_X emissions is to reduce the sulphur content of the fuel.

Achieved environmental benefits

The sulphur content of fuel oil is regulated by the Council Directive 1999/32/EC, which sets a limit of 1 %, with possible derogations for specific circumstances. Two types of fuel oils with various sulphur grades are available: <1 % sulphur and <0.3 % sulphur. Natural gas is essentially sulphur free.

Table 4.30 below shows typical ranges of SO_X emissions from soda-lime glass furnaces, with fuel oil and natural gas, without the application of secondary measures for SO_X reduction. The figures are only indicative and actual figures may vary significantly (see Table () in Section 3.3.2.2).

Fuel	SO_X (as SO_2) mg/Nm^3
Natural gas	300 – 1000
1 % Sulphur fuel oil	1200 – 1800

Table 4.30: Indicative ranges of SO_X emissions from soda-lime glass furnaces for different fuels

Cross-media effects

The general experience within the industry is that conversion to natural gas results in higher NO_X emissions, 25 – 40 %, although with increased experience, the differential is narrowing. This issue is discussed in more detail in Section 4.4.2.1 (Fuel choice). The use of natural gas is associated with lower specific emissions of CO_2 compared to fuel oil; however, the specific energy consumption per tonne of melted glass might increase due to a lower emissivity/luminosity of the flame, a different flue-gas volume and heat capacity.

Fuel oil needs to be heated up to 110 - 120 °C before being delivered to the burners, requiring additional energy consumption or the use of recovered heat.

The conversion to a lower sulphur content fuel generally results in increased costs due to the higher fuel price. However, if the filter dust resulting from flue-gas desulphurisation cannot be recycled to the furnace, a cost reduction is expected due to lower quantities of dust to be disposed of into landfills.

Operational data

No additional data reported.

Applicability

The use of natural gas is extensive within the industry. For example, almost all fossil fuel fired glass wool furnaces, most continuous filament glass fibre furnaces, all the glass frit furnaces, and more than 50 % of all container glass furnaces are fired on natural gas.

The conversion to gas firing requires different burners, the gas supply system to the burners, and modifications to burner and fuel ports. A full conversion of existing furnaces to gas firing is not always possible, due to potential glass quality and furnace lifetime problems; in these cases a mixed firing may be applied. An increasing number of glass furnaces are equipped for using both types of fuels.

However, the main influencing factor in selecting the fuel is the fuel price differential between gas and oil.

In addition, the different strategies and energy policies of the EU Member States and the geographical availability of natural gas and fuel oil may affect the choice.

Economics

As already stated above, the economics related to the selection of fuel are country specific and due to a potential geographical unavailability of some types of fuel, a general evaluation of costs is not meaningful.

Hot blast cupolas used in stone wool production are heated by coke. The variation in the sulphur content of coke used by the sector is quite low (0.6 - 0.9 %) and depends on the source. Coke derived SO_2 usually represents 30 – 70 % of the total emissions, depending on the use of blast furnace slag and cement bonded waste. Low-sulphur coke can be expensive to transport unless the plant is located close to a convenient source, and the reduction in emissions is likely to be disproportionate to the cost. The sector does not utilise high-sulphur alternatives such as petroleum coke, and in many cases, the coke sulphur content will have been reduced as far as economically practicable.

Driving force for implementation

Specific local environmental conditions and consequently stringent limit values for SO_X emissions might be the driving force for switching to low sulphur or sulphur-free fuel.

Example plants

None specified.

Reference literature

[88, FEVE Proposal Ch.4-NO_X2007]

4.4.3.2 Batch formulation

Description

In conventional glass making, sulphates are the main source of SO_X emissions from batch materials. Sulphates are the most widely used fining agents and are also important oxidising agents. By far the most common sulphate used is sodium sulphate, which on melting and fining dissociates to give gaseous SO_X and Na_2O which is incorporated into the glass. Sulphates of potassium and calcium are also widely used. In most glass furnaces, the levels of batch sulphates have been reduced to the minimum practicable levels, which vary depending on the glass type.

The conversion of a furnace from air-fuel fired to oxy-fuel fired can cause a decrease in the sulphate retention of the glass melt. In such cases, batch modifications may be required, in order to provide the correct amount of fining agent for the melting process. The issues surrounding the reduction of batch sulphates are discussed in Section 4.4.1.1 and the issues relating to the recycling of filter/ESP dust are discussed in Section 4.4.3.3. Typical emissions associated with fining and oxidising agents are 200 – 800 mg/Nm^3 and 0.2 – 1.8 kg/tonne of glass melted.

In stone wool production, important sources of SO_2 emissions (in addition to coke) are the use of blast furnace slag and cement bound briquettes in the batch. Slag usually contains 0.6 – 1.5 % sulphur by weight and the vast majority of the sulphur will be released as H_2S and SO_2. If an afterburner is used then the emissions will be largely oxidised to SO_2. The options for purchasing blast furnace slag with low sulphur levels are few, and plants are usually restricted by their proximity to a very limited number of suppliers within economical transport distances.

The percentage of slag in the batch varies greatly from close to 100 % for slag wool to zero in many normal stone wool plants. In most cases where slag is used, it composes less than 30 % of the total batch (excluding coke). The only application where its use is necessary to the product is in the production of white fibres for applications such as gun sprayed fibres and ceiling boards. These applications represent only a small percentage of the total output of the sector, but certain plants may produce only these products.
For a plant using around 30 % slag in the batch, the unabated SO_2 emissions are in the region of 2 – 3 times higher than for a slag free batch. It is estimated that at the time of writing (2009), approximately 10 % of European stone wool plants use blast furnace slag.

The beneficial effect on the SO_2 emissions of eliminating the use of slag is clear. However, the use of slag does convey a number of advantages, which are summarised below:

- lower energy use and reduced CO_2 emissions, arising from the partial replacement of limestone by slag. Energy consumption and CO_2 emissions are typically 5 – 15 % lower than in a basalt-limestone charge
- the charge contains less iron, which reduces the required tap out frequency and can improve yields. There are fewer interruptions to production and a slight reduction in solid waste
- in some cases, slag usage is claimed to improve the fiberising properties of the melt which can contribute to improved process efficiencies and lower waste levels by reducing shot
- blast furnace slag is a waste material that, if not utilised, is more likely to be disposed of to landfill. Furthermore, it replaces natural stone and reduces the demand for quarried materials
- slag is also generally cheaper than the materials it replaces.

Achieved environmental benefits
In general, the minimisation/optimisation of raw materials which contain sulphur in the batch formulation has an effect not only on SO_X emissions, but also on dust formation. The recycling of filter dust in place of a raw material, as a fining agent, reduces the use of primary raw materials.
The optimisation of the amount of sulphates used in the batch may result in a reduced solid waste stream that generates from a scrubbing system.

It is possible that most of the advantages described above could also be achieved by the increased utilisation of recycled process waste. A site-specific assessment of the impact of slag usage on pollution of the environment as a whole may be appropriate in some cases. However, in a general qualitative assessment, the advantages of using slag are unlikely to outweigh the emissions generated. If slag usage is required for product colour, its use can be minimised by the use of recycled internal process waste. If secondary SO_X abatement measures are used, the environmental balance for slag usage could change.

Cross-media effects
In general, the minimisation/control of sulphur content in the batch formulation is not associated with cross-media effects. However, an excessive reduction of the amount of sulphur would generate quality problems on the final glass product. The substitution of sulphur compounds with other materials providing the same fining effect may be difficult because of a higher environmental impact related to the alternative materials.

Operational data
No additional data reported.

Applicability
Not reported.

Economics
Not reported.

Driving force for implementation
The containment of costs for the batch formulation, together with the minimisation of the initial levels of SO_X emissions may be the driving force for the implementation of this technique.

Example plants
None specified.

Reference literature
[89, EURIMA Suggestions 2007] [tm29 Infomil] [30, Infomil 1998] [tm26 EURIMA] [27, EURIMA 1998]

4.4.3.3 Dry or semi-dry scrubbing

Description
The reaction principles of dry and semi-dry scrubbing are the same. The reactive material (the absorbent) is introduced to and dispersed in the waste gas stream. This material reacts with the SO_X species to form a solid, which has to be removed from the waste gas stream by an electrostatic precipitator or bag filter system. The absorbents chosen to remove SO_X are also effective in removing other acidic gases, particularly halides (HCl and HF), but also other volatile compounds such as selenium, boric acid, etc. In some applications, the absorbent is injected directly into the waste gas ducting, but the techniques are substantially more efficient if a reaction tower (dry process) or reaction chamber (semi-dry process) are used.

In the dry process, the absorbent is a dry powder (usually $Ca(OH)_2$, $NaHCO_3$,or $Na_2(CO)_3$ to which air can be added to assist dispersion. In the semi-dry process, the absorbent (usually Na_2CO_3, CaO or $Ca(OH)_2$) is added as a suspension or solution and water evaporation cools the gas stream. In other industrial applications, the semi-dry process as described above is often referred to as semi-wet; however, within this document, the term 'semi-dry' is used exclusively, as it is the usual term used within the glass industry.

The dry process is found more commonly in the glass industry than the semi-dry process. In general, the abatement rate depends strongly on the following parameters:

- type of scrubber - the design of the scrubber may affect the contact between the gas phase and the absorbing agent and the available reaction time
- composition of the flue-gas - there is a different reactivity of waste gas pollutants with the various absorbents and competing reactions occur between the different species, especially if the ratio of reactant to acidic gases is relatively low
- temperature - the ideal temperature should be as close as possible to the dew point of the flue-gas (below 180 °C) or much higher (around 400 °C). The temperature range of 180 - 350 °C seems to be less suitable for dry SO_2 absorption by hydrated lime
- humidity of the flue-gas
- molar ratio of absorption agent/acid gases - it is normally necessary to have an over-stoichiometric ratio of absorbent. The specific amount of absorption agent is often expressed by the molar ratio which can be defined in two ways:
  - MR1 = molar ratio of absorbent over SO_X abated
  - MR2 = molar ratio of absorbent over total SO_X input
- filtration system - either the dry or the semi-dry process can be used in conjunction with electrostatic precipitators, but with bag filters the waste gases will require cooling. The most common scrubbing process used in the glass industry is the dry process in conjunction with an electrostatic precipitator, using $Ca(OH)_2$ as the absorbent. This is because $Ca(OH)_2$ achieves a relatively good abatement rate at a temperature of around 400 °C, which can be readily achieved in the waste gas without cooling and is within the operating range of an electrostatic precipitator. Ideally the reaction temperature should be around 400 °C; in practice, temperatures in the range of 300 - 350 °C are more common, due to operational constraints. Where bag filter systems are used, the temperature has to be reduced to below 200 °C. Cooling can be achieved by a heat exchanger, or cooling air, and is also assisted in the semi-dry process by the evaporation of water. The use of bag filters generates a filter cake on the fabric, due to the deposited absorption reagent, which causes an increase of the pressure drop and normally improves the absorption of the acid gases

- type of reagent - the most used scrubbing agents within the glass industry are: hydrated lime $Ca(OH)_2$, sodium carbonate Na_2CO_3, sodium bicarbonate $NaHCO_3$, and less frequently sodium hydroxide NaOH and limestone, $CaCO_3$. The chemical composition of the reagent is an important factor for determining the possibility of recycling the resulting solid products back to the melting furnace. The specific surface of the reagent, expressed as BET (m^2/gram) is a determining factor for achieving a good reaction rate. Reagents are normally injected as fine powder with a specific surface area of up to 40 m^2/g.

An additional option for the "dry scrubbing" of acid gases consists of direct batch preheating. In this case the alkaline components of the batch composition have the function of absorption agents. The use of this technique is discussed in Section 4.8.5

Achieved environmental benefits

The majority of installed SO_X scrubbing systems operate with dry lime scrubbing at a temperature in the range of 300 - 400 °C which is the waste gas temperature obtained from an efficient regenerative type furnace. At these temperatures, a SO_X reduction of around 30 - 40 % can be achieved by using a good quality dry lime and an over-stoichiometric $Ca(OH)_2/SO_2$ ratio. Better removal efficiencies can be achieved by using sodium bicarbonate or a solution of sodium carbonate, with a SO_X reduction of around 60 % or higher, depending on the amount of reagent. A comparable or improved SO_X reduction rate can be reached at temperatures of around 200 °C and with a humid atmosphere. This can be obtained by the injection of a water - dissolved sorbent in connection with bag filters. However, this semi-dry technology lowers the temperature of the waste gases to a level that is not generally compatible with secondary heat recovery or for downstream applications that require higher temperature levels (e.g. SCR or cullet preheating). In these cases, consideration could also be given to the conventional (or “true”) semi-dry process, although there is currently very little experience with this technique in the glass industry. This stresses the need for an integrated analysis prior to the application of desulphurisation, taking into account all effects, side-effects, costs and priorities (e.g. acidification policy, energy policy, waste policy, etc).

It must be noted that high stoichiometric rates of sulphur absorbent imply an increased load on downstream dust abatement equipment. In practice, the limited absorption improvement must be balanced against the technological requirement and any additional costs for an increased precipitator capacity.
The scrubbing process is also effective for other gaseous acid pollutants, such as HCl and HF, with different reduction rates. Typical removal efficiencies correlated to the type of reagent and operating conditions are reported in the section 'Operational data', presented below.

Cross-media effects

The techniques are effective in removing certain other gaseous pollutants, namely fluorides, chlorides, and certain selenium compounds. The techniques could also have an effect on other acidic emissions, such as HBO_2 and H_3BO_3, but no information is available on the reduction levels.

In some current examples within the glass industry an important motivation for the installation of the techniques has been for the protection of dust abatement equipment or, in some cases (e.g. continuous filament, frits), for the removal of fluoride emissions. In specific cases, if dust or fluoride abatement is not required, it might be more economical to switch to gas firing rather than install these techniques.

The techniques generate a significant amount of solid residue, but in most applications this material can be recycled to the furnace. Problems may be encountered particularly with oil-fired furnaces using high levels of cullet. If sodium carbonate is used as the absorbent, filter dust would be recycled in soda-lime glasses in place of a more valuable raw material, because of the substantial requirement for sodium carbonate. However, the high reduction rate of sodium carbonate and sodium bicarbonate towards HCl causes a significant enrichment in NaCl of the filter dust, which can generate problems when re-introduced into the furnace in the batch composition. The volatilisation of NaCl in the furnace leads to chemical attack of the silica/silicate refractory materials in the furnace or regenerators.

In general, for a certain type of glass, the uptake of sulphur in the melt is fixed, in order to guarantee the redox state and the colour of the glass. Therefore, the recycling of sulphate dust presents a quantitative limitation.

At low levels of cullet, the collected sulphate will usually be less than that required for refining, and, for some specific cases, it may also be possible to increase the uptake of the sulphur from the collected dust in the glass (i.e. higher SO_3 %). In these cases, the overall emissions are lowered and sodium sulphate consumption is reduced. If the sulphate collected is greater than the sulphate required in the batch then a solid waste stream is created for disposal off-site. Alternatively, if all the material is recycled in greater quantities than required, then the system becomes a closed loop reaching a dynamic equilibrium with the only sulphur sinks being the glass and the emissions to the air. At high cullet levels, the requirement for the sulphate fining agent is much lower; therefore, unless a portion of the dust is removed, the SO_X emissions increase and the overall benefit of SO_X reduction is greatly reduced. The problem is most evident in reduced glasses, where the sulphur solubility is relatively low, and when high cullet levels are used.

In practice, if this was to occur, the costs of disposing of dust that cannot be recycled can often be higher than the cost of lower sulphur fuels (e.g. low sulphur oil or natural gas).
Therefore, in many circumstances, an operator would choose to change fuels rather than create a solid waste stream for disposal. However, a high cost differential between low sulphur fuel (particularly natural gas) and other fuels may make such an option economically unattractive.
If calcium hydrate is used as the absorbent, most glass compositions will have a limit as to how much calcium can be recycled. Adjustments can normally be made to the batch composition to compensate for the filter dust, but in batches, with high cullet levels, the possibility to adjust the batch is limited. In high cullet batches the calcium content may be greater than can be tolerated in the glass, creating a solid waste. In such a case, a solution can be a change of absorbent and a switch to sodium carbonate or bicarbonate, or a mixture of the different absorbents.

In regions that have high cullet recycling rates the system becomes even more of a closed loop as the levels of various compounds build up in the constantly recycling glass. This can be a problem for metals, fluorides and chlorides as well as sulphur. The presence of metals in the filter dust, particularly lead, can cause a progressive accumulation in the glass mass, with concentrations that might preclude the possibility to comply with the limits set to the content of heavy metals for packaging materials, according to the Packaging Directive 94/62/EC and subsequent derogations for glass containers.

Where the volume of the collected material presents a problem for recycling, techniques are available to re-use a portion of the absorbent reducing the overall volume. Problems of inconsistent formulation of the collected dust are not usually an issue. Such problems can be overcome by careful analysis and, if necessary, stockpiling and blending of the material before recycling.

In stone wool production, the SO_X reduction must take place after the waste gas incinerator and before the filter system. In most applications the filter system is positioned prior to the incinerator, which is designed to treat a clean gas. In these cases, the installation of the technique on existing plants will require an incinerator and an additional filter system. The expected investment will be EUR 4 million - 5 million.

The semi-dry process has not been proven as economically viable in this sector.

The recycling of the material back to the furnace is more difficult in stone wool than in other sectors because the process does not require the addition of sulphates and the uptake of sulphur in the melt is low. Therefore, the majority of the pollutant would be re-emitted. This means that the collected waste must be disposed of as a solid waste stream or, if possible, valorised. The choice of absorbent for stone wool is also limited if recycling is considered. The product requires very low soda levels so sodium carbonate and sodium bicarbonate can only be used if the collected material is not recycled.

In stone wool production, an alternative to dry or semi-dry scrubbing could be the use of a venturi scrubber system. Good SO_X removal efficiencies (90 - 95 %) can be obtained but the technique is less effective than a bag filter for dust abatement. Also an aqueous waste is generated and the material is difficult to recycle. A small number of installations have been operating this technique successfully for over 20 years.

Operational data

As mentioned above, the reductions achieved with these techniques depend on a number of factors including waste gas temperature, the amount and type of absorbent added (or more precisely, the molar ratio between reactant and pollutants) and the dispersion of the absorbent. The tables below give an estimation of efficiencies obtained with various absorbents and processes. The actual results achieved will vary from case to case and both higher and lower results have been experienced.

Due to the different absorption rates occurring within the cake on bag filters and the different operating temperatures associated with ESP and bag filters, separate results are given for the two types of filters in Table 4.31.

Pollutant	**ESP**		**Bag filter**
	~ 400°C	**200 - 280°C**	**130 - 240°C**
SO_2	50 %	10 %	10 %
SO_3	80 %	90 %	95 %
HCl	70 %	35 %	80 %
HF	95 %	95 %	95 %
SeO_2	90 %	70 %	90 %

Table 4.31: Dry absorption efficiencies (indicative figures) with $Ca(OH)_2$

More generally, references give the following results for the dry process with $Ca(OH)_2$.

Temperature	**SO_X abatement rate**	
	130 - 140°C	**170 - 180°C**
Molar ratio Ca/S =1	30 %	22 %
Molar ratio Ca/S =2	50 %	40 %
Molar ratio Ca/S =3	70 %	55 %

Table 4.32: SO_X abatement rates for dry scrubbing with $Ca(OH)_2$

An abatement rate of 65 % has been reported in the case of a float furnace using dry scrubbing plus an ESP with a molar ratio MR1 of 4.4, using 180 kg/h of $Ca(OH)_2$ at a temperature of around 400 °C. All the dust is recycled in the furnace.

Experiences of the dry process with Na_2CO_3 as the absorbent are summarised in the Table 4.33 below for the temperature range 300 °C to 400 °C. The abatement rate ranges given are again largely dependent on temperature and on the quantity of absorbent used.

Pollutant	**SO_X abatement rate**
SO_2	<50 %
SO_3	90 %
HCl	50 - 75 %
HF	10 - 40 %
SeO_2	30 - 60 %

Table 4.33: SO_X abatement rates for dry scrubbing with Na_2CO_3

The results of experiences with $NaHCO_3$ as the absorbent show a very good absorption rate for SO_X especially for the lower temperature range, with up to 90 % SO_X removal possible.

A comparison of removal efficiencies observed from field measurements for different types of alkaline reagents and diverse operating conditions is shown in Table 4.34.

Reagent	Type of depollution system	Waste gas temperature	Stoichio metric ratio	Removal efficiency[3]		
		°C	Reagent/SO_2	SO_X (%)	HCl (%)	HF (%)
$Ca(OH)_2$ specific surface 14 m^2/g	ESP + dry scrubbing[1]	335	0.5	17	<5	62
			0.65	22	56	70
			2	37	95	97
$Ca(OH)_2$ specific surface 34 m^2/g	ESP + dry scrubbing[1]	335	0.5	26	56	72
			0.7	34	65	81
			1	40	78	89
			1.7	43	95	97
$NaHCO_3$	ESP + dry scrubbing[1]	342	0.2	7	24	<5
			0.45	24	28	<5
			2	56	51	17
$NaHCO_3$	Bag filter + dry scrubbing[2]	200	0.3	32	76	28
			0.4	44	83	39
			0.5	45	93	63

1. Installation with two oil-fired furnaces for container glass.
2. Installation with one gas-fired furnace for container glass.
3. Data refer to average values of three half-hour measurements for each operating condition.

Table 4.34: Actual removal efficiencies of acid gaseous pollutants for dry scrubbing with different type of absorption reagent and operating conditions
[84, Italy-Report 2007]

The semi-dry process is used on a limited number of applications within the glass industry. In combination with a bag filter and the use of Na_2CO_3 solution as the absorbent, very high abatement rates have been reported. These results are summarised in Table 4.35 below. The SO_2 abatement of 95 % is the maximum possible percentage. On current industrial operation the range of reduction obtained is more usually 80 - 90 %.

Pollutant	SO_X abatement rate
SO_2	90 - 95 %
HCl	>90 %
HF	>85 %
SeO_2	>90 %

Table 4.35: SO_X abatement rates for semi-dry scrubbing with Na_2CO_3 solution

More generally in other industrial applications, references give the results shown in Table 4.36 below for the semi-dry process with $Ca(OH)_2$. However, semi-dry applications using lime are not commonly found in the glass industry.

	SO_X abatement rate
Molar ratio Ca/S =1	80 %
Molar ratio Ca/S =1.5	90 %
Molar ratio Ca/S =2	92 %

Table 4.36: SO_X abatement rates for semi-dry scrubbing with $Ca(OH)_2$
[tm48 ADEME SOx] [49, ADEME 1999]

An effect on NO_X emissions has also been reported when using Na_2CO_3 or $NaHCO_3$ in the semi-dry process. For $NaHCO_3$ the optimal range is located between 120 – 160 °C, and the efficiency of the reaction depends on the molar ratio SO_2/NO_X. The abatement rate is favoured by a high SO_2/NO_X ratio. At higher temperatures, the NO_X emissions reduction rate is much lower. Under normal representative conditions in the glass industry, only a moderate effect on NO_X abatement rates has ever been observed.

In summary, the reduction achieved depends on a number of factors related to the process and absorbent. Under favourable conditions, high abatement rates can be achieved; in the best case up to 95 % for total SO_X expressed as SO_2. The value for SO_3 abatement rate is generally greater than 80 %.

The actual emission concentration or mass/tonne of glass will depend on the inlet concentration and the desulphurisation efficiency. These inlet concentrations depend on the following factors:

- fuel sulphur input
- glass type (colour, oxidation state and sulphur content)
- technological requirements for refining, quality and amount of sulphates
- amount and type of cullet (internal or external, sulphur and contaminants content)
- filter dust composition and recycling rate
- combustion conditions (close to stoichiometric combustion conditions, for NO_X reduction by primary measures, may increase the SO_2 content in raw waste gas).

However, overall reduction of emissions requires the elimination (by internal or external recycling or landfill) of the solid waste stream of the sulphated dust produced. In the case of landfill, the cost for SO_X reduction can be estimated at between EUR 0.5 and 1.2 per tonne of glass depending on the context [76, TNO SO2 2007].

In practice, the complete recycling of filter dust, including this sulphated waste, is very frequently considered to be a reasonable environmental and economic option, where this is technically possible. In this case, the overall reduction of SO_X emissions is limited (by mass balance considerations) to the reduction at the source obtained by substituting sulphate in the raw materials by filter dust. Clearly this is in addition to other appropriate primary measures to reduce overall sulphur input to the melt by the optimisation of sulphur levels in all feed materials (including cullet) wherever practicable.

Therefore, in order to reduce acid gas emissions, it may be necessary to consider an external disposal route for a portion of the collected material. An external option for recycling or re-use would be preferable to landfill. However, in most cases there is no economically viable external re-use of the material. Existing legislative requirements defining such materials as waste may act as additional barriers to external recycling. The determination of what represents the best protection to the environment as a whole can often be site specific and may involve consideration regarding the disposal of the solid waste stream.

With closed loop filter dust recycling, the SO_X emission levels observed at the time of writing (2009), for natural gas firing furnaces, are generally in the range of 200 – 800 mg/Nm^3 for glasses produced with a low cullet recycling rate, and 600 - 900 mg/Nm^3 for the most common container glass production using high levels of external cullet. Emissions in the range of 800 – 1600 mg/Nm^3 with a fuel oil with 1 % sulphur can be achieved depending on the above-mentioned factors**.** Especially for glasses with a high cullet recycling rate and a low capacity for sulphur uptake (e.g. reduced glasses such as certain green and brown container glasses), values in the higher end of the range are expected. There are examples in the glass industry where the net desulphurisation efficiency is close to zero when the dust containing sulphur is fully recycled. However, in these situations the main goal was not desulphurisation, but removal of HCl, HF, metals and dust. Nevertheless, even in these cases, lower levels may be obtained with the consequent creation of a sulphated waste stream for external disposal.
Thus, when considering desulphurisation in the glass industry, it is important to take into account the possible counteracting effects and the jeopardising of other environmental targets. The most important environmental targets related to SO_2 abatement are:

- high cullet recycling rates
- minimisation of waste production through internal or external dust recycling
- waste heat recovery
- other atmospheric emission reductions.

Cullet recycling is an important environmental target because of energy savings, waste reduction and reduction in the consumption of natural resources.

The European Directive 94/62/EC sets targets for the recycling of packaging waste, including glass, with the result that most European Member States are recycling about 60 - 70 % of the container glass that is put on the market. For instance, for container glass furnaces the legislative quota in Germany for cullet recycling is 75 % as an annual mean value and this quota is regularly exceeded. Where cullet is used with a higher sulphur content than the glass produced, the excess sulphur may result in increased SO_X emissions. This is, for example, the case in green and brown reduced glasses that use mixed post-consumer cullet. Mixed post-consumer cullet is, in some cases, the only available source of this type of cullet to the producers and its sulphur content is higher than the product due to the presence of oxidised glass (flint glass, flat glass, certain green glasses) in the cullet mixture. The progressive improvement in selective cullet collecting and sorting will improve the situation. However, the oxidised coloured glass, like certain green glasses, can also have higher levels of sulphur because of their oxidation state, and colour sorting will be less effective in reducing the sulphur content in cullet when significant proportions of such glasses are present.

Filter dust recycling is also an important target for reasons of waste prevention. Recycling of filter dust implies the substitution of some of the sulphate contained in the batch material. In principle, filter dust acts as a refining agent but it may be less effective in some cases and a 100 % substitution is not always possible. Depending on the different glass types (e.g. colour, oxidation state) the absorption of sulphate arising from filter dust sulphur varies and is sometimes limited. With respect to full filter dust recycling and in consideration of the above-mentioned variations, particular care has to be given to the sulphur mass balance and the scrubbing equipment should be designed to enable an appropriate selection of scrubbing agents.

A summary of the main advantages and disadvantages associated with the use of dry and semi-dry scrubbing techniques is shown in Table 4.37.

Advantages

- substantial reductions in SO_X emissions can be achieved (depending on the specific sulphur balance and recycling)
- reduced emissions of other substances (chlorides, fluorides, selenium compounds, other acids, e.g. boric acid)
- in most glass melting facilities, the collected dust can be recycled, reducing the consumption of new raw materials. This is not the case for stone wool.

Disadvantages

- the technique consumes energy
- may result in the generation of a solid residue which cannot always be recycled (especially at high absorption efficiencies), due to an unbalance in the sulphur input-output, chloride accumulation or glass quality issues, thus increasing the waste levels. In most cases dust can be recycled but this requires adjustments to the process and can limit the overall SO_X reduction efficiency. For some types of glass production, the solid residue is totally or partially disposed of into landfill. For stone wool, this dust cannot be recycled at all in the process
- in many countries, this waste is considered hazardous (depending on chemical composition), and where landfill areas do not exist, the waste has to be transported over long distances to other countries (e.g. to salt mines in Germany)
- involves substantial capital and operating costs.

Table 4.37: Main advantages and disadvantages of dry and semi-dry scrubbing techniques

Applicability

In principle, the techniques are applicable to all processes (including new and existing) with waste gases which contain acidic substances. Due to the high dust loading, dust removal is essential. The dry process is much more widely used within the glass industry; because it has been the most cost-effective way of achieving the prevailing technical and regulatory requirements. The most commonly used absorbent is hydrated lime, $Ca(OH)_2$,.

The principles of these techniques are common regardless of the size of the installation. However, it should be remembered that the scale and therefore the actual cost, and possibly the cost effectiveness would vary significantly from application to application. In particular, there is limited experience with semi-dry scrubbing for smaller processes.

Economics

The costs for scrubber systems in combination with ESPs and bag filters are given in Sections 4.4.1.2 and 4.4.1.3. Sodium bicarbonate is substantially more expensive than the other absorbents and is not used as often.

A cost estimation for typical dry scrubbing applications has been carried out, based on the methodology described in Section 8.1. The main results include the following:

- capital costs of dry scrubbing systems (excluding the filter) are typically about EUR 100000 for a simple injection system up to EUR 300000 for larger reaction chambers and recirculating of the filter dust. These costs do not include piping and the filter system
- for applications on float glass furnaces, the costs of the scrubbing system is in the range of EUR 250000 up to 500000, including filter dust removal and storage
- in the container glass sector, investment costs for a bag filter applied to a medium size furnace (<300 tonnes/day) vary from EUR 700000 to 1.25 million. The specific costs for the bag filter and dry scrubbing are between EUR 4 - 7 per tonne glass, assuming a complete filter dust disposal (EUR 400 per tonne of residue); the higher figure being for the smaller size furnace. For larger furnaces or melting capacities (450 - 600 tonne/day) a specific cost of EUR 2.7 - 5.5 per tonne glass is estimated; the higher price refers to smaller and more recent installations (2007 - 2008). The lowest cost levels are found for gas-fired furnaces, with complete recycling of the filter dust in the batch
- in the container glass sector, investment costs for an ESP applied to large furnaces (300 - 600tonnes/day) vary from EUR 1.5 to 3 million. Capital costs increase for melting capacities above 750 tonnes/day (e.g. two to four furnaces connected to one filter) and could exceed EUR 4 million. The related, specific costs for the combined ESP and dry scrubbing are respectively EUR 10 - 16 per tonne glass for furnaces of 100 - 150 tonnes/day, EUR 4.5 - 6.5 per tonne glass for furnaces of 200 - 300 tonnes/day, and EUR 3.5 - 5.5 per tonne glass for furnaces of 600 - 800 tonnes/day. In the case of multiple gas-fired furnaces with a combined capacity of >1000 tonnes/day, specific costs are EUR 3.5 - 4.6 per tonne glass; the higher value refers to complete filter dust disposal. For oil-fired furnaces, specific costs can be about EUR 1.5 per tonne glass higher
- for float glass furnaces, the application of a bag filter requires an investment cost in the range of EUR 2 - 2.5 million. The associated, specific costs for the combined filtration and dry scrubbing are EUR 4.5 - 7 per tonne glass
- for float glass furnaces with a dry scrubber and an electrostatic precipitator, the costs for a float glass furnace of about 500 tonnes/day including a scrubber, piping, insulation, construction, fan(s) and chimney modifications are about EUR 3.5 - 4 million. The value increases up to EUR 5.5 million for a large furnace of 900 tonnes/day. The associated specific costs are in the range of EUR 4 - 6.5 per tonne glass
- in other sectors, for furnaces <40 tonnes/day, specific costs are estimated to be EUR 10 - 14 per tonne glass with the use of bag filters; higher costs in the range of EUR 15 - 17 per tonne glass are indicated for the application of electrostatic precipitators to furnaces of similar capacities
- energy consumption associated with the use of dry scrubbers is related to the pressurised air for injecting the absorption reagent, cleaning of the filter, pneumatic transport of the filter dust, fans, and electrostatic fields (for ESP installations). The specific consumption is typically 12 - 20 kWh/tonne glass with bag filters and 8 - 11 kWh/tonne glass for electrostatic precipitators.

Specific costs indicated above include depreciation, interest on investments (including filter, scrubber, piping, fans, monitoring and control equipment, electricity supply, foundation/buildings), maintenance, energy, and reagents/chemicals [94, Beerkens - APC Evaluation 2008].

For the stone wool sector, the specific costs of dry scrubbing in addition to the standard technique of bag filters are estimated to be approximately EUR 9 - 9.5 per tonne molten glass [115, EURIMA-ENTEC Costs evaluation 2008]. The capital costs of dry scrubbing in addition to the standard technique of bag filters are estimated at EUR 2.5 million for a new plant with operating costs of EUR 0.3 to 0.8 million per year.

When semi-dry (quasi-dry) scrubbing systems are used, the associated costs are the following:

- investment costs for semi-dry scrubbing systems depend on the size of the reaction chamber. The combination of a semi-dry scrubbing stage and bag filter applied to a container glass furnace of about 350 tonne/day, with a waste gas volume of 25000 - 30000 Nm^3/h requires an investment cost of EUR 2.25 million. For a float glass furnace with a waste gas volume of 65000 Nm^3/h, the cost is about EUR 4.5 - 5 million, including piping and control equipment. For large furnaces of up to 900 tonne/day, the investment costs can be as high as EUR 7 million
- for a float glass furnace, the application of a bag filter and semi-dry scrubbing system with a soda solution to a gas-fired float furnace involves specific costs of about EUR 6 - 8 per tonne glass, corresponding to EUR 0.75 per kg SOx removed and EUR 15 - 22 per kg dust removed (primary dust present in the flue-gas before adding the absorption agent), in cases when all the filter dust is recycled back into the furnace. When fuel oil is used for combustion, specific costs are higher, due to the extra costs for the disposal of part of the filter dust and are in the range of EUR 10 - 14 per tonne glass, about 50 – 100 % higher than the costs for dry scrubbing
- for container glass furnaces, with a capacity of 300 - 400 tonnes/day, the application of filtration plus semi-dry scrubbing involves specific costs in the range of EUR 5.5 - 6.5 per tonne glass or even higher according to the increased prices applied for most recent installations.

Driving force for implementation

The accomplishment of the legal emission limits is, in general, the main driving force for implemention.

The possibility of reducing emissions of acid gaseous pollutants, particularly SO_2, HCl and HF, together with the necessity, in most but not all cases, of protecting the filter from corrosion are the driving forces for the application of these techniques.

The need to reduce emissions of metals (e.g. selenium from flint glass or bronze flat glass) might be the driving force of some applications, when their prevailing presence in the flue-gas is in the form of gaseous compounds.

Example plants

There are many examples of these techniques being used for glass furnaces, particularly the dry-process in conjunction with an electrostatic precipitator or bag filter. Most of the furnaces in Europe where secondary dust abatement is fitted utilise these techniques. Very few applications are present in the stone wool production sector.

Reference literature

[tm48 ADEME SO_X] [49, ADEME 1999] [tm41 VDI2578] [42,VDI 1997] [75, Germany-HVG Glass Industry report 2007] [76, TNO SO2 2007] [86, Austrian container glass plants 2007] [89, EURIMA Suggestions 2007] [94, Beerkens - APC Evaluation 2008] [65, GEPVP-Proposals for GLS revision 2007] [94, Beerkens - APC Evaluation 2008].

4.4.3.4 Wet scrubbers

Description

In the wet scrubbing process, the gas species (such as HF, HCl, SO_3, and SO_2) are first dissolved in a liquid, based on the solubility of these gases in the selected liquid. The solubility increases with the alkalinity of the solution or suspension used. The dissolution rates of the gases can be improved by using reactive solutions and special packed towers, enabling an intimate contact between the flue-gas and the liquid phase. Generally, the liquid is an aqueous solution of ionic species that increases the gas solubility. The required excess of reactant in the solution to achieve high acid gas dissolution rates is very small. The rate is mainly determined by the absorption of gas by the liquid.

The design of the reactor is important and often countercurrent gas/liquid flows are applied and a high level of turbulence is maintained in the gas flows to improve the contact. Sodium hydroxide or sodium carbonate solutions are often used for wet scrubbing, although sometimes suspensions or slurries of limestone/lime are applied.

Downstream of the wet scrubber, the flue-gases are saturated with water and a separation of the droplets (containing absorbed gases) is required before discharging the flue-gases. The separated liquid may contain insoluble particles, dissolved material, the reaction products and non-reacted alkaline agent. The resulting liquid has to be treated by a waste water process and the insoluble matter is collected by sedimentation or by filtration to extract the solid material or sludge in a concentrated form. The concentrated sludge is often dried or part of the water is removed before disposal. In most cases it is very difficult to re-use the sludge as a raw material in a batch composition for glass. Typical reactions that occur during wet scrubbing are reported below:

- Scrubbing process with a suspension of hydrated lime

$Ca(OH)_2$ (susp) + $SO_3 \rightarrow CaSO_4$ (susp) + H_2O (g)
$Ca(OH)_2$ (susp) + 2HF $\rightarrow CaF_2$ (susp) + H_2O
$Ca(OH)_2$ (susp) + $2HBO_2 \rightarrow$ Calcium borates + H_2O
$Ca(OH)_2$ (susp) + $2H_3BO_3 \rightarrow$ Calcium borates + H_2O
$Ca(OH)_2$ (susp) + SeO_2 + 1/2 $O_2 \rightarrow CaSeO_4 + H_2O$

(susp = suspension) (g = vapour/gas)

- Scrubbing process with a sodium carbonate solution

Na_2CO_3 (sol) + SO_2 +1/2 $O_2 \rightarrow Na_2SO_4$ (sol) + $H_2O + CO_2$
Na_2CO_3 (sol) + 2HCl $\rightarrow$ 2NaCl (sol) + $H_2O + CO_2$
Na_2CO_3 (sol) + 2HF $\rightarrow$ 2NaF (sol) + $H_2O + CO_2$
Na_2CO_3 (sol) + $H_3BO_3 \rightarrow$ Sodium borates + $H_2O + CO_2$
Na_2CO_3 (sol) + SeO_2 +1/2 $O_2 \rightarrow Na_2SeO_4$ (sol) + CO_2

(sol = solution)

Achieved environmental benefits

Removal efficiencies of more than 90 % are achievable with wet scrubbers depending on the amount of absorption agent used. Gaseous pollutants such as SO_2, SO_3, HF, HCl, H_3BO_3, HBO_2 and SeO_2 might be removed by wet scrubbers from the flue-gases of glass melting furnaces.

Cross-media effects

The main cross-media effect is represented by the amount of waste water that needs to be treated before discharge. In addition, a solid waste (filter cake) or sludge is generated from the separation of the insoluble material from the waste water, by filtration or sedimentation followed by a pressing of the residue. Sludge can be separated in a dry or semi-dried form, depending on the system applied. Direct re-use of sludge or filter cake in the glass forming batch is often not possible, but depends strongly on its chemical composition. In several cases the re-use or recycling of the filter cake or sludge into the glass batch formulation may cause accumulation of species, such as chlorides, fluorides or sulphur, in the glass furnace due to the limited solubility of these components in the glass melt and the high removal efficiency from the flue-gases achieved for these components by using wet scrubbers. In addition, the re-use of sludge or filter cake may also involve handling problems.

Energy consumption is associated with the use of wet scrubbers, including electricity for the injection of the alkaline reagent, cleaning of the filter, pneumatic transport of sludge/filter cake, electrostatic field (in the case the of wet electrostatic precipitators), and use of the fan.

Typical energy consumption for wet scrubbing systems is about 20 - 25 kWh/tonne glass.

Indirect emissions associated with the use of electricity are estimated at about 550 - 660 tonnes CO_2/year for an installation of 100 - 125 tonnes melted glass per day.

Operational data

The typical operating temperature used in the glass industry is between 50 and 80 °C.

In most cases, the conversion efficiency of the applied absorption agents is very high and the stoichiometric amount of reagent is added according to the relative amount of SO_2, HF, HCl, SO_3, H_3BO_3, HBO_2 and SeO_2 present in the flue-gases.
However, the higher removal efficiency of gaseous pollutants achieved by wet scrubbing systems may be offset by a significant reduction of the abatement rate for particulate emissions compared to dry and semi-dry scrubbers in combination with filters.

Applicability
Wet scrubbers are not often used in the glass industry because of the higher costs and the waste water treatment aspects. The waste water treatment often produces sludge or a solid residue, containing the non-reacted material (e.g. lime), the reaction products and water. This sludge cannot always be used as a raw material for glass production and most of the water in the sludge has to be removed before transporting and discharging the waste material to an external disposal site.

Wet scrubbers are used in the mineral wool sector for cleaning gases of the forming area and curing oven. See Sections 4.5.6.1.2 and 4.5.6.2.2.

There are applications of wet scrubbing systems to treat the flue-gases of cold top electric furnaces.

Wet scrubbers are also used to treat the flue-gases from hot end coating installations in the container glass industry to remove tin, organotin compounds and chlorides from the waste gases. This treatment is often used in addition to the procedure of conveying the flue-gases to the dry scrubbing system applied to the melting furnace, with the objective of reducing the concentration of gaseous chlorides sent to the filter.

Economics
A cost estimation for the application of wet scrubbing systems to glass melting furnaces has been carried out, based on the methodology described in Section 8.1. The main results include the following:

- investment costs for the application of wet scrubbing systems are about EUR 2 - 3 million for a flue-gas volume of 10000 - 15000 Nm^3/h. Typical specific costs are in the range of EUR 15 - 20 per tonne melted glass or EUR 1 - 1.5 per kg SO_x removed and EUR 15 - 25 per kg of dust removed. These costs include the operation of a filter which is considered necessary for the reduction of particulate emissions. In this case, the total costs for wet scrubbing are considerably higher than those for dry scrubbing plus a filter.
- the estimated investment costs for the application of wet scrubbing to an oxy-fuel fired furnace or an air-fuel fired recuperative furnace with a production capacity of 100 - 125 tonnes/day of continuous filament glass fibre are in the range of EUR 2.6 - 3.0 million, including sludge and waste water treatment. Annual costs are about EUR 300000 per year, per furnace. The additional production costs are estimated to be between EUR 14 - 6 per tonne glass, considering a cost for disposal of EUR 100 per tonne of waste and excluding the costs for water treatment, which would add significantly to the specific value. These costs would significantly increase with higher waste disposal fees (EUR 400/tonne waste), up to EUR 20 - 22 per tonne melted glass. In this case specific costs for SO_x removal would be about EUR 1 - 1.65 per kg SO_2 removed and EUR 20 - 30 per kg dust removed.
- No cost data are available for applications in the tableware, container glass and float glass installations since the technique is not currently applied in these sectors.

Driving force for implementation
A driving force for implementing a wet scrubbing system could be the need to minimise gaseous emissions that are particularly difficult to control with other techniques, such as boric acids. However, the significant cross-media effects associated with this technique jeopardise the application of wet scrubbing.

Example plants
A very limited number of applications operate in the glass industry. Some systems are applied to continuous filament glass fibre melting furnaces (two furnaces in the Netherlands) and to special glass production (e.g. in Germany and Austria). The technique is applied to a relatively small installation in Italy, in the domestic glass sector, for treating the flue-gases of six electric furnaces.

Data concerning an example installation producing special glass are reported in Table 4.38.

Type of furnace	Electric melting	Emission levels (1)		
Furnace capacity	40 t/d		mg/Nm^3, dry gas	kg/t melted glass
Actual pull rate	32 t/d	Particulate matter	1.8	0.017
Furnace age	3.5 yrs	NOx (2)	159	1.54
Type of glass	Soda-lime for headlights	SO_x	2.3	0.022
Cullet (only internal)	30 %	HCl	<0.2	<0.002
Specific energy consumption (only melting)	4.50 GJ/t glass	HF	<0.1	<0.001
Total energy consumption (per tonne of melted glass)	7.11 GJ/t glass	1. Emission data refer to discontinuous measurements of a half-hour. 2. NO_X emissions arise from nitrates in the batch formulation.		
Waste gas treatment system	Wet scrubber			

Table 4.38: Emission levels associated with the application of wet scrubbing to an electric furnace producing special glass in an example installation.
[111, Austrian Special glass plant 2006]

References to literature
[94, Beerkens - APC Evaluation 2008]

4.4.3.5 Comparison of De SO_X methods

[94, Beerkens - APC Evaluation 2008]

Table 4.39 gives an overview of the different methods for the removal of SO_X, HF, HCl, or boric acids and selenium from the flue-gases of glass melting furnaces. It summarises the performance, advantages, disadvantages, boundary conditions and costs associated with the different $DeSO_X$ techniques. Cost data are given per tonne of molten glass and refer to applications on float or container glass furnaces. Two different options, with the total recycling of filter dust in the batch formulation or with external disposal into a landfill, are presented. The difference between the two values is given by the typical costs for disposal of the filter dust.

The total or partial disposal of the filter dust can be necessary in cases of unacceptable sulphur or chloride accumulation in the system or to avoid fine dust carryover problems in the furnace. Disposal plus transport may cost up to EUR 400 per tonne of dust.

The costs indicated in Table 4.39 consider the average situation in the EU-27 (year 2007). It should be noted therefore, that these costs may vary in the different Member States and will also change over time (e.g. price of energy is very variable).

A summary of the specific costs concerning different air pollution control techniques (APC) applied for the combined abatement of dust and SO_X is presented in Table 4.40.

An estimation of specific indirect emissions, calculated for different glass furnaces and various air pollution control techiques is presented in Table 4.41.

The methodology used for the estimation of costs reported in Table 4.39, Table 4.40 and for the calculation of indirect emissions presented in Table 4.41, is given in Section 8.1.

Scrubbing system									
Scrubber type	**Dry**					**Semi-dry**			**Wet**
Absorption Agent	**$Ca(OH)_2$**	**$NaHCO_3$**	**Uncalcinated trona $Na_3H(CO_3)_2\ 2H_2O$**	**$Ca(OH)_2$**	**$NaHCO_3$**	**$Ca(OH)_2$ suspension**	**Na_2CO_3 solution**	**Na_2CO_3 solution**	**$Ca(OH)_2$ suspension**
Filter type	**Bag filter**	**Bag filter**	**ESP (1)**	**ESP (1)**	**ESP (1)**	**Bag filter**	**Bag filter**	**ESP (1)**	
Application in glass industry	High	Very low	Very low	Very high	Medium	Low	Low	Low	Low
Typical temperature range (°C)	140 - 180	140 – 180	300 – 350	300 - 400	250 - 350	160 - 180	180 - 200	250 - 400	60
SO_2 removal efficiency in % at stoichiometric dosing n=1	10 to 25	75	75 - 90	30 - 40	>60	Not available	70 - 90		>90
Filter dust composition (2)	$CaSO_3$, $CaSO_4$, CaF_2, $CaCl_2$, $CaCO_3$, $Ca(OH)_2$, Na_2SO_4	Na_2SO_4, NaCl	Na_2SO_4, NaCl	$CaSO_4$, $CaSO_3$, CaF_2, $Ca(OH)_2$	Na_2SO_4, NaCl	$CaSO_4$, $CaSO_3$, CaF_2, $Ca(OH)_2$	Na_2SO_4, Na_2SO_3, Na_2CO_3, NaCl	Na_2SO_4, Na_2SO_3, Na_2CO_3, NaCl	$CaSO_4$, $CaSO_3$, CaF_2
Advantages	Simple process, only cooling of flue-gas; bag filter provides dust removal and reaction	Simple process, only cooling of flue-gas; bag filter provides dust removal and reaction	Simple Process, only cooling of flue-gas; bag filter provides dust removal and reaction		High absorption for HCl and SO_X	Low consumption of absorption agent, low costs of chemicals, and lower investments costs compared to wet scrubbers		Good absorption performance, but with dry fine (milled) soda powder good efficiencies can also be achieved	Low consumption of absorption agent, low costs of chemicals
Disadvantages	High consumption of reactants in cases where high removal efficiencies are required; generates large amounts of filter dust	Expensive Reactant	Reactant is difficult to purchase in Europe	High consumption of reactants in cases where high removal efficiencies are required; generates large amounts of filter dust	Expensive reactant	Spray dryer is expensive; costly materials for bag filter; higher investment compared to dry scrubber	Spray dryer is expensive; costly materials for bag filter; higher investment compared to dry scrubber	System needs more maintenance than dry scrubbers	Reheating of flue-gas before stack; production of waste water and gypsum complex, and fouling of equipment; high investments

Scrubbing system									
Scrubber type	**Dry**					**Semi-dry**			**Wet**
Absorption Agent	**$Ca(OH)_2$**	**$NaHCO_3$**	**Uncalcinated trona $Na_3H(CO_3)_2\ 2H_2O$**	**$Ca(OH)_2$**	**$NaHCO_3$**	**$Ca(OH)_2$ suspension**	**Na_2CO_3 solution**	**Na_2CO_3 solution**	**$Ca(OH)_2$ suspension**
Filter type	**Bag filter**	**Bag filter**	**ESP $^{(1)}$**	**ESP $^{(1)}$**	**ESP $^{(1)}$**	**Bag filter**	**Bag filter**	**ESP $^{(1)}$**	
Important parameters	Improvement for temperatures close to dew point; $Ca(OH)_2$ dosing size and BET of $Ca(OH)_2$	Dosing and size of bicarbonate particles	Dosing and size of trona particles <30 microns; mixing into flue-gas is preferred	Higher temperatures >350 °C preferred; size and BET of $Ca(OH)_2$ powder	Dosing and size of particles; mixing into flue-gas	Dosing of lime	Dosing of sodium carbonate	Dosing of sodium carbonate	Contact between liquid and gas temperature; basicity of suspension
Costs per tonne molten glass with filter dust recycling, in EUR/tonne	2.5 - 3	3.5	3.5	3	4	Not known	5 - 6	6 - 8 estimated	10 – 16
Costs per tonne molten glass without filter dust recycling, in EUR/tonne	3 - 4	4.5	4.5	3.5	5	Not known	7 - 10	8 - 11	12 – 20
Combination with $DeNO_X$	No SCR possible without gas reheating	No SCR possible without gas reheating	Temperature downstream of ESP should be >330 °C	Temperature downstream of ESP should be >330 °C	Temperature downstream of ESP should be >330 °C	No SCR possible without gas reheating	No SCR possible without gas reheating	Combination with SCR only if ESP operates above 350 - 360 °C	No SCR possible without gas reheating from 60 to 350 °C

1 Electrostatic precipitator
2 Depends on glass type; in flint glass production $CaSeO_3$ or Na_2SeO_3 can be formed.

Table 4.39: Comparison of De SO_X methods for flue-gases of glass melting furnaces.
[94, Beerkens - APC Evaluation 2008]

4.4.4 Fluorides (HF) and chlorides (HCl)

In this section, all gaseous fluorides and chlorides are expressed as hydrogen fluoride (HF) and hydrogen chloride (HCl) respectively. The vast majority of the halides emitted are in these forms. Emissions of HF and HCl arise from impurities in the batch materials or from batch materials that are selected because they contain these species in sufficient quantities to impart desired product qualities.

4.4.4.1 Reduction at source

In most processes HF and HCl emissions arise from impurities in the batch materials, which are emitted upon melting. Many raw materials contain very low levels of fluorine and chlorine that have little impact on final emission levels. However, some raw materials contain significant levels of these elements as impurities and the main substances of this type include:

- man-made soda ash, which has a residual NaCl content of approximately 0.05 – 0.15 %
- dolomite, which can contain significant fluoride impurities
- post consumer glass cullet, which can contain a range of impurities at significant levels, particularly chlorides, fluorides and metals. The amount of these substances varies depending on the purity of the cullet supply, but in regions with high recycling levels the species can gradually build up in the glass
- recycled dusts from abatement equipment contain fluoride and chloride salts, which can build up in the system
- some fuels (e.g. coke from certain sources) can contain chlorides.

The chloride emissions from those processes using high soda ash levels in the batch (mainly soda-lime glass) are significantly higher than from, for example, glass wool or continuous filament glass fibre (see Chapter 3). Of those processes that do not intentionally include these materials in the batch, the highest emissions of HCl and HF tend to come from flat and container glass processes.

The emission levels can be minimised by the careful selection of raw materials. The issues surrounding NaCl levels in soda ash are discussed in Section 4.4.1.1. A number of the other techniques discussed in Chapter 4 also have beneficial effects on HF and HCl emissions. These are mainly those techniques that reduce volatilisation by lowering temperatures, by reducing airflow and by minimising turbulence. These techniques include:

- increased cullet usage, which lowers temperature and energy usage, and substitutes for soda ash with its associated chloride impurity. Potentially, there is a paradoxical effect if cullet has high HCl or HF levels
- electric boost
- improved furnace design and geometry
- burner positioning
- reduced air/fuel ratio
- oxy-fuel melting
- electric melting.

A number of product types made within the glass industry use materials containing fluorides to impart specific properties to the material or to meet the requirement of the glass quality. The most important examples of this are discussed below.

Continuous filament glass fibre

The production of continuous filament glass fibre generally requires fluoride. The fluoride is added to optimise surface tension and liquidity properties, to aid fiberisation and to minimise filament breakage. These are important factors in the economic and environmental performance of the process. High breakage leads to reduced yield and increased waste. The main source of added fluoride is usually fluorspar (CaF_2), but significant levels can also be present in china clay (alumina silicate).

A lot of effort has been put into developing formulations without added fluorine and in some cases this has been effective. Some companies have developed the methodology for using a non-fluorine batch formulation on many of their furnaces. Another company has developed in a similar way using a no-added fluorine or boron batch, and dust emissions of below 50 mg/Nm^3 and HF emissions in the range of 10 - 50 mg/Nm^3 have been achieved. The optimisation of these techniques can require modifications to the furnace design and forming processes and may be most effectively implemented at a furnace rebuild and process/bushing changes. These batch changes are normally associated with lower dust emissions (no evaporation of sodium and potassium borates).

A potential cross-media effect associated with the use of fluorine and boron-free formulations may be an increase of specific energy consumption due to a higher melting temperature with a consequent increase of CO_2 emissions.

The developments in low-fluorine and low-boron glasses are the result of expensive development work and the technology is closely guarded by the companies that have developed it. Therefore, the technique is not available immediately to all operators. There are also lengthy and expensive product registration procedures that must be completed for new products with changes in the formulation.

Frits manufacture

Emissions of fluorides are directly related to the use of fluoride compounds in the batch. Fluorides are predominantly used in the production of enamel frits and are not usually present to any significant extent in the raw materials used for ceramic frits manufacturing. Some ceramic frits producers may periodically manufacture small quantities of enamel frits in the ceramic frit kilns, giving rise to fluoride emissions, but this constitutes a very small proportion of the overall production of the operators. The emission of fluorides is probably the most significant environmental impact of enamel frits production.

Fluorides provide unique properties to the frits, such as improved thermal and chemical resistance and a reduced risk of blistering of the enamel coating. They are added to the batch as fluorspar, fluorosilicate, cryolite or sodium fluorosilicate. Most producers now offer some fluoride free or low-fluoride enamels, and the availability of these products is increasing. In general, fluoride free products represent less than 10 % of production, with low fluoride products at about 30 %. The fluoride in the batch cannot, generally, be reduced sufficiently to achieve emission levels comparable with scrubbing techniques or other types of frits.

Opaque glasses

Opaque glasses are made in the domestic, special and occasionally the container glass sectors. The addition of fluoride causes crystallisation in the glass giving the characteristic cloudy and opaque appearance. The majority of installations producing these products use dry scrubbing techniques to treat the HF emissions. No practicable alternatives are available that produce a comparable quality. In many cases, opaque glass is melted in cold-top electric furnaces. This lowers the emissions because a significant proportion of the fluoride is absorbed in the batch blanket and less fluoride is needed overall. Also, the use of electric melting greatly reduces the volume of waste gas to be treated.

The special glass sector also produces fluorine crown glass, which is an optical product with a very high fluoride content. The production level of this glass is very low and in the EU it is always carried out with waste gas treatment.

In general, measures to achieve reductions at the source are preferable to waste gas treatment. With glasses containing fluorine, measures to reduce fluorine levels can place severe restrictions on operating conditions and require substantial development resources. Where emission reductions are required by legislation, this has led many producers to favour waste gas treatment and particularly dry scrubbing.

4.4.4.2 Scrubbing techniques

The scrubbing techniques applicable to these emissions are dry, semi-dry and wet scrubbing. These techniques and the emission levels achievable are discussed in Sections 4.4.3.3 and 4.4.3.4 above. The choice of absorbent is important and there is sometimes a need to trade-off between the reduction of SO_2 and the reduction of HF and HCl. In particular, there is a competing reaction between HCl/HF and SO_2 with sodium carbonate. The optimum choice will depend on a number of issues including the relative levels of the different pollutants in the waste gas. The different removal efficiencies for the most common alkaline reagents applied within the glass manufacturing industry are presented in Table 4.31, Table 4.34, and Table 4.35.

Another technique that could be technically and economically viable for very small scale processes (e.g. some frit furnaces) is wet scrubbing, using a packed bed scrubber circulating water or, more effectively, an alkali solution. The main drawback with this approach is that an aqueous waste stream is generated.

4.4.5 Oxides of carbon

Oxides of carbon include carbon dioxide (CO_2) and carbon monoxide (CO). Carbon monoxide arises as a product of incomplete combustion and is rarely emitted from glass industry installations at a level to cause environmental concern. Significant levels are encountered in stone wool cupolas, but most plants are fitted with an afterburner to oxidise the emissions before release. Carbon dioxide arises from the combustion of fossil fuels or other organic materials, from the decomposition of carbonates, and from the oxidation of other raw materials which contain carbon (slag, carbon, etc) present in the batch. Emissions of CO_2 strongly depend on the energy efficiency of the melting process and may vary significantly when primary or secondary techniques are applied for the control of other pollutants, e.g. batch and cullet preheating, reburning or the 3R process, etc.

Carbonates such as soda ash and limestone are the main sources of alkali metal oxides and alkali earth metal oxides in glass making. However, the use of burnt lime and dolomite in place of carbonates has been recently applied for some glass production. The only real alternative sources of these oxides are post-consumer waste and process waste, that is, cullet for glass processes and process wastes, recycled product and slag (for the stone wool production only). The issues surrounding these materials are discussed elsewhere in this document, but generally the main factor limiting their use is the availability of adequate quantities of the materials of sufficient quality and consistency of supply. High utilisation of these materials is generally limited to container glass and glass wool for the use of cullet and stone wool for slag utilisation.

Carbon dioxide has well-known associated environmental effects, but it is not one of the main polluting substances listed in Annex III to Directive 2008/1/EC. The increasing use of recycled materials within the glass industry is driven by the need to save energy and to reduce waste, and the effect on substitution of carbonaceous materials is an added benefit. Similarly, the reduction in emissions of CO_2 derived from reduced fuel usage is driven by the need to reduce energy usage and operating costs, and by the pressure to lower NO_X emissions.

Many techniques discussed in this chapter have important implications for CO_2 emissions, but no techniques beyond those considered for energy and other pollutants are presented for consideration in determining BAT for glass industry installations.

Indirect emissions of CO_2, in particular when electric energy is required in the production process and for operating the air pollution control systems should also be taken into account for assessing the overall contribution of the installation to oxides of carbon emissions.

Dust + SO_X abatement										
Type of glass	**Production**	**ESP + dry scrubber $(CaOH)_2$ Filter dust recycling**	**ESP + dry scrubber $(CaOH)_2$ Filter dust disposal**	**ESP + dry scrubber $(NaHCO_3)$ Filter dust recycling**	**ESP + dry scrubber $(NaHCO_3)$ Filter dust disposal**	**Bag filter + dry scrubber Filter dust recycling**	**Bag filter + dry scrubber Filter dust disposal**	**Bag filter + semi-dry scrubber Filter dust recycling**	**Bag filter + semi-dry scrubber Filter dust disposal**	**Wet scrubber**
	tonne molten glass/day	EUR/t glass	EUR/t glass	EUR/t glass	EUR/t glass	EUR/t glass	EUR/t glass	EUR/t glass	EUR/t glass	EUR/t glass
Float	500	4.8	6.51			6		7 - 7.35	9.6 (gas)-13 (oil)	
Float	700	4.27	5.87	4.39	7.75		6.98			
Float	900	3.88	5.44					5.82	8.33	
Container	100 - 150	11	14							
Container	200					4.63 – 5.9	4.8 – 7			
Container (oil)	200					6.4	9.25			
Container (oil)	300 – 350	4.52 - 6	6.31 - 7.5		7.38 - 8.33	3.86 - 5	4.11 - 7.3	5.3	6.54	
Container	450	3.96 - 5.2	4.77 - 6.5			2.9	3.6			
Container (oil)	600	3.58	5.1			2.7	3.37			
Container (gas)	740	4	5.1							
Container (gas)	1240	3.4	4.6							
Container (oil)	1240	3.7	6.2							
Tableware	30 - 35	15.65	16.7			12.85	13.84			
Tableware	180 - 200		7.66			3.75 - 4.35				
E-glass oxy-fired	100 - 120						11			14.4 – 21.5*
E-glass air-fired	100 - 120									15.7 – 20.5*
* higher value for filter dust disposal at EUR 400 per tonne dust.										

Table 4.40: Overview of specific costs for different air pollution control techniques (APC) applied to glass furnaces for the abatement of dust and SO_X
[94, Beerkens - APC Evaluation 2008]

	APC system	Application and type of fuel	NO_X reduced	NO_X indirect emissions (1)	Net effect NO_X reduction	Dust reduced	SO_X reduced	SO_X indirect emissions (1)	Extra release of CO_2 indirect + direct (2)	Waste disposal	NH_3	$Ca(OH)_2$	$NaHCO_3$	Soda	Electricity
tonnes melted glass/year			g/t	g/t	g/t	g/t	g/t	g/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kWh/t
255500	ESP + dry $Ca(OH)_2$ scrubber	700 TPD float glass furnace, gas	0	21	-21	407	795	74	10	3.82		2.64			11.94
109500	ESP + dry $Ca(OH)_2$ scrubber	300 TPD container glass furnace, gas	0	18	-18	237	795	64	8	3.79		2.75			9.95
10950	ESP + dry $Ca(OH)_2$ scrubber	30 TPD tableware furnace, gas	0	38	-38	423	440	137	17	2.89		2.04			22.28
255500	ESP +dry $NaHCO_3$ scrubber	700 TPD float glass furnace, gas	0	27	-27	407	1620	90	16	6.09			6.33		14.40
182500	Bag filter + dry $Ca(OH)_2$ scrubber	500 TPD float glass furnace, gas	0	35	-35	438	871	125	16	4.00		3.05			20.02
109500	Bag filter + dry $Ca(OH)_2$ scrubber	300 TPD container glass furnace, gas	0	24	-24	192	216	89	10	1.40		1.00			13.68
182500	Semi-dry scrubber and bag filter	500 TPD float glass furnace, gas	0	45	-45	380	1584	165	22	4.97				3.29	26.52
182500	Semi-dry scrubber and bag filter	500 TPD float glass furnace, fuel oil <1 % Sulphur	0	45	-45	459	3644	164	26	11.01				7.54	26.28
40150	Wet scrubber	100 - 120 TPD E-glass furnace, fuel-air fired	0	42	-42	927	548	152	20	20.55		5 - 6 quick lime			24.21
40150	Wet scrubber	100 - 120 TPD E-glass furnace, oxy-fired	0	36	-36	655	448	127	17	20.55		4 - 5 quick lime			20.42
328500	SCR	900 TPD float glass furnace, gas	3820	8	3814			25	4		1.41				3.99
109500	SCR	300 TPD container glass furnace, gas	1461	7	1452			23	3		0.57				3.20
10950	SCR	30 TPD tableware furnace, gas	2160	18	2146			62	8		0.84				8.04
36500	SCR	100 TPD tableware furnace, gas	3562	20	3534				9		1.40				10.68
237250	3R	650 TPD float glass furnace, gas	3987	0	3987				28						
109500	3R	300 TPD container glass furnace, gas	1534	0	1534				18						
116800	SNCR	320 TPD container glass furnace, gas	868	3	865			9	2		0.48				

	APC system	Application and type of fuel	NO_X reduced	NO_X indirect emissions[1]	Net effect NO_X reduction	Dust reduced	SO_X reduced	SO_X indirect emissions [1]	Extra release of CO_2 indirect + direct [2]	Waste disposal	NH_3	$Ca(OH)_2$	$NaHCO_3$	Soda	Electricity
tonnes melted glass/year			g/t	g/t	g/t	g/t	g/t	g/t	kg/t	kg/t	kg/t	kg/t	kg/t	kg/t	kWh/t
36500	SNCR	100 TPD E-glass furnace	1512	6	1507			20	3		0.84				
328500	Low NO_X basic	900 TPD float glass furnace, gas	1689	0	1689				0						
182500	Low NO_X basic	500 TPD float glass furnace, oil	1847		1847				0						
109500	Low NO_X basic	300 TPD container glass furnace, gas							0						
255500	Low NO_X extended	700 TPD float glass furnace, gas	1319		1319										
328500	Low NO_X extended	900 TPD float glass furnace, oil	2761		2761				0						
109500	Low NO_X extended	300 TPD container glass furnace, gas	1023		1023				0						
65700	Low NO_X extended, plus electricity	180 TPD tableware borosilicate glass	10822		10822				171						25.01
182500	Oxy-fuel	500 TPD float glassfurnace, gas	2247	232	2016			844	56						135.56
82125	Oxy-fuel	225 TPD container glass furnace, gas	901	21	879				30						79.22
10950	Oxy-fuel	30 TPD tableware, gas	1735	164	1553				-172						95.71
36500	Oxy-fuel	100 TPD, E-glass, gas	2200	244	1956			885	-51						110.41
14600	Electric melter	40 TPD lead crystal	2438	1295	1144				-15						747.95
10950	Electric melter	30 TPD lead crystal	2466	1032	1425				-59						600.00
7300	Electric melter	20 TPD lead crystal	1918	1918	0				168						1056.16
127750	Batch preheater	350 TPD container glass furnace	225	12	214		407	43	-35+5 [3]						6.86

1. External emissions arise from electricity generation (average EU), ammonia production, soda and sodium bicarbonate production, hydrate lime production, oxygen.
2. Extra release of CO_2 does not include the amount from the manufacturing process of $Ca(OH)_2$.
3. The extra release of CO_2 is equivalent to -30 kg/tonne melted glass. This value derives from 5 kg/t from extra electricity use for the flue-gas fan and 35 kg/t CO_2 emission reduction due to fuel savings in the melting process because of batch preheating.

Table 4.41: Estimation of specific indirect emissions per tonne molten glass for different glass furnaces and for different air pollution control techniques (APC)
[94, Beerkens - APC Evaluation 2008]

4.5 Techniques for controlling emissions to air from non-melting activities

This section covers those activities which are not related to melting or to materials handling. These activities include product forming and any activities carried out on the products which are generally considered to form part of the main process. In most of the activities in the glass industry, the melting of the raw materials is the first major activity carried out and so the subsequent activities are sometimes referred to in this document as "downstream" activities.

Due to the very sector-specific nature of the downstream activities, the discussion is presented on a sectorial basis.

4.5.1 Container glass

The main source of emissions to air from non-melting activities in container glass production is the hot-end coating operation. The coating, a very thin layer of metal oxide, is applied by passing the hot containers from the forming machine through a hood containing vapours of tin or titanium compounds. The most common materials used are anhydrous tin tetrachloride ($SnCl_4$), anhydrous titanium tetrachloride ($TiCl_4$), and monobutyl tin chloride ($C_4H_9SnCl_3$). The emissions consist of HCl, oxychlorides, tin and titanium oxides (SnO_2, TiO_2) as fine particulates, and any unreacted coating materials. Minor emissions of Volatile Organic Compounds (VOCs) could also arise from cold coating operations. These emissions are not considered to be very significant and are not discussed further in this document.

The first step in reducing emissions is to minimise the usage of the coating commensurate with the product requirements. The use of the material can be further optimised by ensuring good sealing of the application areas to minimise losses.

Currently, waste gases from hot-end coating operations are managed in four different possible ways:

- extracted and emitted directly to the air
- extracted and treated by secondary techniques e.g. wet scrubbing or dry scrubbing and filtration
- combined with the waste gas from the furnace
- combining the waste gas with furnace combustion air.

The discharge of waste gases from hot-end coating operations directly to the air is, in general, justified by the relatively low mass flow or concentration of pollutants present in the flue-gas. In fact, in some circumstances, with the application of new generation hoods and distribution systems, emissions can be reduced below 5 mg/Nm^3 metal compounds and 30 mg/Nm^3 HCl. However, this practice is applied only in specific cases; while in most installations, other options are used.

The option to combine the waste gases with the furnace combustion air may limit some of the primary control measures to minimise NO_X and dust emissions and, although, the effects on the glass chemistry and on the regenerator material, not likely to be significant, they may have to be considered. Some installations in Europe apply this technique, combining the waste gas from the hot-end coating with the combustion air before entering the regenerator, although no information regarding these applications is currently available (as for 2009).

The combination of flue-gases from hot-end coating with the waste gas from the furnace is often applied where secondary abatement of the furnace waste gas is installed. From data supplied, this option is reported to be the most frequent technique used in practice for the treatment of hot-end waste gas.

In fact, 25 out of 31 hot-end fume abatement installations were reported to be using this technique, from a total number of 125 plants. Where the collected material is recycled, consideration may have to be given to the build-up of chloride and metals and their effect on the system. These considerations may limit the recycling of the dust in some cases.

Data concerning an example installation producing container glass are shown in Table 4.42.
In this case, the flue-gases from hot-end coating with organic tin are conveyed and treated together with the waste gases from the melting furnaces by applying a dry scrubbing system combined with an ESP.

	Furnace 1	**Furnace 2**
Type of furnace	end-fired	end-fired
Fuel	natural gas	natural gas
Age	4 yrs	1 yr
Bubblers	yes	no
Electric boosting	1000 kW	no
Capacity	230 t/d	240 t/d
Type of glass	soda-lime green	soda-lime white
Cullet	75 %	55 %
Use of filter dust	yes	no
Average specific energy consumption: Melting: 3.94 GJ/t glass - Total 4.47 GJ/t glass		
Flue gas volume: 31240 Nm^3/h, dry gas at 8 % O_2		
Continuous measurements for dust, NOx and SO_2 (monthly mean values) Single, discontinuous measurements for metals (0.5 - 8 h)		
• Depollution system: 1 field ESP + dry scrubbing with $Ca(OH)_2$. • Primary measures for DeNOx. • Flue-gases from hot-end coating with organic tin are combined and treated with flue-gases from the furnace.		
	Emission levels (mg/Nm^3, dry gas at 8 % O_2)	
	Range	**Average value**
Particulate matter	15 - 23	17
NOx	734 - 963	837
SO_2	165 - 354	266
HCl		8.5
HF		1.6
Cd		0.00002
As		0.001
Co		0.02
Ni		0.02
Se		1.23
Sb		0.002
Pb		0.005
Cr		0.005
Cu		0.02
Mn		0.005
∑(Cd, As, Co, Ni, Se, Sb, Pb, Cr, Cu, Mn, Sn)		1.31

Table 4.42: Example installation for combined treatment of hot-end coating flue-gases and waste gases from container glass melting furnaces
[86, Austrian container glass plants 2007]

As discussed elsewhere in this document, wet scrubbers can be effective in reducing gaseous emissions but their effectiveness in treating fine dusts is limited by the pressure drop across the system. The performance will depend on the inlet composition, but a single stage scrubber may be sufficient for achieving compliance with local requirements. If further reductions are necessary, then either a bag filter followed by a packed bed scrubber, or a venturi scrubber followed by packed bed scrubber could be used. These techniques could be expected to reduce HCl to <10 mg/Nm^3, but the efficiency for the removal of particulate matter and total metals is quite low due to the fine particles and the peculiar chemical properties of the reaction products generated by the application of tin or titanium chlorides. Where HCl is present as an aerosol, emissions of <30 mg/Nm^3 could be expected. The costs of these alternatives will depend on the waste gas volume. Local circumstances may mean that comparable figures can be achieved with less sophisticated methods.

Another significant source of emissions from hot-surface treatment operations is associated with the treatment of the inner surface of container glass, mainly destined to pharmaceutical uses, with SO_3. In these cases, wet scrubbing is normally applied for SO_X removal.

Technical details concerning the use of wet scrubbers are given in Section 4.4.3.4 and Section 4.5.6.1.2.

4.5.2 Flat glass

In general, the emissions to air from non-melting activities in flat glass production are very low and do not require abatement measures. If the float bath is correctly operated, there are no appreciable emissions of tin vapours. SO_2 is used at the beginning of the lehr but again, if the process is properly operated, emissions are insignificant. Typical concentrations and mass emissions are reported in Section 3.4.2.3.

The only other potential emissions are combustion products from natural gas heaters in the lehr. The exception to this is where online coating processes are carried out. The emissions from these processes are very case specific and an actual example is used here to describe the techniques that can be used.

The raw materials for this coating process are: tin tetrachloride ($SnCl_4$), hydrofluoric acid (HF), methanol (CH_3OH), and a silane (SiH_4). There are two separate coating stages a SiCO undercoat and a fluorine-doped tin oxide topcoat. Emissions from the undercoat stage pass through a thermal incinerator to destroy any organics, the waste gas is cooled and the solids (amorphous silica) are removed by a bag filter. The collected material is recycled to the furnace.

In the top coating stage, the waste gases, which contain halides and tin compounds, are passed through a high-temperature reactor to oxidise the tin compounds. The solid tin oxide is removed by an electrostatic precipitator and the halides are removed in a packed bed chemical scrubber. The emission levels achieved are:

• particulates	15 mg/Nm^3
• hydrogen chloride	5 mg/Nm^3
• fluorine and its gaseous compounds as HF	<1 mg/Nm^3
• metals	<5 mg/Nm^3

In general, the emissions from these types of activities can be controlled using one of the techniques listed below or a combination of them; in some cases, other, equally effective techniques may be appropriate:

- dust abatement equipment bag filter or ESP, although a bag filter is likely to give lower emissions (1 – 5 mg/Nm^3)
- the techniques above can be combined with dry scrubbing
- wet chemical scrubbing
- high temperature oxidation, e.g. thermal incineration.

Costs are site-specific but are not generally considered to be disproportionate to the results obtained.

4.5.3 Continuous filament glass fibre

Emissions to air from non-melting activities in this sector arise from four main sources:

- application of the coating to the fibres
- cake drying
- cutting and milling
- secondary processing.

Emissions to air from the coating application are usually quite low due to the low volatility of the coating materials and the low glass temperatures at the point of application. An important aspect of this is the selection of coating materials with low levels of organic solvents. However, some volatile species will be present either as solvents or as by-products of the reactions. The coating materials used vary widely between products and installations, but material selection is the most effective method of reducing emissions. The high volumes of air necessary to cool the glass make it very difficult and expensive to control VOC emissions by secondary measures.

The high airflows result in some carryover of droplets and encourage volatilisation of any VOCs present. Wet scrubbing systems are often used to control the waste gas but the effect on volatile substances will be limited to condensation. Wet electrostatic precipitators could also be used in this application but no examples of this are known. Costs of wet scrubbing and wet electrostatic precipitators will be similar to those quoted for the mineral wool sector. The emission levels achieved will depend entirely on the case-specific starting levels; some typical figures are given in Section 3.5.2.3.

The wet cakes are usually dried in ovens and any species volatile at these temperatures will be emitted with the water vapour. In general, the molecular weights of the materials are quite high and a significant proportion of any volatile substances will have been emitted during the coating application. Little information is available on emission levels and currently the only technique used to minimise emissions is material selection. The waste gas volumes are quite small and standard control techniques could be used if significant releases were identified, for example, incineration, adsorption, and scrubbing. No cost information is available for these techniques in this application, but such techniques are readily available for low gas volumes. However, it will always be preferable to control such emissions by optimisation of the coating formulation before any abatement techniques are installed.

Dust emissions arising from cutting and milling can be readily treated by extraction to a filter system. This is the standard technique used throughout the sector and emissions in the range of 1 - 5 mg/Nm^3 can be achieved.

Secondary processing can involve the use of further coating or binder materials. The emissions are very case specific and standard abatement techniques for VOCs and trace gases can be used if primary measures do not achieve the required performance level.

4.5.4 Domestic glass

In the majority of domestic glass processes, there are no significant emissions to air from the activities downstream of the furnace. A number of burner systems are used to maintain the correct glass temperature for fire polishing and in the annealing lehr, but there are no significant emissions requiring specific controls.

The exception to this is the production of articles that require cutting and polishing, particularly full lead crystal, lead crystal and crystal glass. The presence of lead in the dust generated during downstream activities requires a careful control of potential fugitive emissions in order to avoid health and safety issues for the workers.

Cutting involves carving precise patterns on the blank glass articles using diamond impregnated wheels, either by hand or automatically. Other cutting and grinding activities such as edge grinding can also be carried out. Water is usually used as a coolant for cutting and to prevent dust emissions. Extraction may also be provided to remove any mist from the coolant. Where these activities are carried out under a liquid coolant, there are no appreciable emissions to air although a mist eliminator may be necessary on the extraction system. If dry cutting or grinding operations are carried out, the dust can be extracted and passed through an efficient bag filter system to give dust emissions in the range of 1 – 5 mg/Nm^3. In the case of cutting and grinding operations carried out on lead crystal glass, emissions of Pb, after treatment (e.g. bag filter), are expected to be below 1 - 1.5 mg/Nm^3.

Glass cutting produces a grey, unfinished surface on the glass. The glass surface is restored to its original appearance by immersion in a polishing bath of hydrofluoric and sulphuric acids, typically a solution with 30 % H_2SO_4 and 2 - 3 % HF at a temperature of <50 °C is applied. Fumes of HF and SiF_4 are released from the surface of the polishing bath. The most effective way of treating these emissions is usually wet scrubbing either with water or a chemical solution. During this operation, hexafluorosilicic acid (H_2SiF_6) is formed (up to 35 %), and the acidic scrubber liquor requires neutralisation. As an alternative, H_2SiF_6 can be recovered and, where feasible, used as a feedstock in the chemical industry. The main concern about atmospheric emissions from acid scrubbing systems is hydrofluoric acid; values of <5 mg/Nm^3 HF are normally achieved. Water resulting from the polishing operations is normally treated with hydrated lime to remove fluorides and sulphates. The sludge generated from water treatment consists of $CaSO_4$ and low amounts of CaF_2 and is treated externally for a possible re-use (e.g. cement industry).

Very low emission levels can be achieved with wet scrubbers in these applications <5 mg/Nm^3 of HF. Due to the very acidic nature of the emissions, there is a high solubility in water and chemical scrubbing is unlikely to be necessary. Chemical scrubbing results in lower water usage but prevents the recovery of H_2SiF_6 from the effluent. Alternative techniques to acid polishing have been recently developed, e.g. mechanical polishing, and high-temperature polishing either with flames or lasers, but at the time of writing (2009) information concerning the application of these techniques is not available.

4.5.5 Special glass

In general, there are no significant emissions to air from standard downstream activities in this sector. TV glass production involves grinding and polishing activities but these are carried out under a liquid medium and should not give rise to any emissions to air. If TV glass or any other products undergo any dry cutting, grinding or polishing, the emissions can be controlled by extraction to a bag filter system to give dust emissions in the range of 1 – 5 mg/Nm^3. This is a very diverse sector and there may be activities at some installations, which require site-specific consideration.

4.5.6 Mineral wool

Emissions from non-melting activities in the mineral wool sector arise from four main activities: forming, curing, product cooling, and product machining and packaging. Data presented in Section 3.8.2.3 show that the emissions from forming and curing are the most significant. These emissions are largely related to the use of the phenolic resin-based binder system.

The techniques in this section have been described separately for the forming area and the curing area. This is for convenience and because the nature of the waste gases differ. However, several of the techniques are applicable in both areas and, particularly in glass wool production, it can be advantageous to combine emissions for abatement. Where this is the case, the techniques are described most thoroughly for the forming area section and cross-references are made for curing.

There are several important differences between line emissions from glass wool and stone wool processes and these are discussed in the sections relating to the techniques to which they are most relevant.

4.5.6.1 Forming area

In the forming area, the glass or stone melt is fiberised and the binder is applied. The resin coated fibre is directed onto a collection belt that is under suction. In glass wool processes, water is sprayed into the extraction ducting and into the fan. This performs two functions, the prevention of material build-up in the ducting and the removal of some particulate and gaseous components from the gas stream. Stone wool processes vary in their use of in-duct water sprays; some are comparable with glass wool plants, but many use no water sprays at all. Stone wool cupola campaigns last only a few weeks and so there is an opportunity to clean out the ducting, and water sprays are not always deemed necessary.

The forming area waste gas is likely to contain significant levels of particulate matter, phenol, formaldehyde and ammonia. The particulate matter consists of both inorganic and organic material, often sticky and with a very small particle size. Lower levels of VOCs and amines may also be detected if they are included in the binder system. Due to the nature of the process, the gas stream is slightly above ambient temperature, has a high volume and (if in-duct water sprays are used) is saturated with water. These properties, combined with the nature of the pollutants, limit the number of abatement techniques that may be applied.

The releases can be affected significantly by a number of factors but particularly:

- binder system chemistry
- fiberising technique
- operating conditions (temperature, airflow and moisture)
- level of binder applied
- the method of binder application.

The optimisation of these parameters, in conjunction with in-duct water sprays can significantly reduce process emissions. The chemistry of the binder system is one of the most important factors and has major implications for the process water system and for forming, curing and cooling emissions (see Section 2.9.1 for additional information). The binder systems vary between operators and are not generally well understood outside of the sector. These systems can be very site-specific and may need to be considered on an individual basis. The section below summaries some of the main issues.

Resin and binder chemistry considerations

Optimisation of the chemistry of the binder system and the efficiency of the method of application can have a substantial effect on the releases to the environment.

The binder also represents a high proportion of the cost of the final product. Therefore, the process operators consider developments in binder chemistry and application techniques to be highly confidential.

The binder is made up of water, phenolic resin, urea, ammonium sulphate, ammonia, silane, mineral oil, silicone oil and possibly other ingredients particular to the individual process.

The resin is essentially a phenolic resole consisting of a mixture of trimethylol phenol, dimethylol phenol, formaldehyde, minor reaction products of phenol and formaldehyde, and traces of phenol. The resin is water-based and is typically 50 % solids. An excess of formaldehyde is used in the reaction to achieve a low free-phenol level.
Some resins are amine catalysed and can give rise to significant levels of gaseous amine in the waste gas. These emissions can be virtually eliminated by using other species as catalysts in resin production. A number of substances can be used but the precise details of optimised systems are generally considered as proprietary knowledge. By using non-amine catalysed resin systems, emission levels of amines of <5 mg/Nm^3 can be achieved. If a company does not have sufficient in-house expertise to develop a non-amine catalysed resin, then such systems are readily available from specialist resin suppliers.

Urea is reacted with the resin to extend the resin and to reduce free formaldehyde levels and it also has the effect of improving the fire resistance of the final product. The urea reacts with the free formaldehyde in the resin to form methylol ureas, which in turn will react with the active sites on the phenolic resin and take part in the cross-linking mechanism during curing. The urea is acting as a substitute for phenol and results in a cheaper binder. Therefore, there is an incentive for the operator to maximise the amount of urea in the resin, up to the point where product quality or processing parameters are adversely affected.

Urea has two main drawbacks, it reduces the solubility of the resin, and it can breakdown in both the forming area and in the curing oven to form ammonia. Environmentally, the maximisation of urea usage is beneficial because it reduces formaldehyde releases, it replaces phenol, and the urea breakdown products are preferential to the phenolic derivatives and partial combustion products that would otherwise be emitted.

Ammonia plays several important roles in the binder system and allows a degree of flexibility, which is important in optimising the process as a whole. Ammonia improves the solubility of the binder, enabling more urea to be added and allowing the binder to be stored for longer. It also helps to maintain the pH of the system in the correct range and reacts with any free formaldehyde. The nature of the process is such that higher than normal releases of ammonia may occur for short periods. The effects of reducing the ammonia levels in the process can be disproportionate to the effects on the rest of the process, and higher ammonia release levels may result in lower overall emissions.

Ammonium sulphate is added to control the curing of the resin. Silane provides a vital interface between the inorganic glass and the organic binder. Silane hydroxyl groups interact with the glass oxides, and the organic functional group reacts with the resin to form a strong bond. Mineral and silicone oils are added to improve the product handling characteristics, to suppress dust formation, and to provide a degree of water repellence.

When the binder is applied to the hot glass in the forming area, the volatile components (e.g. ammonia, formaldehyde, and phenol) will be vaporised and extracted to the release point. The level of volatile releases will be a function of the amount of unreacted volatile material in the binder, the dilution of the binder, the temperature in the forming hood and the temperature of the glass. The binder is applied as a fine spray and any droplets that are not retained on the mat will be released in the extracted air. The extent of binder retention on the product will depend on droplet size distribution, the mat thickness and the level of suction applied.
Several alternatives to phenolic resin-based binders have been evaluated, but none have been found to give acceptable product quality.

4.5.6.1.1 Impact jets and cyclones

Description

An important factor in considering appropriate abatement systems for the forming area is the water content of the gas stream. The continuous nature of glass wool production requires the use of a cleaning mechanism to prevent the build-up of sticky organic material and fibre in the extraction ducting and in the fan. The normal technique applied is in-duct water spraying, which can take various forms. The discontinuous nature of stone wool cupola production (campaigns of one to three weeks) provides the opportunity to clean the ducting if required. Also stone wool production involves relatively less binder usage per unit volume of product and so the build-up is slower. Some stone wool processes utilise water sprays in the forming area, but this is largely due to operator preference or to site-specific operating requirements.

Where water sprays are used to clean ducting, it is logical to optimise their use to also clean the waste gas. In this situation, the two objectives are entirely complementary; the more material removed from the waste gas, the more effective the cleaning function. The systems have generally been adapted beyond the minimum necessary to prevent unacceptable build-up in the ducting. Within the sector, the term "impact jets" is used to describe this optimised technique.

In order to optimise the efficiency of gas cleaning, the systems can apply the water in high volume and at a high pressure, but this does not produce a significant pressure drop. The design of the impact jets will differ between processes but is intended to optimise the efficiency of the technique, for both duct cleaning and waste gas scrubbing. To remove the entrained water from the waste gas, impact jets are always combined with cyclones (or other devices), which also have an effect on particulate levels depending on the design as described in Section 4.4.1.4.

Particulate and droplet removal will occur by impaction/impingement and to a lesser extent by diffusion. Some systems may involve a narrowing of the duct to improve the removal efficiency, but the particulate removal efficiency is predominantly dependent on pressure drop, which is low for all these systems. In general, due to the low pressure drop in the system, the removal efficiency for fine particulate matter and droplets is quite low, while large particles and fibres are well removed.

Gaseous substances will be partially absorbed by contact with the water. The efficiency of gas absorption depends on the difference between the partial pressure of the gas in the waste gas stream and the vapour pressure of the gas in the liquid, the solubility of the gas in the liquid,the surface area for contact, and to a lesser extent the contact time. There will also be a condensation effect, which can be important if the waste gas is warm.

Process water is usually used for impact jets, which already contains most of the substances present in the gas stream in varying quantities. This will particularly affect the efficiency of gaseous substance removal. The recycling process water is filtered before it is reapplied but will contain significant levels of soluble materials. The system is in dynamic equilibrium, and the process water system is described later in this document.

Achieved environmental benefits

The use of impact jets and cyclones allows an easy removal of the solid material which is present in significant amount in the flue-gases of the forming area in quite large and fibrous form. However, due to a low efficiency for the removal of fine particles, cyclones and impact jets are mainly used as a pretreatment technique. The final emissions are very dependent on the binder and process water chemistry and on the amount of binder applied.

Cross-media effects

Unless another technique such as packed bed scrubbing is used, cyclones (or sometimes an alternative device) are incorporated with impact jets to remove entrained water. This is necessary to reduce water consumption and to achieve acceptable levels of plume visibility and dispersion.

Where other wet techniques are used (e.g. wet ESPs or packed bed scrubbing), impact jets are generally used upstream.

Operational data

The results that are achieved using this technique are given in Table 4.46.

Applicability

In principle, this technique is applicable to all glass wool and stone wool processes. It is not used in many stone wool plants because it is not deemed necessary for process cleaning, and could adversely affect other abatement techniques being used. For forming area emissions, impact jets and cyclones are used in approximately 90 % of glass wool plants and 10 % of stone wool plants.

Economics

Costs for this technique are given in Table 4.48 and depend largely on the airflow and plant size. The costs of the technique as an abatement measure are difficult to assess, because where impact jets are used, some form of cleaning mechanism is an inherent requirement of the process. The costs given in the Table represent the total cost for the system. There are no examples of systems being implemented just to clean ducting; they are always installed for the dual purpose. It is estimated that the gas cleaning element represents 60 % of the total cost. However, this analysis is somewhat academic, because in most Member States, completely unabated emissions would not be permitted and other abatement costs would be incurred.

Driving force for implementation

In the forming area, a significant amount of the solid material is quite large and fibrous, and this can easily be removed by the impact jets and cyclones, especially for glass wool production.

Example plants

This technique is so widely applied that it is not useful to specify example plants.

References to literature

[89, EURIMA Suggestions 2007]

4.5.6.1.2 Wet scrubbers

Description

Wet scrubbing systems can be used to control both gaseous and particulate emissions. Whilst the basic technology for both of these is similar, the design criteria for particulate or gas removal are very different. However, to keep down capital costs, wet scrubbing systems are often used to control mixed emissions of particulates and gases. The design is inevitably a compromise, but may represent BAT where separate control systems are prohibitively expensive. Wet scrubbing is a well-documented technique and only the main principles and the issues specific to this sector are discussed here.

Particle collection by liquid scrubbing occurs by three main mechanisms: inertial impaction, interception and diffusion. Trace gas removal by wet scrubbing occurs by absorption and, to a lesser extent, condensation. Absorption involves mass transfer between a soluble gas and a solvent in a gas-liquid contacting device.

The particle collection efficiency of wet scrubbers is strongly dependent on the total energy usage, particularly on the pressure drop across the collection zone. If the liquid is evenly dispersed within the scrubber, similar pressure drops will often give similar efficiencies on the same dust for quite different scrubber designs. Thus, it is not possible to design a wet scrubber which has high efficiencies on particles of 1 µm and below, and which does not have a high pressure drop. High energy scrubbers can give good collection efficiencies for particles of <0.5 µm, but the high running costs mean that alternative techniques may be more economical.

The efficiency of gas absorption depends on the difference between the partial pressure of the soluble gas in the waste gas stream and the vapour pressure of the gas in the liquid, the solubility of the gas in the liquid, the surface area for contact, and, to a lesser extent, the contact time. There will also be a condensation effect, which can be important if the waste gas is warm. Solubility obviously depends on the gas and the liquid. Water is suitable for absorbing soluble acidic gases such as hydrogen chloride, hydrogen fluoride, silicon hexafluoride, and for ammonia. Alkaline or acid solutions are suitable for absorbing less soluble gases, and in some applications, oxidising solutions can control organic odours. The surface area is determined by the packing material or droplet size.

Packed bed scrubbers consist of an outer shell which contains a bed of packing material on support grids, liquid distributors, gas and liquid inlets and outlets, and a mist eliminator. Liquid is distributed continuously over the packing material forming a film, which provides a large surface area for gas/liquid contact. The dirty gas stream flows through the packed bed and the liquid and gas flow may be countercurrent, concurrent or cross-current. There are various types of packing material, which can be packed in random or regular arrangements. The liquid film over the packing material provides a large surface area for mass transfer. Countercurrent packed bed absorbers maximise the driving force for absorption because gas leaving the packed bed encounters fresh absorbing liquid. Packed beds can become blocked by insoluble particulate matter, scale and biological growth.

In some applications, venturi scrubbers may be considered. The characteristic feature of a venturi scrubber is the constriction to the duct (venturi throat) causing an increase in gas velocity. Liquid is introduced to the scrubber and forms a film on the walls, which is atomised by the gas stream in the venturi throat. The efficiency of the venturi scrubber depends on the pressure drop, and consequently, they have high power consumption and operating costs. Venturi scrubbers are generally the most efficient wet scrubbing devices for particle collection, because they are suitable for submicron particles. They can also be used for trace gas removal, but efficiency is limited by low contact time.

The most commonly used wet scrubbers within the sector are packed bed scrubbers, usually with impact jets upstream. The impact jets remove the larger particulate matter and so help to prevent blocking of the packing. Some operators have installed ionising wet scrubbers (IWS), which are intended to combine the advantages of the low capital cost of wet scrubbers, with the low operating costs of electrostatic precipitators. The IWS is basically a packed bed scrubber maintained in a neutral charge condition and preceded by an ionising section to charge the particles. The bed is normally composed of plastic packing. Gas velocities through the bed are low so as to ensure that the particles spend as much time as possible close to the packing elements.

When the waste gas from the forming area comes into contact with water in an efficient scrubbing system, the following events will occur:

- a proportion of the entrained particulate matter, predominantly the larger particles and droplets will be held in suspension
- a proportion of any soluble resinous material will be absorbed by the water
- the volatile substances will form an equilibrium between the gaseous and aqueous phases.

Process water is the most commonly used scrubber liquor within the sector. This presents the potential problem of maintaining sufficiently low concentrations of volatile materials in the scrubbing medium to facilitate efficient absorption, and to prevent release back to the gas phase. The mineral wool manufacturing process is a net consumer of water, and the performance of the scrubber can be improved by introducing the clean water top up into the system in the scrubber. This benefit can be optimised by using a combined multistage scrubbing process with the water flowing from stage to stage countercurrent to the gas stream. In this way, the dirtiest water is used to scrub the incoming (dirtiest) gas stream and clean water is used in the final scrubbing stage.

A possible solution to the problem would be to separate the scrubbing medium from the process water system and either use clean water with a sufficiently high purge to maintain efficient absorption or chemically dose the scrubber liquor with substances that would react with the volatile species. However, there are important limitations to both of these approaches. To achieve a substantially better performance by using a clean water system, the volume of the purge would be too great to recycle to the process water system, and would give rise to a new waste stream requiring separate treatment. The volume of water coming from the impact jets would exacerbate this problem.

The water content and resinous nature of the substances contained in waste gas would cause blocking and scrubber liquor volume problems in a chemical scrubber unless a high volume purge is used. Due to the chemical content, none of this could be recycled to the process water system, again giving rise to a new waste stream requiring separate treatment. A further complication is that the chemical reagents necessary to remove phenol/formaldehyde and ammonia are incompatible and would require separate stages. Chemical scrubbing stages could be positioned in series with a process water scrubber, but this would greatly increase costs and unless it is extremely efficient, would not overcome the problems discussed. Also, when the aqueous waste stream is considered, the difference in overall emissions between such a technique and a process water scrubber with good process control is likely to be limited.

Multistage scrubbing either in a combined unit or in separate units is, in theory, a potential option for the forming area and for combined forming and curing oven emissions. However, no mineral wool processes operate multistage scrubbers and so no information is available on their environmental performance, costs or potential operating problems. Therefore, the technique cannot currently be considered to be fully available. It could, however, be considered as an option if line emissions are very high at a particular installation.

Achieved environmental benefits
The emission levels achievable with packed bed scrubbers (with process water as the scrubber liquor) in the mineral wool industry are given in Table 4.47.

Cross-media effects
An important consideration for wet scrubbers is the potential cross-media effect of creating an aqueous waste stream that requires treatment. In the mineral wool sector, this problem has been avoided by using process water as the scrubbing medium with 100 % recycling to the process water system. The use of clean water or chemical scrubbers would result in an aqueous waste stream.

Operational data
The removal efficiency is limited for particulate matter by the low pressure drop, and for gaseous substances by the use of process water as the scrubbing medium. Significantly lower emission levels for phenol, formaldehyde and ammonia would be expected with clean water scrubbing. The process water equilibrium is a critical factor and it is possible in some rare instances (e.g. a low binder product following a sustained period on a high binder product) that the efficiency of the scrubber could be negative for gaseous components.

Several operators have used ionising wet scrubbers in recent years, but overall results have been disappointing. Improvements in efficiency over packed bed scrubbers have generally been less than 10 %.

There is no experience of chemical or multistage scrubbing in this sector but experience in the chemical industry suggests that emissions of below 10 mg/Nm^3 could be readily achieved for phenol, formaldehyde and ammonia, if the associated problems could be overcome. Compared with the data shown in Table 4.47, this only represents a significant improvement for ammonia.

Applicability

In principle, packed bed scrubbers circulating process water are applicable to all processes within the sector. The technique is not limited to new plants or substantial modifications, but costs are likely to be higher for existing installations. In some applications, particularly stone wool, other techniques can be used to achieve similar or lower emission levels.

In glass wool production, slightly less than 20 % of installations use packed bed scrubbers, either for combined forming area and curing oven emissions or just for the forming area. In stone wool production, packed bed scrubbers are used for approximately 10 % of installations for forming area emissions and the same for the curing area. Emissions from the two areas are not generally combined in stone wool installations.

Economics

Costs for this technique are given in Table 4.48 and depend largely on airflow and plant size. Incorporation of an ionising stage as in the ionising wet scrubber (IWS) involves an increase in capital costs of approximately 75 %, and an approximate 10 % increase in operating costs. Multistage chemical scrubbing could be expected to cost up to twice the totals given in the table. The cost of a combined multistage scrubber would probably be more comparable to the IWS system. However, it would be necessary to completely separate the stages, which would add to the cost, and more expensive corrosion-resistant materials may be necessary.

Driving force for implementation

A benefit of this technique is the opportunity to combine the forming area and curing oven emissions in a single treatment stage. The volume of the forming area waste gas is generally ten times greater than that of the curing oven. If implemented at the design stage, the combination of the waste gases does not add substantially to the overall cost of the technique.

Example plants

Knauf Insulation, St Helens, UK
URSA, Spain
Isover Orange, France

Reference literature

[89, EURIMA Suggestions 2007]

4.5.6.1.3 Wet electrostatic precipitators

Description

The basic principles and operation of ESPs are described in Section 4.4.1.2. In wet precipitators, the collected material is removed from the plates of the collectors by flushing with a suitable liquid, usually water, either intermittently or by continuous spray irrigation. The three main types of ESPs are plate and wire, plate and plate, and tube and wire, and can all be operated wet. In plate types, the gas flow is horizontal; in tubular designs the gas flow is vertical with the liquid flow countercurrent to the gas. In some more robust designs, rods replace the wires. Some mechanism is usually installed to remove water droplets before discharge and either a demister, or sometimes the last field can be operated dry.

Whilst in general dry precipitation is preferable, wet precipitators are useful for removing dust from wet gases with temperatures close to the dewpoint and for collecting liquid aerosols and sticky materials such as resinous particles and tars. The performance of wet precipitators is less dependent on particle properties as the moisture present in the gas precipitates readily and will assist the precipitation of a difficult dust.

Tubular units are most commonly used in wet applications and it is easier to make them explosion resistant if tars are present. However, tubular units generally have only a single electrical field and are less suitable for achieving very high efficiencies.

All three types have been used in mineral wool manufacturing but the plate and wire, and tube and wire types are now preferred. Usually a deluge system is installed to extinguish fires.

At the entrance of the wet electrostatic precipitator (WESP), the exhaust gases must be well distributed to produce a uniform and low gas velocity between all elements. The waste gas is conditioned by the impact jets upstream of the ESP; large fibrous material is removed and the gas is saturated and cooled. To ensure operation within the design parameters, clean water is also used; it is sprayed at the entrance to the ESP to ensure saturation and it is used to clean the electrodes. In glass wool processes, the volume of this water is generally low enough to be discharged to the process water circuit, and may represent the main top up in the circuit. In most stone wool processes, the evaporation potential from the forming process is much less and it is not possible to use such a volume of clean water.

Achieved environmental benefits

Wet ESPs are efficient in removing particulate matter, aerosols and droplets in the size range of 0.01 to 10 µm. Performance will depend on a number of factors, particularly the gas velocity. A new purpose designed wet ESP would achieve a removal efficiency of >98 % for total particulate matter >1µm in diameter, although removal efficiency falls off rapidly for particles <1 µm. Performance may decline over the lifetime of the equipment and maintenance is very important.

In general, wet ESPs show limited efficiency at removing gaseous substances. This depends very much on the product range, and the binder and process water chemistry. However, due to the high degree of saturation and the use of a substantial amount of clean water, some absorption of gaseous substances does occur.

Data concerning an example installation producing glass wool, where a wet ESP is used in combination with a wet scrubber, a cyclone separator and a biological treatment are shown in Table 4.43.

Glass wool production - Forming area		
Production capacity: 36000 - 38000 tonnes/year		
Flue-gas volume: 191707 Nm^3/h		
Depollution system: wet scrubber, cyclone separator, suction ventilation, biological treatment with six vertical washing towers, three fields wet ESP		
	Emission levels (mg/Nm^3) (1)	**Mass flow (kg/h)**
Formaldehyde + phenol	4.3	0.82
Total organic compounds (TOC), as C	4.4	0.84
Particulate matter	21	4.03
Ammonia (NH_3)	18	3.45
HF	<0.02	<0.004
HCl	7	1.3
SO_2	~ 3	~ 0.6
NOx (as NO_2)	9.9	1.9
Copper (Cu)	0.0217	0.004
Manganese (Mn)	0.0381	0.007
Odourimetry	64 ouE/m^3	
1. Emission values from continuous measurements (average value of 4 - 6 half-hour measurements, expressed at measured 20.5 % O_2)		

Table 4.43: Solid and gaseous emissions from the forming area of a glass wool installation where a WESP is used

[112, Austrian glass wool plant 2006]

Cross-media effects

A summary of the main advantages and disadvantages associated with the use of WESPs is presented in Table 4.44.

Advantages:

- good removal efficiencies for particulates and for droplets/aerosols; <20 mg/Nm^3 achievable
- absorption of gaseous substances is possible with high saturation and clean water use
- applicable to forming and curing emissions
- low pressure drop hence relatively low operating costs and energy usage
- blockages rare if impact jets used to remove large fibrous matter
- long operating life with low maintenance

Disadvantages:

- generation of aqueous effluent; this is generally recyclable in glass wool but less so in stone wool production
- removal efficiency of gaseous substances is generally low
- energy is consumed, but this is relatively low compared to other process requirements
- when high concentrations of CO are present (e.g. stone wool production), it may not be applicable
- relatively high capital costs
- substantial space requirements
- maintenance is low but critical; poor maintenance causes a considerable drop in performance
- high voltage imposes safety requirements.

Table 4.44: Main advantages and disadvantages of wet electrostatic precipitators (WESPs)

Operational data

The results that can be achieved using this technique are given in Table 4.47.

Applicability

In principle, the technique is applicable to new and existing glass and stone wool processes. The main disadvantage for stone wool is the potential difficulty of disposing of the aqueous effluent stream. The technique is suitable for both forming area and curing oven emissions, and for combined emissions. In 1997, approximately 30 % of glass wool installations were using this technique for either separate or combined forming and curing oven emissions. No stone wool plants were operating WESPs.

Economics

Costs for this technique are given in Table 4.48 and depend largely on airflow and plant size.

Driving force for implementation

The accomplishment of the legal emission limits is, in general, the main driving force for implementation. Issues related to ambient air quality could also determine the need to apply this technique.

Example plants

Knauf Insulation, St Helens, UK
Saint Gobain Isover G + H AG, Germany
Saint Gobain Isover Etten-Leur, Netherlands
Saint Gobain Isover, Stockerau, Austria

References literature

[89, EURIMA Suggestions 2007]

4.5.6.1.4 Stone wool filters

Description

Conventional passive filtration processes (e.g. bag filters) are unsuitable for treating the waste gases from the forming area and curing oven operations.

The adhesive and sometimes moist nature of the waste gas would lead to rapid blinding, even with intensive cleaning and maintenance. In stone wool activities where forming processes are often dry, stone wool slab filters can be employed. These consist of a steel or concrete housing in which stone wool slabs mounted on cassettes act as a filtration medium. This type of filter has good removal efficiency for particulate matter and binder droplets, but has a low efficiency for the removal of gaseous components. The filtering medium needs to be exchanged periodically in order to maintain particulate removal efficiency and to prevent increased resistance to the airflow. The used filter slabs can usually be recycled to the furnace if a briquetting process exists on site.

Operation can be on a semi-dry basis, but overall efficiency is greatly improved if the operation is dry. Neither system generates an aqueous waste stream and the moist filter slabs can also be readily recycled through a briquetting process.

An earlier version of this design was based on a tower filter with stone wool rolls as the filter medium. This technique is less efficient and has been largely superseded by the slabs mounted on cassettes design. The tower filter design was more suitable for waste gases with more moist, higher binder content but could not handle waste gases treated with impact jets.

Achieved environmental benefits

Stone wool filters are very efficient in removing particulate matter and droplets/aerosols. The emission figures that can be achieved using this technique are given in Table 4.47. The technique does not have a significant effect on gaseous substances, but in combination with primary controls (e.g. dry operation) and low aerosol emissions, the levels shown in the table are achieved. This also leads to very low plume visibility from this type of filter.

Cross-media effects

A summary of the main advantages and disadvantages associated with the application of stone wool filters is presented inTable 4.45.

Advantages:

- good removal efficiencies for particulates; <20 mg/Nm^3 is achievable
- used filter slabs can be recycled to the process if facilities are available
- no aqueous waste is generated
- low capital costs
- low pressure drop hence relatively low operating costs and energy usage

Disadvantages:

- energy is consumed, but this is relatively low compared to other secondary techniques
- limited removal efficiency for gaseous substances
- not considered applicable for glass wool processes

Table 4.45: Main advantages and disadvantages of stone wool filters

Operational data

No information submitted.

Applicability

This technique was mainly limited to stone wool process forming areas, although it is applied more and more in stone wool curing ovens (see Section 4.5.6.2.5). The technique is applicable to both new and existing stone wool processes.

More than 90 % of stone wool processes use this technique for treating forming area waste gases, about 30 % use it for curing oven emissions, and nearly 40 % use it for the treatment of cooling gases. The limited use in the past for stone wool curing ovens was partly due to the high temperature of the gas, and partly due to the widespread use of incineration. However, currently, the use of a passive stone wool filter may be considered a preferable technique for curing ovens.

There are no known applications of the technique in glass wool processes. The main reasons the technique is not used in glass wool processes are discussed below.

The continuous nature of glass wool production requires the use of a continuous cleaning mechanism to prevent material build-up in the extraction ducting and in the fan. The normal technique applied is impact jets. These are not generally used in stone wool production, because the discontinuous nature of the process provides the opportunity to clean the ducting. Also,stone wool production involves relatively less binder usage and so the build-up of material is slower.

In the stone wool process, fibre is usually collected as a mat of constant thickness, which is then layered on a separate forming conveyor to give the desired product properties. The primary mat is thin, imposes only a small, constant pressure drop and enables a single and relatively low volume extraction system to be used. In glass wool manufacturing, a single conveyor forming system is used. The mat thickness increases along the forming conveyor and varies depending on the product. The change in differential pressure along the conveyor necessitates the use of several extraction systems of different capacities and the overall air extraction must have reasonably high pressure and be variable and controllable. The level and distribution of extraction is an important process control tool, which is frequently varied by process operators. The variable higher volume and higher pressure conditions of the glass wool waste gas are not ideal for filtration systems.

The water saturated high binder content of glass wool forming area waste gas would cause the stone wool filter to block rapidly. This would necessitate frequent filter medium changes and would give rise to a high level of wet waste requiring recycling or disposal.

A further complication with the use of mineral wool filters in glass wool processes is the greater difficulty in recycling the material to the furnace. Recycling fibrous wastes in mineral wool furnaces is discussed in Section 4.7.

Economics

Costs for this technique are given in Table 4.48 and depend largely on airflow and plant size. Capital costs are particularly low, and the low pressure drop leads to low operating costs compared to other conventional filter systems.

Driving force for implementation

Stone wool filters are very efficient in removing particulate matter and droplets/aerosols with relatively low investment and operating costs and low energy usage.

Example plants

Rockwool Lapinus, Roermond, Netherlands
Partek Rockwool AB, Hällekis, Sweden

Reference literature

[89, EURIMA Suggestions 2007]

4.5.6.2 Curing oven

The wet product mat enters the oven which is at approximately 250 °C. The moisture is driven off along with any volatile material, and the binder begins to cure. The temperature and residence time in the oven is critical.

The binder must be adequately cross-linked but not over cured or the product quality will suffer. The emissions from the oven will consist of volatile binder materials, binder breakdown products and combustion products from the oven burners. In general, glass wool products contain relatively higher binder levels than stone wool products, resulting in higher emissions. Oven emissions also tend to be odorous if not treated.

The oven is usually gas-fired and under extraction. Oven emissions are sticky and represent a potential fire risk due to the deposition of combustible material in the extraction system, particularly in glass wool ovens. To prevent fires, the gas stream must either be water scrubbed or additional heat provided to destroy the sticky nature of the pollutants. In those processes without incineration, water is usually sprayed into the extraction ducting to prevent the build-up of resinous material, and to prevent fires. The water sprays will also remove some of the material entrained in the gas stream.

4.5.6.2.1 Impact jets and cyclones

Description
The technique is described in Section 4.5.6.1.1 above, but there are several other issues that should be considered. The waste gas from the oven has a much lower volume and a higher temperature than the forming area waste gas. Therefore, particularly in glass wool processes, the build-up of resinous material in the ducting represents a risk of fire and even explosion. The water sprayed into the gas has a substantial cooling effect and some substances are condensed from the waste gas. This does not necessarily mean the substances are removed and in the early parts of the system, material will be volatilised from the dirty process water.

Achieved environmental benefits
Due to the low pressure drop in the system, the removal efficiency for fine particulate matter is quite low; however, the use of impact jets and cyclones promote condensation of some substances, avoiding the build-up of residues in the ducting and the risk of fire, with consequent atmospheric emissions. As in the forming area, the system is a dynamic equilibrium and gaseous emissions are heavily dependent on the process water and binder chemistries.

Cross-media effects
Unless another technique is used to remove entrained water (e.g. packed bed, cyclone, demister), this technique can lead to high water consumption and emissions of mists.

Operational data
The emission levels that are achieved using this technique are given in Table 4.47.

Applicability
As for the forming area, in principle, this technique is applicable to all mineral wool processes. It is not used in many stone wool plants because it is not deemed necessary for process cleaning, and could adversely affect the performance of other techniques. Impact jets and cyclones are extensively applied for curing ovens in approximately 90 % of glass wool plants, often for combined forming and curing flue-gases. The technique is used as a pretreatment in conjunction with other techniques.

Economics

Costs for this technique are given in Table 4.48 and depend largely on airflow and plant size. The issues relating to how much of the cost can be considered as an abatement cost are the same as for the forming area.

Driving force for implementation

Particularly in glass wool processes, the build-up of resinous material in the ducting represents a risk of fire and even explosion. The water sprayed into the gas has a substantial cooling effect and some substances are condensed from the waste gas.

Example plants

This technique is so widely applied that it is not useful to specify example plants.

Reference literature

[89, EURIMA Suggestions 2007]

4.5.6.2.2 Wet scrubbers

The technique is described for the forming area in Section 4.5.6.1.2, and the discussion is equally applicable to oven emissions. The main considerations for curing oven emissions treated by wet scrubbers are that the volume is much smaller and pollutant concentrations differ; in general, particulate matter is lower, phenol is comparable but ammonia and formaldehyde are significantly higher.

The emission levels achievable with packed bed scrubbers (with process water as the scrubber liquor) in the mineral wool industry are given in Table 4.47 (see Section 4.5.6.1.2 for discussion). Oven emissions are relatively higher in gaseous emissions compared to forming area emissions, so the overall efficiency may be higher. Again, this will depend on the amount of clean water used and the binder and process water chemistry.

The costs for this technique are given in Table 4.48 and depend largely on airflow and plant size. The costs given are for combined forming and curing emissions. Most examples of curing oven emissions treated by wet scrubbers are for combined emissions, and due to the low volume, the extra cost is usually low. The variation in the cost given is largely related to airflow and a rough estimate for treating the curing oven emissions alone can be made by scaling down the cost, but the cost relationship is not linear.

In principle, the technique is applicable to all plants (see Section 4.5.6.1.2 for discussion).

4.5.6.2.3 Wet electrostatic precipitators

The technique is described for the forming area in Section 4.5.6.1.3, and the discussion is equally applicable to oven emissions. The use of wet electrostatic precipitators (WESPs) to treat only oven emissions is not common and usually systems are for combined emissions. Due to the higher relative concentrations of gaseous and odorous substances in oven waste gas, a WESP would not be the first choice of abatement technique for oven emissions alone. However, when combined with forming area emissions and the inherent dilution this involves, a WESP can be a logical option.

The emission levels achieved with this technique are given in Table 4.47 and the costs in Table 4.48. In principle the technique is applicable to both new and existing installations.

4.5.6.2.4 Waste gas incineration

Description

Incineration is widely used for controlling organic emissions from industrial processes. It has the disadvantages of destroying the material (preventing recovery), often requiring energy addition and producing carbon dioxide and oxides of nitrogen. However, it can be designed to be energy efficient and may form an integrated part of the heat supply to drying or curing operations. Incinerators can be of two types: thermal incinerators (>750 °C), or catalytic incinerators (350 to 400 °C).

Thermal incineration destroys organic compounds by thermal oxidation to carbon dioxide, water, oxides of sulphur and nitrogen, and other combustion products. The main requirements for effective combustion are:

- residence time in the combustion chamber must be sufficiently long to ensure complete combustion. Destruction efficiency of 99 % will usually require a residence time of 1 to 4 seconds at the relevant temperature
- the operating temperature should be 200 – 400 °C above the auto-ignition temperature of the most stable substance; typical operating temperatures are around 800 °C. Where the gas stream contains chlorinated and aromatic substances, temperatures must be increased to 1100 - 1200 °C, and rapid flue-gas cooling is required to prevent the formation of dioxins
- turbulence is necessary to provide efficient heat and mass transfer in the combustion zone, and to prevent "cool spots". This is usually achieved by using burners that generate a swirling combustion flame and by incorporating baffles in the combustion chamber.

Catalytic incineration is unlikely to be a practicable option in this sector, because the high particulate loading and the presence of resinous materials would lead to catalyst poisoning.

Achieved environmental benefits

Incineration is an effective technique for removing organic substances from waste gas streams, but does not reduce inorganic particulate matter. Incineration uses energy and gives rise to emissions of CO_2 and nitrogen oxides, which in the quantities emitted may be considered preferable to the substances destroyed and can increase the amount of energy to be recovered from the flue-gases. The waste gas from curing ovens also contains ammonia and other substances containing nitrogen, which are partially oxidised to produce nitrogen oxides. A well designed incinerator will reduce total organic compounds to below 10 mg/Nm^3.

Cross-media effects

A summary of the main advantages and disadvantages associated with the application of waste gas incineration is presented in Table 4.46.

The energy consumption associated with the use of waste gas incineration is equivalent to 200 m^3 gas per kg phenol and formaldehyde removed, or 20 m^3 per kg of ammonia removed. The consequent increase of CO_2 emissions is estimated at about 400 kg per kg phenol/formaldehyde and 40 kg per kg ammonia.

Advantages:

- high efficiency for destruction of organic pollutants and odours
- no aqueous or solid waste is generated

Disadvantages:

- energy consumption is high. The energy of the flue-gas should be recovered as far as technically possible
- carbon dioxide and oxides of nitrogen are emitted. Part of the ammonia is converted into nitrogen oxides
- no removal efficiency for inorganic particulate matter
- significantly higher costs than combined treatment with forming emissions, where possible.

Table 4.46: Main advantages and disadvantages of waste gas incineration
[89, EURIMA Suggestions 2007]

Operational data

The emission figures that can be achieved using this technique are given in Table 4.47.
Data concerning the energy consumption associated with the use of waste gas incineration are not available.

Applicability

At the time of writing (2009), the technique is only used to treat emissions from stone wool curing ovens, and 60 – 70 % of installations use this technique. Alternative options are described below.
Due to the high volume, low concentration, low temperature, and sometimes high moisture content, the technique is considered to be prohibitively expensive for the forming area waste gas. In principle, the technique is equally applicable to new and existing processes.

For both glass and stone wool, there is usually the option to combine curing oven emissions with forming area emissions for treatment by a single technique, which is often much more economical. In principle, there is no technical reason why glass wool curing oven emissions cannot be abated by incineration. However, it may not represent the most cost-effective solution.

Economics

Costs for waste gas incineration are given in Table 4.48 and depend largely on airflow and plant size. The economics of incineration depend greatly on the opportunities for heat recovery. The costs depend on a number of factors, but particularly:

- volume of waste gas to be treated which determines the dimensions of the combustion chamber
- temperature of the waste gas which affects the design of the combustion equipment and auxiliary fuel requirements
- the calorific value of the gas which affects the auxiliary fuel requirements
- combustion temperature which determines the construction materials
- instrumentation
- heat recovery options
- the installation requirements; indoor, outdoor, ground level, rooftop, etc.

Driving force for implementation

The accomplishment of the legal emission limits for organic emissions and issues related to odour complaints from local residents may represent the driving force for implementation.

Example plants

Rockwool Lapinus, Roermond, Netherlands
Partek Rockwool AB, Hällekis, Sweden
Owens Corning, Queensferry, UK

Reference literature

[89, EURIMA Suggestions 2007]

4.5.6.2.5 Stone wool filters

Description

Stone wool filters can be used as a combined filtration system for the waste gases from forming and curing areas or as a separate filter from the curing area alone. A detailed description of the technique is given in Section 4.5.6.1.4.

Achieved environmental benefits

The filters will reduce organic and inorganic particulates effectively, but will not reduce gaseous emissions significantly. This will lead to increased emissions of organic components plus ammonia from the binder, but the energy consumption and the emissions of nitrogen oxides and CO_2 will be reduced compared to an incinerator. The increased emissions of binder components are normally insignificant compared to the emissions from the forming area.

Cross-media effects

The stone wool filter will retain most of the particulates, organic and inorganic, but the gaseous components are only slightly reduced.

Operational data

The results concerning the use of stone wool filters are shown in Table 4.47, in comparison with other abatement techniques.

Applicability

Stone wool filters are used to treat emissions from stone wool curing ovens as an alternative to waste gas incinerators.The particulate concentration in the curing off-gas is normally very low, so several existing plants use only primary measures and a stack to treat the off-gas from curing ovens. The stack can either be a separate or a combined forming/curing stack.

Economics

Costs for this technique are given in Table 4.48 and depend largely on the waste gas volume and plant size.

Driving force for implementation

The accomplishment of the legal emission limits for organic emissions may represent the driving force for implementation.

Example plants

No information submitted

Reference literature

[89, EURIMA Suggestions 2007]

4.5.6.3 Product cooling

A large quantity of air (typically from 10000 to 40000 m^3/h) must be passed through the product to cool it to an acceptable temperature after leaving the oven. This gas is likely to contain fibre, particles of cured binder, and low levels of organic fumes that may be odorous. This gas stream is not a major issue within the sector but it can cause local problems. There are three main methods for treating the gas, examples of all are found in the sector and all are accepted as available and affordable. All three can achieve relatively low emission levels and the preferred option will depend on local circumstances. In some cases, if emissions are very low, secondary abatement may not be necessary. The three techniques are:

- use of a filter system to remove dust combined with a sufficient discharge velocity and height to avoid ground level odours
- use of a wet scrubbing system combined with adequate dispersion. A venturi type system would give the lowest particulate and fume emissions
- combining the cooling air with the forming area or the curing oven waste gas treatment system.

The combination option is probably the most environmentally and economically efficient method.

4.5.6.4 Product machining and packaging

Mineral wool processes involve a number of product trimming, cutting and slitting operations, which generate dust emissions. The accepted way of treating these emissions is by efficient collection and extraction, and then the extracted air is passed through an efficient dust removal system, usually a bag filter.
Packaging operations are also potential sources of dust releases and should be treated in the same way.

Gas volumes from these operations can vary widely (from 5000 to 70000 m^3/h). In order to minimise capital and operating costs of abatement equipment, the extracted air volumes should be reduced to the minimum commensurate with good dust collection.

4.5.6.5 Odours arising from mineral wool production

Technical odour assessment is difficult, expensive and potentially subjective, and there is little information available. However, mineral wool installations can be the source of odour complaints from local residents. This problem has declined in recent years due to improved operation and control but is still an issue for many installations. This section discusses odours from all parts of the process including melting.

Conventional air-gas-fired, and oxy-gas-fired furnaces do not usually give rise to odour problems, even when recycled material is melted, due to the high temperatures. Cold-top electric melters rarely cause odour problems but can if mineral wool waste is being recycled. Binder materials can undergo partial thermal breakdown during the melting process, and some odorous substances may be emitted. This problem can be minimised by the addition of oxidising agents or pretreatment of the fibre.

Cupola melting gives rise to significant emissions of odorous hydrogen sulphide. The accepted solution to this is combustion in an afterburner system, which also deals with any other odorous emissions from recycled material or raw materials.

The main sources of odour are from the downstream operations, particularly forming and curing. Odours can also arise from product cooling, particularly from dense or high binder products or if a degree of over-curing has taken place. Odour from the individual chemicals used in the process is not considered to be very significant. Odour results predominantly from the chemical and thermal reactions of the organic binder used in the process. The characteristic smell is of 'burned bakelite'. Complaints of formaldehyde or ammonia odours are very rare outside of the plant.

Most odours are thought to arise from the curing oven, where the main chemical reactions and thermal processes take place. The drying process will also give rise to a certain amount of steam distillation of binder compounds and intermediates. The inside of most curing ovens shows a build-up of fibrous and resinous material which may also give rise to odorous compounds under the influence of the oven temperature. Small fires and localised instances of smouldering are also not uncommon in curing ovens and the smoke and fume emitted can be very odorous.

Instances of odour can be greatly reduced by good oven maintenance and cleaning, wet scrubbing systems, adequate dispersion and provision for the rapid extinguishing of any fires. Incineration of curing oven waste gases is a very effective solution to the problem.

The forming area activities can also result in the formation of odorous compounds particularly when the binder is sprayed onto the hot fibres. However, the atmosphere is cooler and therefore more moist than the curing oven, and the gas volumes are very much higher and concentrations of any odorous compounds are diluted. Although a significant mass of odorous compounds can be emitted from the forming area, an odour only "exists" if the compound is in a concentration above the odour threshold, and so forming area emissions are generally less odorous than curing oven emissions. If forming area emissions do give rise to odours, they can be minimised by wet scrubbing and adequate dispersion. Problematic odours can be addressed by wet scrubbing using an oxidising agent, but this would have to be separate from the process water system. The issues of chemical wet scrubbing are discussed in Section 4.5.6.1.2.

Emissions (1)								
(Substance)	**Particulate**	**Phenol**	**Formaldehyde**	**Ammonia**	**NO_X**	**CO_2**	**VOCs (4)**	**Amines (4)**
Process/technique	mg/Nm^3 (kg/tonne product)	mg/Nm^3 (kg/tonne product)	mg/Nm^3 (kg/tonne) product)	mg/Nm^3 (kg/tonne) product)	mg/Nm^3 (kg/tonne product)	mg/Nm^3 (kg/tonne product)	mg/Nm^3 (kg/tonne product)	mg/Nm^3 (kg/tonne product)
Combined fiberising, forming and curing								
Cyclone	15 (0.6)	2 (0.08)	1 (0.04)	10 (0.4)			14 (0.56)	
Impact scrubber + cyclone	9 - 64 (0.6 - 3.2)	0.4 - 14 (0.03 - 0.8)	0.7 - 6.4 (0.06 - 0.25)	8 - 61 (0.36 - 5.0)			3 - 28 (0.13 - 1.7)	
Impact scrubber + cyclone + WESP(2)	19 (1.21)	7.0 (0.46)	3.6 (0.269)	56 (3.6)			20.3 (1.43)	
Impact scrubber + cyclone + settling chamber	18.1 (0.65)	1.31 (0.0465)	3 (0.1)	48.8 (1.81)		5236 (194)	23.7 (0.89)	
Stone wool filter (3)	18.3 (0.8)	18.8 (0.7)	6.5 (0.23)	39.3 (1.41)	48 (2)			
Combined fiberising and forming								
Cyclone	14.5 (1.11)	1.88 (0.14)	1.65 (0.13)	19.5 (1.49)			9.3 (0.71)	
Impact scrubber + cyclone + PBS(2)	11 (0.35)	0.75 (0.024)	1.4 (0.044)	30.9 (0.97)	2 (0.06)		20.7 (0.65)	
Stone wool filter (3)	7 - 44 (0.15 - 1.2)	0.5 - 14 (0.01 - 0.25)	0.7 - 5.4 (0.017 - 0.14)	6.7 - 64.2 (0.18 - 1.4)	70.4 (2.75)			0.08 (0.0016)
Curing alone								
Cyclone	81 (0.33)	1.02 (0.0043)	1.4 (0.018)	125 (0.84)			14.4 (0.08)	
Impact scrubber + cyclone + PBS(2)	1.9 (0.0048)	0.18 (0.0005)	0.03 (0.00007)	44.3 (0.11)			42.7 (0.11)	
Waste gas incineration (3)	3 - 29 (0.01 - 0.16)	0.2 - 30 (0.0004 - 0.1)	0.22 - 7.1 (0.001 - 0.06)	6 - 90 (0.05 - 0.24)	45 - 204 (0.08 - 1.3)	16000 - 18000 (35 - 81)		0.07 (0.0002)
Stone wool filter (3)	11 (0.25)	5.85 (0.019)	5.4 (0.022)	65 (0.28)	34 (0.12)			
Incineration + stone wool filter(4)	13.5 (0.03)	1.2 (0.004)	5 (0.011)	83 (0.26)	225 (0.3)			0.3 (0.001)
Cooling								
Cyclone	12.5 (0.04)							
Stone wool filter (3)	4 - 50 (0.02 - 0.41)	5.5 (0.047)	3.89 (0.02)	18.3 (0.08)	43.3 (0.12)			

1. Emission data given as a range refer to a significant number of measurements (min. 9, max. 23). Single emission data refer to the average value of a limited number of measurements (min. 1, max. 4).
2. WESP= Wet Electrostatic Precipitator; PBS = Packed Bed Scrubber
3. These techniques apply only to the stone wool production
4. Available data are limited

Table 4.47: General achievable values for emissions to air from non-melting activities in the mineral wool sector, applying different techniques [89, EURIMA Suggestions 2007]

Abatement technique	Installation capacity (tonnes/day)	Investment cost (M EUR) (1)	Operating cost (M EUR per year) (2)	Specific cost (EUR/tonne) (2)
Forming + curing				
Impact scrubber + cyclone	50	1.1	0.15	16.5
Impact scrubber + cyclone + WESP	150	4.4	0.6	23.5
Impact scrubber + cyclone + wet scrubbers	100 - 150	2.3	0.5 (100 t/d) 0.62 (150 t/d)	18.5 (150 t/d) 20.5 (100 t/d)
Stone wool filters	150 - 350	0.9 (200 t/d)	0.86 (200 t/d)	16 (200 t/d)
Forming + curing + cooling				
Impact scrubber + cyclone + wet scrubbers + WESP	250	7.6	0.95	21
Dry + wet scrubbers + WESP (3)	250	13.7	0.73	28.5
Forming + cooling				
Stone wool filters	150	1.3 - 4.3	0.4 - 0.55	17 - 18.5
Forming only				
Impact scrubber + cyclone	25	0.8	0.16	29
Cross flow scrubbers	100	3.1	0.15	15.5
Stone wool filters	150 - 350	1.0 (150 t/d) 8.4 (350 t/d)	0.55 - 0.6	8.5 - 17
Curing only				
Stone wool filter + afterburner	150 - 200	0.8 - 1.3	0.2 (recycling) 0.4 (disposal)	5.5 (recycling) 14.5 (disposal)
Curing + cooling				
Waste gas incineration (afterburner)	150 - 350	0.6 - 1.3 (150 - 250 t/d) 3.5 (350 t/d)	0.3 - 0.6	5.5 - 14

1. Investment costs include site preparation
2. Operating and specific costs are based on total recycling of the filter dust, unless otherwise specified.
3. In the case of dry and wet scrubbers + wet electrostatic precipitator: investment costs include the wash-water recycling plant; specific costs exclude associated costs of the wash-water recycling plant.

Table 4.48: Investment and operating costs of abatement techniques for non-melting activities in the mineral wool sector

[115, EURIMA-ENTEC Costs evaluation 2008]

4.5.7 High temperature insulation wools

The principal environmental concern from non-melting activities related to the High Temperature Insulation Wool (HTIW) sector is the release of particulate matter to the air which may include high temperature insulation wool itself. In addition, some secondary processing operations may give rise to VOC emissions, especially during drying and curing operations.

Particles and fibrous dust emissions can be generated from a number of areas within the process; these include: fiberisation and collection, needling, lubricant burn-off, slitting, trimming, cutting, packaging, and areas of secondary processing.

The technical possibilities for reducing emissions from downstream activities are normally based on the filtration of particulates with dedicated filters close to the source of release, where flue-gases are conveyed.

During the production of fibres, a lubricating agent is added to reduce the friction between the individual fibres. Following fiberisation, the individual fibres are laid onto an air-permeable mesh belt made of woven wire in the fibre collection chamber with the help of suction.

The dust-laden gases are conveyed pneumatically through a pipeline into a fabric filter (dry separator) where the dust is removed. The fabric filters are cleaned pneumatically at certain intervals. The removed fibres and fibre dust are packed in sealable polyethylene bags and used partly as raw material for the vacuum-formed products or in alternative material recycling.

As a result of the softening process, the dust emissions during needling of the web/mat are reduced. The dust produced at the needling machine is extracted directly at the machines. The extracted air is cleaned in filter separators. To remove the organic softening agent, the needle mat undergoes thermal treatment prior to further processing. The waste and strips produced during trimming and any dust produced are extracted by suction, fed to a press in a closed system and packed as a product in polyethylene (PE) bags. Before the mat is packed, it passes through a cooling zone in which ambient air is sucked through the mat to cool it down. Any dust produced in this process is collected in filtering separators. The material removed in all systems is used as a raw material for vacuum-formed parts or boards.

All areas where particulate or fibrous dust release may be generated can be served by an efficient extraction system that vents to a fabric filter system. A well-designed and efficiently operated primary filtration system is capable of achieving emission levels in the range of 1 - 5 mg/Nm^3 (<1 mg/Nm^3 for fibres).

Where a process relies on primary filters, some form of bag failure device will provide a safeguard. Many plants are fitted with alarmed pressure drop monitors, but these cannot be relied on exclusively.

Filter systems with the extraction fan installed on the clean side of the fabric filter (negative pressure systems) are usually the preferred option. Positive pressure systems, with the fan on the untreated side may lead to leaks in the system downstream of the fan that could result in the release of material.

Cleaning cycles for fabric filters can be optimised to ensure maximum filtration efficiency. In some applications, particularly those involving fibrous releases, shaker mechanisms can be more effective than reverse jet systems. Due to the nature of the collected material, it is important to ensure that it is handled and disposed of in a manner which prevents any release to the air or to water. In some cases it may be possible to recycle the collected material to the furnace.

Organic releases can be generated during lubricant burn-off or from curing or drying operations during secondary processing. Operational experience has shown that these releases tend to be very low. However, if emissions are significant (e.g. >100 g/hour) they can be controlled either by primary formulation measures or by standard abatement techniques, e.g. incineration or absorption.

4.5.8 Frits

Frits production does not present any significant specific emissions to air from downstream activities. Product grinding and milling is usually carried out wet, but dust control measures may be necessary if dry milling is carried out and potentially in dry product packaging areas. The most effective technique is likely to be extraction followed by a bag filter system.

4.6 Techniques for controlling emissions to water

In general, emissions to water are relatively low and there are few major issues that are specific to the glass industry. This document does not cover those general water pollution issues that are common to many industrial processes and which are discussed in great detail in the technical literature. This section briefly summarises the general issues and, where appropriate, provides further information on those issues that are specific to the glass industry. In general, water is used mainly for cleaning and cooling and can be readily recycled or treated using standard techniques. The main potential sources of water pollution are identified below.

- surface water drainage
- spillages or leaks from raw material storage
- drainage water from areas contaminated with liquid or solid materials
- water used for product cleaning
- cooling water and cooling water blow down from closed circuit systems
- wet scrubber effluents.

Excluding domestic waste water, discharges generally only contain glass solids, some oil contamination, some soluble glass making materials (e.g. sodium sulphate) and cooling water system treatment chemicals. Where any potentially harmful materials are used, measures can be taken to prevent them from entering the water circuit. Wherever practicable, closed cooling systems can be used and blow down minimised. Standard pollution control techniques can be used to reduce emissions further if necessary; for example, settlement, screening, oil separators, neutralisation, and discharge to municipal waste water schemes.

Standard good practice techniques can be used to control emissions from the storage of liquid raw materials and intermediates such as:

- provision of adequately sized containment (bunding)
- inspection/testing of tanks and bunding to ensure integrity
- overfill protection (cut off valves, alarms, etc)
- positioning of vents and filling points within the bund or other containment.

The issues considered specific to the glass industry are:

- mineral wool process water systems
- continuous filament glass fibre effluent
- special glass (TV glass)
- domestic glass (lead crystal, crystal glass).

Mineral wool

Mineral wool processes are, under normal circumstances, net consumers of water with substantial amounts of water vapour emitted to air from the forming and, to a lesser extent, the curing operations. There are no inherent waste water discharges except the general issues mentioned above. Most processes operate a closed loop process water system (see Figure 2.11), and, where practicable, cooling water blow down and cleaning waters are fed into that system. Process cleaning waters and binder spillages are usually recycled to the process water circuit.

The process water system has a limited volume but can be designed to include a holding tank to accommodate volume overloads, which can then be bled back into the system. Most of the materials used in the process are compatible with the process water chemistry. Small amounts of contaminated waste water may arise from chemical bunds, spillages and oil interceptors. Where such materials are not compatible with the process water system, they can be routed to a holding tank. Due to the very low volumes of these materials, they are usually disposed of to municipal waste water sewers or sent for off-site disposal. The techniques listed in Table 4.49 could be used but are unlikely to be economical for these very small volumes.

The large volume of the process water system represents a potential for contamination of clean water circuits such as surface water and cullet quench water. Systems can be designed and operated to minimise this risk. For example, clean water systems should be sealed where they pass through areas where contamination may occur.

Continuous filament glass fibre

Emissions arise from the forming area, binder preparation, cleaning, cooling, tissue/mat binder application, and from water-based scrubbing systems. The main source of emissions is the forming area. Due to the high speed of the winders and movement of the filaments during the forming process, a proportion of the applied binder is thrown off and squeezed out. The main pollutants in the untreated waste water are the binder materials themselves. Careful handling procedures, particularly in the binder preparation area, can significantly reduce emission levels from the overall production processes.

The pollutant species and concentrations will vary quite widely due to the variations in binder systems and operating practices. The waste water pollutant concentrations are sometimes quite low due to the dilution by wash down water, but they usually contain high levels of organic pollutants arising from binder materials. The effluent will usually require treatment either by discharge to municipal sewers or by treatment on site using an appropriate combination of the techniques listed in Table 4.49. If the effluent is to be disposed of directly to a watercourse, the most effective on-site treatment is likely to be biological treatment. However, careful design and operation of the treatment system is required because the effectiveness of biological treatment is sometimes compromised due to low concentrations and the high proportion of polymeric species.

Special glass

The special glass sector is very diverse and it is not possible to identify all potential emissions to water and the abatement techniques that are appropriate. Most of the activities in this sector only involve the general waste water issues described above. However, the manufacturing of certain products, particularly TV glass and optical glasses involves wet grinding or polishing operations. This gives rise to an aqueous stream containing the grinding and polishing aids (e.g. cerium oxide, silicon carbide) and fine glass that may contain lead. This waste stream can be treated by a combination of the standard solids removal techniques listed in Table 4.49 below. The lead in the glass is essentially insoluble and the total lead content will depend on the solids content.

Domestic glass

In general, the domestic glass sector has very low emissions to water. In common with other sectors in the industry, the major water uses include cooling and cleaning, and aqueous emissions will contain the cooling water system purges, cleaning waters and surface water run-off. However, certain activities, in particular the production of lead crystal and crystal glass have more specific associated emissions, namely:

- water used in cutting operations contains cutting aids and quantities of fine glass particles. This effluent can be treated using standard solids separation techniques. The water can be re-used for cutting to minimise emissions levels, although a small volume would have to be bled off from the circuit. The lead contained in the glass is essentially insoluble

- in the case of acid polishing, after dipping in acid, the glass has a layer of lead sulphate on the surface. This is washed off with hot water which will become acidic and will contain soluble lead sulphate. This effluent can be treated by a combination of chemical and physical techniques. The lead sulphate can be reacted to precipitate out the lead (e.g. with calcium carbonate to give lead carbonate) which can then be removed, usually by coagulation and flocculation followed by a physical separation. Using these techniques it should be possible to reduce lead levels to <0.5 mg/l
- the acidic waste from the wet scrubbers will require neutralisation before discharge. Alternatively, hexafluorosilicic acid can be recovered and sold as a chemical feedstock.

A list of possible techniques for waste water treatment is shown in Table 4.49.

Physical/chemical treatment	
• screening • skimming • settlement • centrifuge • filtration	• neutralisation • aeration • precipitation • coagulation and flocculation
Biological treatment • activated sludge • biofiltration	

Table 4.49: List of potential waste water treatment techniques for use in the glass industry

4.7 Techniques for minimising other wastes

A characteristic of the glass industry is that most of the activities produce relatively low levels of solid waste. Most of the processes do not have significant inherent by-product streams. The process residues consist of unused raw materials and waste glass that has not been converted into the product. The main process residues encountered in the glass industry and the techniques used to control them are discussed below.

Waste batch materials

These arise from materials handling and storage and, where quality requirements allow, can be readily recycled to the process. In cases where material has built up, it may not be of sufficient purity to recycle, but the amount of this type of material can be minimised by the techniques described in Section 4.3.

Dust collected from waste gas streams

In most cases dust collected from the waste gas streams can be recycled to the process. Where acid gas absorbents are used, they can usually be chosen to be compatible with raw materials to enable recycling although the batch composition may have to be adjusted. This issue is discussed further in Section 4.4.1.

The use of filter dust in the batch formulation can be a source of long-term problems, due to carryover and potential corrosion of the refractory materials, and short-term problems related to the accumulation of sulphur in the flue-gases.

In regenerative furnaces, a substantial amount of dust is deposited in the regenerators during the furnace campaign. During the rebuild/repair, this material is dug out and disposed of to an appropriately licensed site. It is not generally practicable to recycle this material.

Melt not converted into product

This waste stream arises mainly from interruptions to the forming processes, either malfunctions or product changes. The most commonly used and effective technique is to cool and shatter the melt in water and then to use the cullet formed in this way directly as a raw material. There are a number of examples where this is not practicable or is not practised.

In the float glass process, the interruptions to production usually occur after the float bath and so the waste is usually a solid glass, which can also be broken and recycled as cullet. Similarly, in continuous filament glass fibre production, interruptions generally occur after fibre formation and the waste material is fibre. A further source of this type of waste is drain glass, which involves withdrawing a flow of molten glass taken from the bottom of the channel to remove denser unmelted particles. If not removed, these particles can cause fiberising problems, which could result in expensive damage and increased waste. The internal recycling of this material is not usually desirable, because it involves returning the separated impurities to the furnace that will flow back to the bushings. This could lead to a gradual build-up of unmeltable material and potentially a higher level of waste due to fiberisation problems. In some cases it is possible to recycle this material in other sectors of the glass industry.

In HTIW production, there has been little financial incentive to recycle the waste melt but the tendency is to recycle the maximum waste possible due to increasing costs for waste disposal and raw materials.

In stone wool production, fine materials cannot be recycled to the cupola, because they would disrupt the airflow within the material bed. This problem can be overcome by briquetting the waste material to form pieces of comparable size to the standard raw materials. This technique is now widely used and can be considered as proven both economically and technically, although the economics will vary with scale. Stone wool shot (unfiberised particles) can also be recycled in this way (see Section 3.8.4).

Waste products

This category includes material that results out of the required specification, edge trims, waste products from change-overs, breakages, and quality samples. Wherever possible, measures to minimise this type of waste are preferable to recycling; for example, edge trims can be reduced to the minimum width. These measures usually also result in economic benefits.

“Hard” waste, for example flat glass edge trims and container glass rejects, are readily recycled as cullet following crushing. In some installations this may not occur either because of variations in product formulation or simply because it is not considered economically attractive. In theory, all “hard” glass waste can be recycled in this way.

In the mineral wool sector, such product wastes are fibrous and so cannot be recycled directly to the furnace. The solution to this is to mill or grind the material and then recycle it as a powder to tank furnaces or via the briquetting process for stone wool cupolas. Although apparently simple in principle, this technique is quite expensive and is only recently becoming economically viable due to increasing disposal costs. At the time of writing (2009), this technique is not commonly practised. A further problem in glass wool production is the organic content of the material, which must be oxidised in the furnace. This generally requires the increased use of nitrates that decompose to release NO_X and sometimes MnO_2, which is also used as oxidiser. Wherever possible, fibrous waste is processed and sold as blowing wool. Edge trim waste is usually shredded and recycled directly back to the fibre veil. There is a limit to the amount of waste that can be recycled in this way (edge trim only) and it cannot usually be done for products with high strength requirements.

Fibrous waste from the HTIW sector involves the same issues as for mineral wool. The sector is recycling more and more of the fibrous waste and work on this issue is ongoing.

The production of continuous filament glass fibre involves very high quality requirements and at the time of writing (2009), there are no known full-scale examples of waste fibre being directly recycled to the furnace. The problem is apparently related to the organic component of the fibre.

Solid waste from waste water systems
In general, waste separated from the process water systems is not recycled and is disposed of to landfill. In some sectors, particularly domestic glass (lead crystal cutting sludge), initiatives are ongoing to recover and valorise these waste streams. In most sectors it is not financially viable to recover these wastes either because of the low volumes or due to unpredictable/contaminated composition.

In the container glass sector, waste from cooling water systems is often internally recycled (fine particles of glass mixed with oil).

The recycling of post-consumer waste (e.g. from bottle banks) is not discussed in this section because it is not a process waste stream and so is outside of the scope of the IPPC Directive in this respect. However, its use does have important effects on the process and is considered in Sections 4.4 and 4.8. Furthermore, in addition to reducing the specific energy consumption of the melting process, the practice lowers the consumption of virgin raw materials, which is a positive consideration under the IPPC Directive.

4.8 Energy

Glass making is a very energy-intensive process and the choices of energy source, heating technique and heat recovery method are central to the design of the furnace and to the economic performance of the process. The same choices are also necessary for some of the most important factors affecting the environmental performance and energy efficiency of the melting operation. In general, the energy necessary for melting glass may account for over 75 % of the total energy requirements of glass manufacture, with an average of about 65 % of the total energy input when considering all the sectors of the glass industry. This section concentrates on techniques to reduce the energy requirements for melting activities.

The cost of energy for melting is one of the largest factors in operational costs for glass installations and there is a significant incentive for operators to reduce energy use. Economic savings have traditionally been the motivation for implementing energy saving techniques, but recently the environmental aspects of energy use have increased in importance. In fossil fuel fired furnaces, the energy use also affects the emissions per tonne of glass of those substances which relate directly to the amount of fossil fuel burned, particularly CO_2, SO_2 and NO_X, but also particulate matter. These issues are discussed in the substance-specific sections of this chapter.

Energy use and the main factors affecting energy efficiency are discussed in Chapter 3. This chapter discusses techniques for improving furnace efficiency.

4.8.1 Melting techniques and furnace design

[tm18 CPIV, tm5 EEO, tm14 ETSU] [19, CPIV 1998] [6, EEO 1995] [15, ETSU 1992]

The selection of the melting technique can have a great effect on the energy efficiency. The choice is largely determined by a range of economic considerations. The main factor is the desired production rate and the associated capital and operating costs over the life of the furnace. An important aspect of the operating costs is the energy usage, and in general, the operator will choose the most energy-efficient design possible.

In conventional fossil fuel fired furnaces, the main difference in furnace design is whether the heat recovery system is based on regenerators or a recuperator. The differences in the design and operation are discussed in Chapter 2. One of the main factors in the choice is the furnace size, which is discussed further in Section 4.2.

Regenerative furnaces achieve a higher combustion air preheat temperature for the combustion gases; up to 1300 - 1400 °C, compared with a maximum of 800 °C for recuperative furnaces, resulting in better melting efficiencies. The generally larger size of the regenerative furnaces also makes them more energy efficient than the smaller recuperative furnaces. This is because specific structural losses are inversely proportional to the furnace size, the main reason being the change in surface area to volume ratio. A modern regenerative container furnace will have an overall thermal efficiency of around 50 %, with waste gas losses of around 25 - 35 % (about 14 - 20 % when batch and cullet preheating is used), and structural losses making up the vast majority of the remainder. The thermal efficiency of a recuperative furnace without heat recovery will be closer to 20 %.

Regenerative furnaces can be end-fired or cross-fired. The end-fired furnaces are more thermally efficient (up to 10 % higher), but combustion control is more limited and there is an upper limit to the furnace size (currently around 150 m^2 for container glass). Float glass and tableware furnaces are less efficient than container glass furnaces, because the specific pulls are much lower due to quality requirements and/or refining chemistry.

The energy recovered by regenerators may be maximised by increasing the quantity of refractory bricks employed. In practice, these may be organised in enlarged regenerator chambers or in separate but connected structures, given the term multi-pass regenerators. The law of diminishing returns applies as the regenerator efficiency is approaching asymptotically its maximum limit. The principle limitations are the cost of the extra refractory bricks, and in the case of existing furnaces, the limitations are of available space and the additional costs of modifying the furnace infrastructures. This principle is more commonly applied to end-fired furnaces due to their simple regenerator geometry, although some applications on cross-fired furnaces have been made. Modification of regenerator structures on existing furnaces (if this is technically and economically feasible given the plant layout) can only be made during furnace reconstruction. Energy consumption may be reduced by up to 15 % with respect to the equivalent furnace with typical single pass regenerators, depending on the size of the original single pass regenerator. Modern furnaces equipped with single pass regenerators show heat recovery efficiency close to 65 %. In these cases, the use of multi-pass regenerators would not achieve significant improvements of the energy efficiency of the furnace.

The only negative impact is the increased volume of refractory materials to be handled at the end of the furnace life. This negative impact is limited, as a significant proportion of the extra refractory bricks withstand two or more furnace campaigns, and solutions exist, and will continue to be developed, for recycling these materials. Although the increased air preheat temperatures of furnaces equipped with multiple pass regenerators is potentially a factor to increase flame temperature and hence NO_X formation, these furnaces do not, in practice, demonstrate high NO_X levels when appropriate measures of reduction at the source are taken.

There are a variety of materials available for use as heat storage media and packing in regenerators. The simplest solution is to use refractory bricks stacked in an open or "basketweave" pattern and this will generally give a regenerator efficiency of 50 % or more (heat recovered by air compared to heat contained in the waste gas). However, heat transfer can be improved by using specially shaped packing and fusion cast materials. For example, fusion cast corrugated cruciforms will enhance the heat exchange efficiency compared to standard brick packing. The effect of this type of refractory bricks on energy consumption depends on the starting situation and size of the regenerator; fuel savings of about 7 % are quoted. In addition, these materials are very resistant to chemical attack from volatiles in the waste gas stream and show very much reduced deterioration in performance (compared to bricks) throughout the campaign. So far (2009), around 320 installations of corrugated cruciforms have been reported worldwide, of which 120 are within the EU-27.

The maximum theoretical efficiency of a regenerator is about 77 % ("infinitely" large regenerator) because the mass of waste gases from a furnace exceeds that of the incoming combustion air and the heat capacity of exhaust gases exceeds that of the combustion air.

In practical terms, the efficiency will be limited by the cost and the structural losses become more significant as the size of the regenerators increases.
In practice, it is difficult to conceive a cost-effective regenerator design with an efficiency of greater than 70 %.

Furnace geometry is constantly undergoing refinements to optimise thermal currents and heat transfer, both to improve glass quality and to save energy. The developments are often combined with developments in combustion systems to reduce emissions and save energy. Furnace geometry changes are only possible for new furnaces or rebuilds.

Electrical melting, either partial or 100 %, improves energy efficiency when considered at the site level, but when power generation efficiency and distribution losses are taken into consideration, the situation is less clear. These techniques are described in more detail in Section 4.2. Oxy-fuel melting can also result in lower energy consumption, but this is a complex subject that is discussed in more detail in Section 4.4.2.5.

The advances in refractory materials over the past decades have allowed furnaces to operate with longer campaigns and with higher levels of insulation. The limitation of temperature to which the furnace superstructure could be subjected was, in the past, a limiting factor for high insulation. Today, the insulation must be carefully designed according to the part of the furnace and the operating conditions (temperature, type of glass, etc). Not all parts of the furnace can be insulated. The flux line and the throat must be left uninsulated and they will have to be cooled to extend furnace life. Most glass contact and superstructure refractories are made with fusion cast materials that are very dense with low porosity and can resist liquid glass and volatile compounds in the superstructure. They have high thermal conductivity and need, in general, a good insulation level leading to substantial energy savings. In soda-lime glass, the crown is normally in silica and heavily insulated. For oxy-fuel fired furnaces, other materials may be applied (fused cast alumina or AZS) in order to withstand possible attacks from alkali vapours. Silica limits the temperature of the crown of the furnace to 1600 – 1620 °C, while other crown refractory materials, such as fused cast AZS, mullite or fused cast alumina can withstand temperatures higher than 1620 °C. Any increase in furnace temperature may also adversely affect emissions of NO_X and any emissions derived from volatile components of the batch.

Additional insulation can be applied to certain areas of the furnace with little risk of structural damage. Sprayed fibre insulation can significantly reduce heat losses when applied to the regenerator structure. This simple, cost-effective technique can reduce regenerator structural heat losses by up to 50 % and give energy savings in the region of 5 %. There is also the additional benefit that the material will effectively seal any cracks in the regenerator structure, thus reducing ingress of cold air and escape of hot air.

4.8.2 Combustion control and fuel choice

[tm5 EEO, tm14 ETSU] [6, EEO 1995] [15, ETSU 1992]

In recent decades the predominant fuel for glass making has been fuel oil, although the popularity of natural gas has been constantly increasing. At present, the use of both fuels is comparable. Natural gas firing results in lower SO_X emissions but generally gives rise to higher NO_X emissions. This is because the natural gas flame is less radiant and the heat capacity of the flue-gases from gas-firing (per GJ combustion) is different than that from oil-firing. This results in different heat losses even at the same flue-gas temperature, and in general, in higher energy consumption which is approximately 7 – 8 %. However, as experience of gas firing increases, performance levels progressively approaching those associated with oil firing can be achieved; although, in general, oil-fired furnaces still show a higher energy efficiency. Natural gas has a higher ratio of hydrogen to carbon and its use reduces overall emissions of CO_2 by up to 25 % for a given pull rate.

The developments in low NO_X burner systems have also resulted in energy savings. By reducing the amount of combustion air to close to stoichiometric levels, less energy is lost in the waste gas.
The improvements made to the combustion system, the heat transfer systems and general process control during developments intended for NO_X reduction have, in many cases, also led to improvements in furnace operation and efficiency.

A technique frequently used in the past to improve energy efficiency and pull rate was oxygen enrichment of the combustion air. The reduced gas volumes and higher flame temperatures improve energy efficiency, but unless the technique forms part of a carefully controlled overall low NO_X combustion system, NO_X levels can be substantially increased. The use of this technique in isolation is becoming less common due to these environmental concerns. However, oxygen enrichment is often applied where nitrogen is separated from air (for tin bath chamber in float glass production) and oxygen-enriched air is therefore available.

4.8.3 Cullet usage

[tm29 Infomil, tm14 ETSU] [30, Infomil 1998] [15, ETSU 1992]

The use of cullet in a glass furnace can significantly reduce the energy consumption and its use is generally applicable to all types of furnaces, i.e. fossil fuel fired, oxy-fuel fired and electrically heated furnaces. Most sectors of the glass industry routinely recycle all internal cullet. The main exceptions are continuous filament glass fibre, where it is not considered possible due to quality constraints and frits production (where cullet as such is not produced). In the stone wool sector, shot and bypass melt are recycled only if a briquetting process is in use (see Section 3.8.4). The base internal cullet level in the batch will usually be in the range of 10 - 25 %.

Cullet has a lower melting energy requirement than the constituent raw materials because endothermic chemical reactions associated with glass formation have been completed and its mass is 20 % lower than the equivalent batch materials. Therefore, increasing the cullet level in the batch has the potential to save energy and, as a general rule, each 10 % of extra cullet results in a 2.5 - 3.0 % reduction in furnace energy consumption. The use of cullet generally results in significant cost savings as a result of the reduction in both energy and raw material requirements. However, the price of cullet has been increasing significantly and its availability is becoming more difficult; therefore, the use of cullet is not always economically beneficial.

A distinction should be made between internal cullet (recycled glass from the production line) and external cullet (recycled glass from consumer or external industrial sources). The composition of external cullet is not as well defined and this limits its application. Quality issues often limit the use of cullet in the batch formulation due to contamination in the cullet which is difficult to detect and remove. This is particularly the case for tableware, special glass and flat glass productions where high quality requirements of the final product restrict the use of foreign cullet. However, the container glass sector is uniquely placed to take advantage of using significant quantities of foreign cullet from bottle recycling schemes. The recycling of glass cullet is regulated by European legislations, in particular European Directive 94/62/EC which sets targets for the recycling of packaging waste. At the time of writing (2009), except where special schemes are established, the significant use of external cullet is restricted to the container glass sector and some areas of the mineral wool sector, particularly glass wool. Although the container glass sector is the main user of external cullet, the high-quality requirements for the final glass product demanded by the customers is not always compatible with the quality of the cullet available, because of its content of impurities, particularly glass ceramics, which results in a consequent reduction of its usage in the batch formulation. Glass sectors with higher quality demands or low availability of external cullet (e.g. flat glass) may try to contract large consumers to recycle the waste glass they generate.

Cullet use in container glass production varies from <20 to >90 %, with an EU average in the region of 50 %.
Recycling rates vary widely between Member States depending on the material schemes for post-consumer glass collection. High-quality container glass products have lower cullet levels than standard products.

In the domestic glass sector, quality considerations generally prevent the use of external cullet in the process. Internal cullet usage is limited by the availability of cullet at the correct quality and composition. In general, the average amounts of internal cullet used are around 25 % for soda-lime products, although amounts as high as 50 % are possible depending on the type of article produced; for lead crystal, average amounts of 35 % are normally applied.

For the manufacture of flint (colourless glass) only very low levels of coloured cullet can be tolerated since coloured glass cannot be decolourised. Therefore, recycling schemes are more effective where colour separation is included. In general, throughout the EU, there are ample supplies of mixed coloured, green and brown cullet. However, flint cullet tends to be less common and because of this situation, furnaces melting coloured glass operate at higher cullet levels, particularly for the production of green glass where a mixture of different colours can be used. The situation varies significantly between Member States due to regional differences, for example, it is a problem in the UK since the bulk of production is flint glass, yet a substantial proportion of cullet is coloured, from imported wine bottles. Consequently, furnace cullet levels in the UK are lower, on average.

In terms of furnace operation, high cullet levels can also give other benefits such as lower particulate emissions. Cullet is easier than batch to preheat. The output of the furnace can also be greatly increased, but there are a number of drawbacks to the manufacturer when operating at high cullet levels such as:

- metallic impurities such as bottle caps or foils from wine bottles can cause serious refractory damage and shorten the furnace life. The metallics sink to the bottom where a phenomenon known as "downward drilling" takes place. Metals, particularly lead, through chemical reactions effectively cause holes through the furnace bottom. Metal contamination, the presence of lead crystal glass and reducing components in the cullet may cause defects in the glass
- ceramic inclusions, such as earthenware or pottery and glass-ceramics that are insoluble in the glass melt will appear as "stones" or knots, often with an opaque colour, in the final product and lead to rejects
- at high cullet levels, the control of composition and therefore the physical characteristics of the glass melt can be reduced, possibly leading to final product quality problems. The variable content of organic matter (food residues, paper labels, plastics) in particular can cause problems in the oxidation-reduction state, leading to colour and refining difficulties
- aluminium caps and foils act as strong local reducing agents causing the silica of the glass to reduce to silicon metal (Si). The silicon forms inclusions in the glass products (small beads), which significantly reduce the mechanical strength of the glass, due to stresses resulting from the high difference of thermal expansion coefficient between the glass and silicon
- impurities from cullet can lead to air emissions (lead, fluorine and boron compounds, etc).

In addition to the substantial energy savings possible with cullet usage, there are a number of other important associated environmental benefits. Emissions of CO_2, SO_X, NO_X and dust are greatly reduced due to reduced fuel usage and lower furnace temperatures. Emissions of other volatile substances may also be lower due to the reduced temperatures. However, impurities in the cullet may lead to higher emissions of HCl, HF and metals and SO_X (when glasses with low sulphur content are produced). This is particularly relevant in areas with high recycling rates where impurities can build up in the recycled material. Many raw materials in glass making are carbonates and sulphates, which release CO_2 and SO_X upon melting.

The increased cullet usage reduces these raw material derived emissions and reduces the consumption of virgin raw materials.

4.8.4 Waste heat boiler

The principle of this technique is to pass waste gases directly through an appropriate tube boiler to generate steam. The steam may be used for heating purposes (space heating and heating of fuel oil storage and piping) or, via a suitable steam motor or turbine to drive electricity generation equipment or plant items such as air compressors or Individual Section (IS) machine ventilator fans.

Incoming gases from regenerators/recuperators are usually in the temperature range from 600 to 300 °C. The outlet temperature determines the available recoverable heat which is limited to approximately 200 °C due to the risk of condensation in the boiler and to ensure correct stack operation. Boiler tubes exposed to furnace waste gases can become coated with condensed materials (e.g. sodium sulphate, depending on the composition) and sticky and corrosive compounds (e.g. sodium bisulphate) could form, depending on the temperature and composition of the flue-gases which may react with the metal structure of the pipes. Therefore, boiler tubes must be periodically cleaned to maintain recovery efficiency (this is not as important for boilers operating downstream of dust removal devices). In situ cleaning may be carried out automatically by steam, by mechanical means, or by periodic maintenance.

The applicability and economic feasibility of the technique is dictated by the overall efficiency that may be obtained (including effective use of the steam generated). In practice, waste heat boilers have only been considered to recover residual heat downstream from regenerator or recuperator systems and there is thought to be at least two examples with oxy-fuel fired furnaces (see Table 4.20). In many cases, the quantity of recoverable energy is low for efficient power generation and supplementary firing may be needed to generate superheated steam to drive turbines. Recuperative furnaces with higher waste gas temperatures or installations where it is possible to group the waste gases from several furnaces offer more opportunities for power generation. Waste heat boilers are in industrial use on some container glass facilities but most applications are with float glass furnaces. All float furnaces in Germany and many in other Member States have waste heat boilers.

Investment costs can exceed EUR 1 million with variable pay back periods, depending on performance and prevailing energy prices. The ongoing improvements in primary energy efficiency are eroding the cost-effectiveness of waste heat boilers. In some applications, there may not be an attractive pay back period, but this will vary from case to case. The 3R process can help to make existing waste heat boiler systems more effective and would likely improve the economic performance of any new system proposed for installation. However, if for whatever reason the installation of a waste heat boiler is considered inappropriate or economically unattractive, the installation of the 3R process will not necessarily change this situation.

In Table 4.50 are reported data concerning example installations where waste heat boilers (heat exchangers) are applied in different sectors of the glass industry.

Type of glass	CONTAINER	CONTAINER	FLAT	FLOAT	SPECIAL	SPECIAL
Type of furnaces	Oxy-fired (2 furnaces)	End-port, regenerative	Side-port, regenerative	Side-port, regenerative	Oxy-fired	Side-port, regenerative
Fuel	Natural gas	Natural gas/fuel oil	Fuel oil	Natural gas/fuel oil	Natural gas	Natural gas/fuel oil
Furnace capacity	650 tonnes/day (total)	300 tonnes/day	350 tonnes/day	800 tonnes/day	40 tonnes/day	220 tonnes/day
Actual pull rate	502 tonnes/day (total)	297 tonnes/day	259 tonnes/day	700 tonnes/day	40 tonnes/day	180 tonnes/day
Last main repair	2000 - 1996	1997	2000	2002	2004	-
Electric boosting	-	yes	yes	yes	yes	yes
Type of glass	Brown-green	Brown	White, bronze, yellow	White	Glass ceramics	Not available
Cullet	66 % (average)	72 %	30 %	35 %	50 %	25 %
Type of heat exchanger	Pipe bundle	Pipe bundle	Tube register	Tube register	-	Tube register
Place of installation	Before bag filter	After ESP	Before ESP	Before ESP	Before bag filter	After ESP
Heat carrier	Water/steam	Water/steam	Water/steam	Water/steam	Water/steam	Water/steam
Use of recovered energy	Electric energy, compressed air	Electric energy, industrial water	Industrial water, firing, oil preheating	Industrial water, electricity, firing	Industrial water	Water for domestic use
Dedusting	Online	Online	Online	Online	Not available	None
Dust disposal	Added to the batch	Added to the batch	Special disposal	Recycling or special disposal	Not available	Recycling or special disposal
Temperature difference	From 1380 to 200 °C	Approx. 150 °C	Approx. 200 °C	Not available	Not available	Not available
Amount of recovered energy	6472 kWh/h	1500 kWh/h (estimated)	1500 kWh/h	3000 kWh/h	550 kWh/h	1140 kWh/h
Specific heat recovery	0.31 kWh/kg glass	0.12 kWh/kg glass (estimated)	0.14 kWh/kg glass	0.10 kWh/kg glass	0.33 kWh/kg glass	0.15 kWh/kg glass
Specific energy consumption	4.20 GJ/t melted glass (average)	4.21 GJ/t melted glass	5.71 GJ/t melted glass	5.20 GJ/t melted glass	12.31 GJ/t melted glass	16.44 GJ/t melted glass
Investment/replacement costs		EUR 1.67 million (1)	EUR 0.5 million (1)	EUR 1.0 million (1)		
Duration of amortisation		10 yrs	10 yrs	10 yrs		
Operating costs		EUR 33500	EUR 60000	EUR 70000		
Annual amortisation costs		EUR 222111	EUR 65000	EUR 133000		
Total annual costs		EUR 255611	EUR 255611	EUR 203000		
Estimated costs per tonne of glass		EUR 2.36/tonne glass	EUR 1.34/tonne glass	EUR 0.79/tonne glass		

1. Investment costs for the heat exchanger include accessories.

Table 4.50: Example installations of waste heat boilers applied in different sectors of the glass industry
[75, Germany-HVG Glass Industry report 2007]

4.8.5 Batch and cullet preheating

[tm29 Infomil] [30, Infomil 1998] [65, GEPVP-Proposals for GLS revision 2007]

Description

Batch and cullet is normally introduced cold into the furnace, but by using the residual heat of the waste gases to preheat the batch and cullet, significant energy savings can be possible. This only applies to fossil fuel fired glass furnaces. In the stone wool industry, predominantly cupola furnaces are used, which have a design that preheats the raw materials intrinsically.

Preheating temperatures should not be lower than 350 °C but should not exceed 500 – 550 °C. In practice, most batch and cullet preheaters operate at temperatures between 275 and 325 °C.

Batch/cullet preheaters have been developed and installed by Nienburg/Interprojekt (direct preheating), Zippe (indirect preheating) and Sorg (direct preheating). A combined direct cullet preheater and electrostatic precipitator was developed and installed by Edmeston, now Praxair EGB. A new type is under development in the USA for high temperature flue-gases of about 1300 °C, which should allow preheating the batch and cullet up to about 500 °C.
The available systems are described below:

- direct preheating - this type of preheating involves direct contact between the flue-gas and the raw material (cullet and batch) in a cross-counter flow. The waste gases are supplied to the preheater from the waste gas duct behind the regenerator or the recuperator. They pass through the cavities in the preheater, thereby coming into direct contact with the raw material. The outlet temperature of the cullet is up to 400 ºC. The system incorporates a bypass that allows furnace operations to continue when preheater use is either inappropriate or impossible. Direct preheaters are developed and installed by Nienburg/Interprojekt and by Sorg. An example installation for the application of direct cullet preheating is reported in Table 4.51.
- indirect preheating - the indirect preheater is, in principle, a cross-counter flow, plate heat exchanger, in which the material is heated indirectly. It is designed in a modular form and consists of individual heat exchanger blocks situated above each other. These blocks are again divided into horizontal waste gas and vertical material funnels. In the material funnels, the material flows from the top to the bottom by gravity. Depending on the throughput, the material reaches a speed of 1 – 3 m/h and will normally be heated from ambient temperature up to approximately 300 °C. The flue-gases will be let into the bottom of the preheater and flow into the upper part by means of special detour funnels. The waste gases flow horizontally through the individual modules. Typically the flue-gases will be cooled down by approximately 270 - 300 °C. The indirect cullet preheater has been developed by Zippe
- Praxair EGB filter - the Edmeston electrified granulate bed (EGB) filter system is a hybrid system between an electrostatic precipitator for dust removal and a direct cullet preheater. The hot waste gas enters the top of the system and passes through an ionising stage, which imparts an electrical charge to the dust particles. The gas then passes into a bed of granular cullet, which is polarised by a high voltage electrode. The charged dust particles are attracted to the cullet where they are deposited. The cullet is in a shaft and is constantly added at the top and removed from the bottom. The preheated cullet (up to 400 °C) and the attached particulates are charged into the furnace. However, the Praxair EGB cullet preheater is not currently applied within the glass industry in Europe. An application is running at Leone Glass in the USA in connection with an oxy-gas fired furnace producing flint container glass.

Achieved Environmental Benefits

These techniques have a number of environmental effects, which can vary from case to case. In general, the following benefits have been experienced:

- energy savings of between 10 and 20 % with a consequent reduction of CO_2 emissions
- reduction in NO_X emissions (due to lower fuel requirements and lower furnace temperatures)
- in the case of direct preheating, reduction of acidic compounds in the flue-gases SO_2, HF and HCl, of 60 %, 50 % and 90 % respectively have been found (difference before and after the cullet bed)
- an increase of pull rate of up to 10 - 15 %, is possible for applications to existing glass furnaces, with preheating of the batch to 300 °C.

Cross-media effects

The technique can give an increase in furnace capacity of 10 – 15 % without compromising the furnace life. If the pull rate is not increased, a small increase in furnace life may be possible. By getting more heat into the furnace, the technique can also reduce the requirement for electric boosting.

In some cases, problems with odour generation from the preheater have arisen, due to organic fumes released during the pre-drying of the cullet. The problems are caused by the burning of food particles and other organics in the external cullet. Solutions to these problems (e.g. incineration) are being developed.

The use of a direct preheating causes increased emissions of particulate matter (up to 2000 mg/Nm^3) and secondary particulate abatement is necessary. The collected dusts can normally be recycled back into the furnace.

When direct material preheating requires the use of an electrostatic precipitator, electric energy is consumed. This offsets a portion of the energy savings but it is not substantial.

There is a possibility that direct preheating might lead to dioxin emissions, particularly if waste gases containing HCl from the hot-end coating are included. Measurements have been performed to check the possible presence of dioxins in the flue-gases; however, information is not available to support this.

Operational data

In order to keep the loss of heat of the transport system below the heat exchanger as low as possible, the preheater should be located as close to the doghouse as possible. The ideal location would be directly above the batch charger. For economic reasons, the temperature of the waste gas available should be at least 400 - 450 °C. Furthermore, a cooling of the flue-gases by at least 200 - 250 °C is needed. To prevent material agglomeration, the maximum entry temperature of the flue-gases should not exceed 600 °C.

Applicability

Cullet/batch preheating systems can theoretically be installed at any existing glass melting furnace with greater than 50 % cullet in the batch, although, there are some applications operating with a percentage of cullet as low as 30 %. Preheating of only the batch has been problematic and is not considered proven technology. The preheating of a batch and cullet mixture is more complicated than the preheating of cullet only. Due to these limitations, the application of batch and cullet preheating is almost exclusively done in the container glass sector.

Economics

The economics of batch/cullet preheaters are strongly dependent on the capacity of the furnace and the preheater. As an indicative example of costs, an estimation has been made for two different examples in the container glass sector for the application of an indirect preheater.

The results are the following:

- for a 350 tonnes/day cross-fired regenerative furnace, the additional investment cost associated with the use of the preheater is about EUR 2.5 million, including some adaptations in the batch-charging machinery. The annual operational cost savings are about EUR 820000 per year, assuming a fuel price of EUR 9.4 per GJ gross combustion value. The average cost savings during the furnace campaign are estimated at EUR 3 per tonne molten glass, calculated on the basis of current energy prices.
- the application of batch/cullet preheating to a 450 tonne/day furnace allows an increase in pull capacity from 450 to 500 tonnes/day and to save energy. The investment costs are EUR 3.4 million and cost savings (based on a 500 tonne/day capacity) are EUR 1.1 million per year. In this case, the payback time is three years. The total cost savings are equivalent to EUR 5 - 6 per tonne glass, partly due to the increased melting capacity of the furnace without the need of enlarging its structure.

At the time of writing (2009), the technology is not extensively applied due to relatively high investment costs and, in some case, space limitations. However, the position can vary from region to region and is constantly under review as energy prices and other factors (e.g. emissions limits) change.

An example installation for the application of direct batch preheating to a container glass furnace producing flint glass is presented in Table 4.51.

Driving force for implementation

The main driving force for implementation would be to reduce energy consumptions, with a consequent CO_2 emission reduction. An increase in the melting capacity of the furnace (up to 10 % or more) may also represent a driving force.

Example plants

All the applications of batch and cullet preheating are in the container glass sector:

- direct preheating:
    - three furnaces at Nienburger Glas, Nienburg, Germany
    - Wiegand Glas, Steinbach am Wald, Germany

- indirect preheating:
    - Ardagh Glass, Dongen, Netherlands
    - Edmeston EGB filter:
    - Leone Industries, Bridgeton, New Jersey, US (oxy-fuel fired furnace).

Reference literature

[tm29 Infomil] [30, Infomil 1998] [65, GEPVP-Proposals for GLS revision 2007]
[94, Beerkens - APC Evaluation 2008] [75, Germany-HVG Glass Industry report 2007]

Operating conditions		
Type of furnaces	cross-fired, regenerative	
Fuel	natural gas	
Furnace capacity	350 t/d	
Actual pull rate	275 t/d	
Last main repair	Year 2005	
Electric boosting	yes	
Type of glass	flint	
Cullet	60 %	
Specific energy consumption	3.78 GJ/t glass	
Filter type	ESP with 3 fields	
Temperature before filter	200 °C	
Sorbent	none	
Use of filter dust in the batch	100 %	
Energy consumption including	194 kWh/h	
Service interval	As required	
Type of raw material preheater	Direct contact with exhaust	
Dedusting	None	
Exhaust gas volume	17000 m^3/h	
Exhaust gas temperature -	Approx. 450/200 °C	
Raw material temperature -	Approx. 20/300 °C	
Amount of recovered energy	Approx. 900 kWh/h	
	Filter system, including accessories, pipeline, ventilator	Raw material preheater, including accessories
Investment/replacement costs	EUR 1.5 million	EUR 1.0 million
Duration of amortisation	10 yrs	12 yrs
Operating costs	EUR 120000	EUR 10000
Annual amortisation costs	EUR 199500	EUR 113333
Total annual costs	EUR 319500	EUR 123333
Estimated costs per tonne of glass	EUR 3.18/t glass	EUR 1.23/t glass
Emission levels (1)		
	(mg/Nm^3, dry gas at 8 % O_2)	**kg/t glass**
Particulate matter	23.8	0.037
NOx	909	1.42
SO_x	386	0.60
HCl	4.8	0.0075
HF	3.0	0.0047
Metals		
Class I (Hg, Tl)	0.003	$0.005x10^{-3}$
Class II (Pb, Co, Ni, Se)	0.76	$1.2x10^{-3}$
Class III (Sb, Cr, Cu, Mn, V, Sn)	1.01	$1.6x10^{-3}$
1. Emission data refer to half-hour average values		

Table 4.51: Example installations for the application of a direct cullet preheater to a container glass furnace

[75, Germany-HVG Glass Industry report 2007]

4.9 Environmental management systems

Description

The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive's definition of 'techniques' as "*both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned*".

For IPPC installations an Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. An EMS includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

All effective EMSs contain the notion of continuous improvement meaning that environmental management is a process, not a project which eventually comes to an end. There are various process designs, but most environmental management systems are based on the plan-do-check-act cycle (which is widely used in other company management contexts). The cycle is a reiterative dynamic model, where the completion of one cycle flows into the beginning of the next, see Figure 4.8.

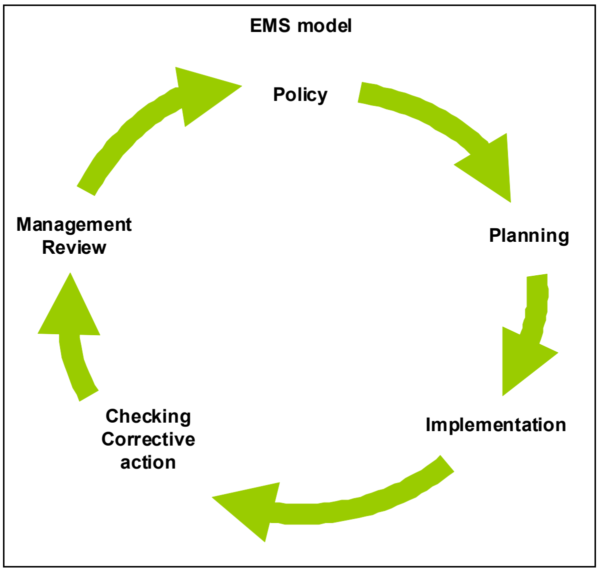


Figure 4.8: **Continuous improvement in an EMS model**

Within the European Union, many organisations have decided on a voluntary basis to implement environmental management systems based on EN ISO 14001:2004 or the EU Eco-Management and Audit Scheme, EMAS. EMAS includes the management system requirements of EN ISO 14001, but places additional emphasis on legal compliance, environmental performance and employee involvement. It also requires external verification of the management system and validation of a public environmental statement (in EN ISO 14001 self-declaration is an alternative to external verification). There are also many organisations that have decided to put in place non-standardised EMSs.

While both standardised systems (EN ISO 14001:2004 and EMAS) and non-standardised ('customised') systems in principle take the *organisation* as the entity, this document takes a narrower approach, not including all activities of the organisation e.g. with regard to their products and services, due to the fact that the regulated entity under the IPPC Directive is the installation (as defined in Article 2 of the Directive).

An Environmental Management System (EMS) for an IPPC installation can contain the following components:

a. commitment of top management
b. definition of an environmental policy
c. planning and establishing objectives and targets
d. implementation and operation of procedures
e. checking and corrective action
f. management review
g. preparation of a regular environmental statement
h. validation by a certification body or an external EMS verifier
i. design considerations for end-of-life plant decommissioning
j. development of cleaner technologies
k. benchmarking.

These features are explained in somewhat greater detail below. For detailed information on components (a) to (h), which are all included in EMAS, the reader is referred to the reference literature indicated below.

a. Commitment of top management:

The commitment of top management is the precondition for a successful EMS. It is important that top management:

- place environmental management high on the company agenda, make it visible and give it credibility
- identify one top manager with responsibility for environmental management
- help create an environmental management culture and create the necessary driving forces for implementation
- define a strategy (long term visions) to achieve environmental objectives
- set company targets to achieve these environmental objectives
- define short and medium term concrete actions to achieve the long term vision
- provide the platform to integrate decision-making in order to achieve integrated pollution prevention and control, particularly for when planning new installations or significant upgrading
- guide the company to make investment and purchasing decisions that achieve integrated pollution prevention and control on a continuing basis. Integrated pollution prevention and control is achieved through integrated decision-making and actions, including the buying of utilities and capital equipment, planning, production, and maintenance as well as environmental management
- define an environmental policy, see (b) below.

b. Definition of an environmental policy:

Top management are responsible for defining an environmental policy for an installation and ensuring that it:

- is appropriate to the nature, scale and environmental impacts of the activities
- includes a commitment to pollution prevention and control including the efficient use of raw materials, energy and water

- includes a commitment to comply with all relevant applicable environmental legislation and regulations, and with other requirements to which the organisation subscribes
- provides the framework for setting and reviewing environmental objectives and targets
- is documented and communicated to all employees
- is available to the public and all interested parties.

c. Planning and establishing objectives and targets:

It is important to have:

- procedures to identify the environmental aspects of the installation, in order to determine those activities which have or can have significant impacts on the environment, and to keep this information up-to-date
- procedures to evaluate proposals for new processes, units and equipment, change in raw and auxiliary materials or fuels, upgrades, rebuilds and replacements in order to identify the environmental aspects and to influence the planning and purchasing to optimise the environmental performance of the installation with regard to the objectives of the IPPC Directive
- procedures to authorise the modifications indicated above and to undertake checks after modifications have been implemented and before the process starts up
- procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the environmental aspects of its activities
- establishing and reviewing documented environmental objectives and targets, taking into consideration the legal and other requirements to which the organisation subscribes and the views of interested parties
- establishing and regularly updating an environmental management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved
- carrying out audits to review e.g. the efficient use of energy, water, raw and auxiliary materials.

d. Implementation and operation of procedures:

It is important to have systems in place to ensure that procedures are known, understood and complied with, therefore effective environmental management includes:

i. Structure and responsibility
    - defining, documenting, reporting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative (in addition to a top manager (see (a) above)
    - providing resources essential to the implementation and control of the environmental management system, including human resources and specialised skills, technology and financial resources.

ii. Training, awareness and competence
    - defining, documenting and communicating skills and competencies required for each job
    - identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training for all modes of operations they can encounter, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions.

iii. Communication
  - establishing and maintaining procedures for internal communication between the various levels and functions of the installation, as well as procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties.

iv. Employee involvement
  - involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion book system or project-based group works or environmental committees.

v. Documentation
  - establishing and maintaining up-to-date information, in paper or electronic form, to describe the core elements of the management system and their interaction and to provide direction to related documentation.

vi. Efficient process control
  - adequate control of processes and equipment (including pollution prevention and control equipment) under all modes of operation, i.e. preparation, start-up, routine operation, shut-down and abnormal conditions
  - identifying the key performance indicators (e.g. flow, pressure, temperature, composition, quantity) and methods (e.g. weighting systems, metering systems, calculations, sampling and analysis) for measuring and controlling these parameters
  - documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that abnormal events do not recur (this can be facilitated by a ‘no-blame’ culture where the identification of causes is more important than apportioning blame to individuals).

vii. Maintenance programme
  - establishing a structured programme for maintenance (including preventive and corrective maintenance) based on technical descriptions of the equipment, norms, etc. as well as any equipment failures and consequences of the failures
  - identifying from routine maintenance, breakdowns and/or abnormalities, possible decreases in environmental performance, or where environmental performance could be improved
  - supporting the maintenance programme by appropriate record keeping systems and diagnostic testing
  - clearly allocating responsibility for the planning and execution of maintenance.

viii. Emergency preparedness and response
  - establishing and maintaining procedures to identify the potential for and response to accidents and emergency situations, and for preventing and mitigating the environmental impacts that may be associated with them.

e. Checking and corrective action (see also benchmarking (e):

i. Monitoring and measurement
  - establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on the environment. This includes the recording of information for tracking performance, relevant operational controls and conformance with the installation's environmental objectives and targets (see also the Reference Document on the General Principles of Monitoring)
  - establishing and maintaining a documented procedure for periodically evaluating compliance with relevant environmental legislation and regulations.

ii. Corrective and preventive action
  - establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements and commitments as well as objectives and targets

  - taking action to mitigate any impacts caused by abnormal events and for initiating and completing corrective and preventive actions that are appropriate to the magnitude of the problem and commensurate with the environmental impact encountered.

iii. Records
  - establishing and maintaining procedures for the identification, maintenance and disposition of legible, identifiable and traceable environmental records, including training records and the results of audits and reviews.

iv. Audit
  - establishing and maintaining a programme (or programmes) and procedures for periodic environmental management system audits. Such a programme (or programmes) include discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation. Each audit results in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits), covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained
  - completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of environmental problems - more complex activities with a more significant environmental impact are audited more frequently
  - having appropriate mechanisms in place to ensure that the audit results are followed up.

v. Periodic evaluation of legal compliance
  - reviewing compliance with the applicable environmental legislation and the conditions of the environmental permit(s) held by the installation
  - documentation of the evaluation.

f. Management review:
  - reviewing, by top management, at intervals that it determines, of the environmental management system, to ensure its continuing suitability, adequacy and effectiveness
  - ensuring that the necessary information is collected to allow management to carry out this evaluation
  - documentation of the review.

g. Preparation of a regular environmental statement:

- preparing an environmental statement that pays particular attention to the results achieved by the installation against its environmental objectives and targets. It is regularly produced - from once a year to less frequently depending on the significance of emissions, waste generation, etc.

This statement considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc).

When producing a statement, the operator may use relevant existing environmental performance indicators, making sure that the indicators chosen:

- give an accurate appraisal of the installation's environmental performance
- are understandable and unambiguous
- allow for year on year comparison to assess the development of the environmental performance of the installation

- allow for comparison with sector, national or regional benchmarks as appropriate
- allow for comparison with regulatory requirements as appropriate.

h. Validation by a certification body or an external EMS verifier:
    - having the management system, audit procedure and environmental statement examined and validated by an accredited certification body or an external EMS verifier can, if carried out properly, enhance the credibility of the system.

i. Design considerations for end-of-life plant decommissioning:

- giving consideration to the environmental impact from the eventual decommissioning of the installation at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper
- decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations may include:
    - avoiding underground structures
    - incorporating features that facilitate dismantling
    - choosing surface finishes that are easily decontaminated
    - using an equipment configuration that minimises trapped chemicals and facilitates drain-down or cleaning
    - designing flexible, self-contained units that enable phased closure
    - using biodegradable and recyclable materials where possible.

j. Development of cleaner technologies:
    - environmental protection should be an inherent feature of any process design activities carried out by the operator or its contractors, since techniques incorporated at the earliest possible design stage are both more effective and cheaper. Giving consideration to the development of cleaner technologies can, for instance, occur through R&D activities or studies. As an alternative to internal activities, arrangements can be made to keep abreast with - and where appropriate - commissioned work by other operators or research institutes active in the relevant field.

k. Benchmarking:
    - carrying out systematic and regular comparisons with sector, national or regional benchmarks, including for energy efficiency and energy conservation activities, choice of input materials, emissions to air and discharges to water (using for example the European Pollutant Emission Register, EPER), consumption of water and generation of waste.

Standardised and non-standardised EMSs

An EMS can take the form of a standardised or non-standardised (‘customised’) system. Implementation and adherence to an internationally accepted standardised system such as EN ISO 14001:2004 can give higher credibility to the EMS, especially when subjected to a properly performed external verification.

EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can, in principle, be equally effective provided that they are properly designed and implemented.

Achieved environmental benefits

Implementation of, and adherence to, an EMS focuses the attention of the operator on the environmental performance of the installation. In particular, the maintenance of, and compliance with, clear operating procedures for both normal and abnormal situations and the associated lines of responsibility should ensure that the installation's permit conditions and other environmental targets and objectives are met at all times.

Environmental management systems typically ensure the continuous improvement of the environmental performance of the installation. The poorer the starting point is, the more significant short term improvements can be expected. If the installation already has a good overall environmental performance, an EMS helps the operator to maintain the high performance level.

Cross-media effects

Environmental management techniques are designed to address the overall environmental impact of the installation, which is consistent with the integrated approach of the IPPC Directive.

Operational data

All significant consumptions (including energy) and emissions are managed in a coordinated manner by the operator for the short, medium and long term, in conjunction with financial planning and investment cycles. This means that e.g. adapting short-term end-of-pipe solutions to emissions may tie the operator to long term higher energy consumption, and postpone investment in potentially more environmentally beneficial solutions overall. This requires some consideration of the cross-media issues, and guidance on these and the costing and cost-benefits issues is given in the Reference Document on Economics and Cross-Media Effects and in the BREF on Energy Efficiency.

Applicability

The components described above can typically be applied to all IPPC installations. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

The implementation of an EMS, according to the rules of ISO 14001, to a number of installations within the glass industry, has proven to be a good tool for setting company guidelines for:

- indicating to all employees the direction to focus their work on
- establishing an organisation where the tasks and responsibilities of every function are clearly defined
- describing the production processes so that everyone can act accordingly
- adopting a controlling system to detect faults and abnormalities and to correct them reliably, implementing a system to improve factory performance by fixing and realising specific targets.

Economics

It is difficult to accurately determine the costs and economic benefits of introducing and maintaining a good EMS. A number of studies have been made but do not reflect the size or complexity of the glass production sector. There also economic benefits that are the result of using an EMS and this varies widely from sector to sector. In some Member States reduced supervision fees are charged if the installation has a certification.
External costs relating to verification of the system can be estimated from guidance issued by the International Accreditation Forum (http://www.iaf.nu).
A number of glass companies that have implemented ISO 14001 or internal EMS have observed that costs for ISO 14001 are higher, due to external audit for certification, without any additional benefit compared to the internal system.

The following information about the costs of implementing EMS in the glass production sector and some of the savings made are provided below. **{Information needed from the sector}**

Driving forces for implementation
Environmental management systems can provide a number of advantages, for example:

- improved insight into the environmental aspects of the company
- improved basis for decision-making
- improved motivation of personnel
- additional opportunities for operational cost reduction and product quality improvement
- improved environmental performance
- improved company image
- reduced liability, insurance and non-compliance costs
- increased attractiveness for employees, customers and investors
- increased trust of regulators, which could lead to reduced regulatory oversight
- improved relationship with environmental groups.

Example plants
The features described under (b) to (f) above are elements of EN ISO 14001:2004 and the European Union Eco-Management and Audit Scheme (EMAS), whereas the features (g) and (h) are specific to EMAS. These two standardised systems are applied in a number of IPPC installations.

As an example, all float plants belonging to AGC Flat Glass Europe, Pilkington/NSG and Saint Gobain are certified or are being certified to ISO 14001. These companies are part of large international groups with worldwide activities and therefore have chosen the international standard ISO 14001 rather than the EMAS that is specifically European.

Other European installations producing container glass, glass wool, continuous filament glass fibre, glass frits, etc. are certified ISO 14001 or are registered under EMAS (e.g. Rockwool, OCV, Saint Gobain ISOVER, etc).

Reference literature
[Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community Eco-Management and Audit Scheme (EMAS), OJ L 114, 24/4/2001 http://europa.eu.int/comm/environment/emas/index_en.htm]

[EN ISO 14001:2004, http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html; http://www.tc207.org]
[Reference Document on Best Available Techniques for Energy Efficiency][124, EC 2008]
[Reference Document on Economics and Cross-media Effects (ECM BREF), July 2006 http://eippcb.jrc.ec.europa.eu/pages/locatemr2.cfm?file=ecm_bref_0706.p]

5 BEST AVAILABLE TECHNIQUES FOR THE GLASS MANUFACTURING INDUSTRY

5.1 Introduction

In understanding this chapter and its contents, the attention of the reader is drawn back to the Preface of this document and in particular the fifth section of the preface: “How to understand and use this document”. The techniques and associated emission and/or consumption levels, or ranges of levels, presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key environmental issues for the sector; for the manufacture of glass these are emissions to air from melting furnaces and, for some production types, from downstream activities
- examination of the techniques most relevant to address these key issues
- identification of the best environmental performance levels, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, and the main driving forces involved in implementation of these techniques
- selection of the best available techniques (BAT) and the associated emission and/or consumption levels for this sector in a general sense, all according to Article 2(12) and Annex IV to the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, best available techniques, and as far as possible emission and consumption levels associated with their use, are presented in this chapter that are considered to be appropriate to the sector as a whole and in many cases reflect current performance of some installations within the sector. Where emission and consumption levels “associated with best available techniques” are presented, this is to be understood as meaning that those levels represent the environmental performance that could be anticipated as a result of the application, in this sector, of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are neither emission nor consumption limit values and should not be understood as such. In some cases, it may be technically possible to achieve better emission or consumption levels but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT for the sector as a whole. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The emission and consumption levels associated with the use of BAT have to be seen together with any specified reference conditions (e.g. averaging periods).

The concept of “levels associated with BAT” described above is to be distinguished from the term “achievable level” used elsewhere in this document. Where a level is described as “achievable” using a particular technique or combination of techniques, this should be understood to mean that the level may be expected to be achieved over a substantial period of time in a well maintained and operated installation or process using those techniques.

Where available, data concerning costs have been given together with the description of the techniques presented in Chapter 4. These give a rough indication about the magnitude of costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, subsidies and the technical characteristics of the installation concerned.

It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

The BAT (including the associated emission and consumption levels) given in this chapter are BAT in a general sense (i.e. considered to be appropriate to the sector as a whole). It is intended that they are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way, they will assist in the determination of appropriate 'BAT-based' conditions for the installation or in the establishment of general binding rules under Article 9(8) of the IPPC Directive. It is foreseen that new installations can be designed to perform at or even better than the BAT levels presented in this chapter. It is also considered that existing installations could move towards the BAT levels presented in this chapter or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels when using specified techniques. The appropriate permit conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

This chapter discusses BAT for the main emissions from each sector of the glass industry separately in Sections 5.3 to 5.10. In most of the sectors these are restricted to emissions to air, because these are seen as the priority for the glass industry. Within each of these sector-specific sections, emissions are discussed separately for each substance from melting to, more generally, downstream activities. Emissions to water are, in most instances, relatively low and may represent a relevant factor for specific types of activities, such as downstream operations in the domestic and mineral wool sectors. General consideration for emissions to water and other wastes, and for noise emissions are discussed in Sections 5.11, 5.12 and 5.13.

‘Best available techniques’ for a specific installation will usually be the use of one individual or a combination of the BAT listed in the relevant section.

Where techniques identified individually as BAT can be used in combination, the effects of such combinations should be considered when drawing conclusions on BAT based permit conditions for individual cases.

Recommendation to help users/readers of this document

It is strongly recommended to read Chapter 5 in conjunction with Chapter 4, because the considerations regarding the applicability of the measures/techniques as mentioned in Chapter 4 have to be taken into account. To help the reader in this, references to Chapter 4 or other relevant sections have been included in Chapter 5.

As described in the preface, this document does not propose emission limit values. The best available techniques and ranges of emission or consumption levels associated with best available techniques (BAT-AEL ranges) presented in this document are related to installations with different furnace sizes, different types of melting techniques and fuel, and diverse operating conditions. In this document, special local considerations cannot be taken fully into account. The determination of appropriate permit conditions will involve taking account of local, site-specific factors, specifically the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impacts, and these judgements will often be influenced by local considerations.

Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques and BAT associated emission levels presented here in Chapter 5 will therefore not necessarily be appropriate for all installations.
On the other hand, the obligation to ensure a high level of environmental protection including the minimisation of long-distance or transboundary pollution implies that permit conditions cannot be set on the basis of purely local considerations. It is therefore of the utmost importance that the information contained in this document is fully taken into account.

5.2 General considerations

An important characteristic of many installations in the glass industry is the periodic rebuild of the furnaces. There are two major categories of rebuild; a normal rebuild and a complete rebuild, which are described in Section 4.1. For a number of the techniques discussed in Chapter 4, it may be both technically beneficial and more cost-effective to delay implementation until a rebuild. For some techniques implementation may only be possible during a rebuild (either normal or complete), but for other techniques such a delay may offer little benefit. These issues are discussed further in Section 4.1 and in the specific considerations of the techniques described in Chapter 4.

Another important factor in the decision of what is most appropriate at a particular installation, is the age of the furnace. The appropriate course of action for a furnace that is expected to run for a further 8 to 12 years may be very different than for a furnace which requires rebuilding in 1 or 2 years time. This can particularly affect the balance between, for example, a technique requiring a major change in technology (e.g. oxy-fuel firing) that can only be implemented at a rebuild, and a secondary technique that can be retrofitted to an existing plant.

Additional considerations regarding the BAT conclusions, which are specific to the glass industry, are reported below:

- Particulate matter

In general, BAT for controlling dust emissions from furnaces in the glass industry is considered to be the use of either an electrostatic precipitator or bag filter system, operating where appropriate, in conjunction with a dry or semi-dry acid gas scrubbing system. The performance associated with these techniques is discussed in Chapter 4.

However, in some circumstances, such as the use of cold top electric furnaces or special formulations of the batch composition (no volatile compounds), secondary abatement techniques compared with primary measures may not be fully justified in all cases.

Nevertheless, in this chapter it is considered that the better environmental performance of secondary abatement techniques with regard to dust, metals, fine particulate matter and gaseous emissions support the selection of secondary techniques as BAT and justify their application under normal economic conditions in furnaces of all types and all capacities.

- Nitrogen oxides

The applicability of the different techniques presented in Chapter 4 for the reduction of NO_X emissions vary significantly across the sectors of the glass industry. Most techniques could, in principle, be applied to all the sectors; however, their applicability requires a case-by-case approach, on the basis of both technical and economical constraints. An explanatory introduction is given in the relevant sections throughout the chapter, in order to summarise the characteristics of each sector in the context of defining BAT-AELs for NO_X emissions. The use of nitrates in the batch composition, required for assuring the quality of some glass products, represents an additional element to take into consideration when defining BAT for the different sectors of the glass industry.

- Sulphur oxides

In most glass formulations, the sulphate levels in the batch are already minimised commensurate with the glass formulation and product quality requirements. It is envisaged that, in most cases, BAT for dust emissions will involve the use of a dust abatement system, which will often include acid gas scrubbing. In many cases, the dust produced by filtration, containing sulphates, can be recycled with the furnace raw materials to avoid the generation of a solid waste stream. Where appropriate, this is taken into account in the proposed emission levels associated with BAT. The principle factors affecting emissions of SO_X are therefore, the choice of fuel, the glass type and considerations related to the use of abated dust recycling or other recycled waste, i.e. the use of cement bonded briquettes for the production of mineral wool. The scrubbing system also can be optimised in order to reduce other acid gases or volatile compounds, which might be present simultaneously in the waste gas to be treated. BAT-AELs discussed in the following sections are generally based on the use of such an optimised system.

It is considered outside the scope of this document to specify which fuels (natural gas or fuel oil) represent BAT.

- Other substances

For the purposes of this document, metals have been grouped on the basis of their potential environmental impact, as reported in Section 3.2.2.1, Table 3.3. This classification applies to metals and metal compounds. Those metals which fall outside of these groupings are either specified individually, due to their higher toxicity, or covered only within the category of dust, because their low toxicity, generally, does not justify specific consideration.
Where emission levels for metals are given in this document, these include both metals present in the gas phase and bound to dust (see Section 4.4.1.7).

Standard conditions

Unless stated otherwise, BAT associated emission levels given in this chapter are based on a typical averaging period of no less than 30 minutes and no greater than 24 hours and refer to the standard conditions shown in Table 5.1.

Melting activities	Unit	Standard conditions
Conventional melting furnace in continuous melters	mg/Nm^3	At 273 K, pressure of 1013 hPa, dry gas, referred to 8 % oxygen by volume
Conventional melting furnace in discontinuous melters	mg/Nm^3	At 273 K, pressure of 1013 hPa, dry gas, referred to 13 % oxygen by volume
Oxy-fuel fired furnaces	mg/Nm^3	*Measured values* at 273 K, pressure of 1013 hPa, dry gas, no correction for oxygen. In this case, the use of emission factors (kg/tonne melted glass) is more appropriate
Electric furnaces	mg/Nm^3	At 273 K, pressure of 1013 hPa, dry gas, no correction for oxygen
Frit melting furnaces	mg/Nm^3	At 273 K, pressure of 1013 hPa, dry gas, referred to 15 % oxygen by volume
All type of furnaces	kg/tonne glass	The emission factors refer to a tonne of melted glass
Non-melting activities		
All processes	mg/Nm^3	At 273 K, pressure of 1013 hPa, dry gas, no correction for oxygen
All processes	kg/tonne glass	The emission factors refer to a tonne of produced glass

Table 5.1: Standard conditions for the definition of BAT associated emission levels

Conversion factors and related calculation procedures

Emission levels associated with BAT may be presented as ranges for both emission concentrations (mg/Nm^3) and mass emissions (kg/tonne of melted glass). This dual approach allows for comparison between furnace techniques and provides an indication of the relative impact on the environment of the atmospheric emissions.

In most cases, the emission ranges reported in this chapter refer to a standard oxygen content in the waste gases. The formula for calculating the emissions concentration at a reference oxygen level is shown below:

$$\boxed{E_R = \frac{21 - O_R}{21 - O_M} * E_M}$$

Where:

E_R (mg/Nm^3): emissions concentration corrected to the reference oxygen level O_R
O_R (vol %): reference oxygen level
E_M (mg/Nm^3): emissions concentration referred to the measured oxygen level O_M
O_M (vol %): measured oxygen level

For emissions from fossil fuel fired furnaces, the relationship between emission concentration and the mass emitted per tonne of melted glass depends predominantly on the specific energy consumption for melting:

Mass emissions (kg/tonne of glass) = conversion factor x emissions concentration (mg/Nm^3)
where: conversion factor = (Q/P) x 10^{-6}
and Q = waste gas volume in Nm^3/h
P = pull rate in tonnes of glass/h

The waste gas volume depends mainly on energy consumption, type of fuel, and the oxidant (air or pure O_2). The energy consumption is a complex function of (predominantly) the type of furnace, the type of glass and the cullet percentage.

However, a range of factors can influence the relationship between concentration and specific mass flow, including:

- type of furnace (air preheating temperature, melting technique)
- type of glass produced (energy requirement for melting)
- energy mix (fossil fuel/electric boosting)
- type of fossil fuel (oil, gas)
- type of oxidant (oxygen, air, oxygen enriched air)
- cullet percentage
- batch composition
- age of the furnace
- furnace size.

Although, there is no straightforward way to define overall conversion factors, the dual approach used throughout the GLS BREF is justified by the simultaneous presence of different melting techniques in glass manufacturing installations, which is often the case for the sector and may represent a problem for the definition of the most appropriate BAT-AELs.

BAT-AELs indicated in the following sections refer to normal operating conditions. Lower BAT-AELs than the indicated values may be achieved in particularly favourable operating conditions; however these are difficult to maintain over a long period.

In this chapter, emission concentrations (mg/Nm^3) are given as the prime basis of the emission levels associated with BAT. To give ranges for mass emissions (kg/tonne of melted glass) which "generally equate" to these emission concentrations, a range of conversion factors have been developed corresponding to new and energy efficient air-fuel furnaces. Optimised energy consumption is thus assumed and, in this way, energy consumption is taken into account in the consideration of BAT. These conversion factors are given in Table 5.2.

In many instances, higher energy consumption figures may be observed, but in these cases the performances should be compared with the emission levels associated with BAT expressed as concentrations.

In some cases (electric furnaces, oxy-fuel firing), it is necessary to evaluate the performances only in terms of specific mass emissions (kg/tonne of melted glass).

In these cases, there is no linear correlation between the measured emission concentration and the specific mass emission; therefore, for the calculation of the emissions factor (kg/tonne of melted glass), the emission concentration of a corresponding conventional air-fuel furnace should be used in any case.

		Indicative factors to convert mg/Nm^3 into kg/tonne of melted glass$^{(1)}$
Flat glass		2.5×10^{-3}
Container glass	General case	1.5×10^{-3}
	Specific cases $^{(2)}$	3.0×10^{-3}
Continuous filament glass fibre		4.5×10^{-3}
Domestic glass	Soda lime	2.5×10^{-3}
	Specific cases $^{(3)}$	Case by case study (often 3.0×10^{-3})
Mineral wool		2×10^{-3}
Stone wool cupola		2.5×10^{-3}
Special glass TV glass (panels)		3×10^{-3}
Special glass TV glass (funnel)		2.5×10^{-3}
Borosilicate (tube)		4×10^{-3}
Glass ceramics		6.5×10^{-3}
Lighting glass (soda-lime)		2.5×10^{-3}
Frits		$5 - 37 \times 10^{-3}$

1. This table relates only to full air-fuel fired furnaces.
2. Specific cases correspond to less favourable cases (small special furnaces with a pull of generally below 100 t/day and a cullet rate of below 30 %). This category represents only 1 or 2 % of the container glass production.
3. Specific cases corresponding to less favourable cases and/or non-soda-lime glasses: borosilicates, glass ceramic, crystal glass and, less frequently, lead crystal glass.

Table 5.2: Indicative factors for converting mg/Nm^3 into kg/tonne of melted glass

5.2.1 Environmental management systems

A number of environmental management techniques are determined as BAT. The scope (e.g. level of detail) and nature of the EMS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the range of environmental impacts it may have.

1. **BAT is to implement and adhere to an Environmental Management System (EMS) that incorporates, as appropriate to individual circumstances, the following features (see Section 4.9):**

(a) commitment of top management (commitment of the top management is regarded as a precondition for a successful application of other features of the EMS)

(b) definition of an environmental policy that include continuous improvement for the installation by top management

(c) planning and establishing the necessary procedures, objectives and targets, in conjunction with financial planning and investment

(d) implementation of the procedures, paying particular attention to:

- structure and responsibility
- training, awareness and competence
- communication
- employee involvement
- documentation
- efficient process control
- maintenance programme
- emergency preparedness and response
- safeguarding compliance with environmental legislation.

(e) checking performance and taking corrective action, paying particular attention to:

- monitoring and measurement (see also the Reference Document on the General Principles of Monitoring [122, EC 2003])
- corrective and preventive action
- maintenance of records
- independent (where practicable) internal auditing in order to determine whether or not the environmental management system conforms to planned arrangements and has been properly implemented and maintained.

(f) review of the EMS and its continuing suitability, adequacy and effectiveness by top management.

Three further features are listed below, and while these features have advantages, EMS without them can be BAT:

- having the management system and audit procedure examined and validated by an accredited certification body or an external EMS verifier
- preparation and publication (and possibly external validation) of a regular environmental statement describing all the significant environmental aspects of the installation, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate
- implementation of and adherence to an internationally accepted voluntary system such as EMAS and EN ISO 14001:2004. This voluntary step could give higher credibility to the EMS. In particular EMAS, which embodies all the above-mentioned features, gives higher credibility. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

Specifically for this industry sector, it is also important to consider the following potential features of the EMS:

- the environmental impacts from the eventual decommissioning of the unit at the stage of designing a new plant
- the development of cleaner technologies, and to following developments
- where practicable, the application of sectoral benchmarking on a regular basis, including energy efficiency and energy conservation activities, choice of input materials, emissions to air, discharges to water, consumption of water and generation of waste.

5.2.2 Energy efficiency

General considerations regarding energy consumption are reported in Sections 3.2.3 and 4.8. Additional information regarding the sectors of the glass industry can be found in Chapter 3, in the sector specific sections.

Each sector of the glass industry presents a wide range of specific energy consumption which depends on many factors, among them, the type of furnace and its size, the type of glass produced, the age of the furnace, the cullet percentage used in the batch formulation.

Because of the dependence on the above mentioned reasons, and on the basis of available information, a quantitative BAT could not be established.

2. BAT is to reduce/minimise the specific energy consumption by applying the following measures/techniques individually or in combination:

i. process optimisation, through the control of the operating parameters
ii. regular maintenance of the melting furnace (see Section 4.2.2)
iii. optimisation of the furnace design and the selection of the melting technique (see Section 4.8.1)
iv. application of combustion control measures (see Section 4.8.2)
v. use of increasing levels of cullet, where available and technically possible (see Section 4.8.3)
vi. use of a waste heat boiler for energy recovery, where technically and economically viable (see Section 4.8.4)
vii. use of batch and cullet preheating, where technically and economically viable (see Section 4.8.5).

Furthermore, in this context, see also the Reference Document on Best Available Techniques for Energy Efficiency [124, EC 2008].

5.2.3 Materials storage and handling

General and sector specific considerations regarding diffuse emissions from storage and handling of materials are reported in Sections ().

3. BAT is to minimise/prevent diffuse dust emissions from the storage and handling of solid materials by applying the measures/techniques listed in Section 4.3,individually or in combination.

4. BAT is to minimise/prevent diffuse gaseous emissions from storage and handling of volatile raw materials by applying the measures/techniques listed in Section 4.3, individually or in combination.

Measures and techniques for the storage and handling of solid and volatile raw materials presented in Section 4.3 can be used individually or in combination appropriate to a particular installation.

Furthermore, in this context, see also the Reference Document on Best Available Techniques on Emissions from Storage. [121, EC 2006]

5.2.4 General primary measures/techniques

General considerations regarding the minimisation of energy consumption and emissions to air from the melting process are reported in Section 4.2.2 and 4.4.1.1.

5. BAT is to minimise energy consumption and the emissions to air by carrying out a constant monitoring of the operational parameters and a programmed maintenance of the melting furnace.

Measures for the monitoring and maintenance of the melting furnace are presented in Section 4.2.2. These measures apply mainly to regenerative furnaces and can be used individually or in combination appropriate to the type of furnace.

6. BAT is to carry out a careful selection and control of all substances and raw materials entering the melting furnace in order to reduce or avoid emissions to air.

Measures for selecting the raw materials and controlling the quality of fuels are presented in Section 4.4.1.1. These measures can be applied taking into account the quality and type of glass produced at the installation, and the availability of the raw materials and fuels.

7. BAT is to carry out monitoring of emissions and/or other relevant process parameters on a regular basis, including:

i. continuous monitoring of critical process parameters to ensure the process stability, i.e. temperature, fuel feed and air flow
ii. regular monitoring of process parameters to prevent/reduce pollution, i.e. O_2 content of the combustion gases to control the fuel/air ratio
iii. continuous or regular periodic measurements of dust, NO_X and SO_2 emissions
iv. continuous or regular periodic measurements of NH_3 emissions, when SCR or SNCR techniques are applied
v. continuous or regular periodic measurements of CO emissions when primary measures or chemical reduction by fuel techniques are applied
vi. regular periodic measurements of emissions of HCl, HF, CO and metals.

8. BAT is to operate the waste gas treatment systems during normal operating conditions at full capacity and availability in order to reduce or avoid emissions.

Special procedures can be defined for specific operating conditions, in particular:

i. start-up or shutdown operations
ii. other special operations which could affect the proper functioning of the system (e.g extraordinary maintenance work and cleaning operations)
iii. insufficient waste gas flow which prevents the use of the system at full capacity.

5.3 BAT for container glass manufacturing

5.3.1 Dust emissions from melting furnaces

This section presents BAT for dust emissions arising from the glass melting furnaces applied by the container glass sector.

9. BAT is to reduce dust emissions (particulate matter) from the waste gases of the melting furnace by applying an electrostatic precipitator or a bag filter system.

The emission levels of dust given in Table 5.3 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL [(1)] [(2)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
Particulate matter	Flue-gas cleaning by filtration for new or upgraded installations	<5 - 10	<0.01 - 0.03
	Flue-gas cleaning by filtration for existing installations	<10 - 30	<0.02 - 0.05

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The lower levels of the range are associated to the use of bag filters

Table 5.3: BAT associated emissions levels for dust from the melting furnace in the container glass sector

General considerations regarding the nature of particulate matter and the reported techniques are presented in Sections 4.4.1, 4.4.1.2 and 4.4.1.3.

5.3.2 Nitrogen oxides (NO_X) from melting furnaces

The container glass sector utilises a wide range of furnace types and sizes and there are many primary and secondary techniques available that can achieve good NO_X reduction efficiencies. There are a number of techniques, which can achieve very low NO_X levels, but which may only be applicable in certain circumstances, based mainly on the type of production and capacity of the melting furnace. These techniques are discussed in Chapter 4; for example, the use of electric melting (Section 4.2.1) and the application of special furnace design (Section 4.4.2.3). There are also techniques that are more widely applicable but which may not represent the most appropriate option in all circumstances, for example oxy-fuel firing (Section 4.4.2.5).

The most appropriate selection of the techniques mentioned below that represents BAT will depend very much on site-specific issues.

General considerations regarding the origin of NO_X emissions and the measures/techniques considered as BAT are presented in Section 4.4.2.

10. BAT is to reduce NO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

I. primary measures/techniques, such as:

  i. combustion modifications (see Section 4.4.2.1)
  ii. special furnace designs (see Section 4.4.2.3)
  iii. electric melting (see Section 4.2.1)
  iv. oxy-fuel melting (see Section 4.4.2.5)

II. secondary measures/techniques, such as:

  i. chemical reduction by fuel (see Section 4.4.2.6)
  ii. selective catalytic reduction, SCR (see Section 4.4.2.7)
  iii. selective non-catalytic reduction, SNCR (see Section 4.4.2.8).

11. By applying primary techniques and chemical reduction by fuel, BAT is to achieve the highest efficiency of NO_X emissions reduction, while limiting the associated emissions of CO.

12. By applying SCR and SNCR techniques, BAT is to achieve the highest efficiency of NO_X emissions reduction, while minimising the ammonia slip to concentrations of <30 mg/Nm^3, as the daily average value, or average over the sampling period (spot measurements).

The emission levels of NO_X given in Table 5.4 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL [(1)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Combustion modifications	<600 - 850	<0.9 - 1.3
	Special furnace design	<500	<0.75
	Electric melting	<100	<0.3
	Oxy-fuel melting		<0.5 - 0.8
	Secondary techniques[(2)]	<400 - 600	<0.5 - 0.8

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. In the case of applying SCR or SNCR, the associated emission levels are related to an ammonia slip of <30 mg/Nm^3.

Table 5.4: BAT associated emission levels for NO_X from the melting furnace in the container glass sector

13. When nitrates are used in the batch formulation, BAT is to reduce NO_X emissions by minimising the use of these raw materials, in combination with primary or secondary measures/techniques.

General considerations regarding the possible presence of nitrates in the batch formulation are presented in Section 4.4.2.2, while considerations concerning primary and secondary measures/techniques considered as BAT are presented in Sections 4.2.1, 4.4.2.1, 4.4.2.3 and 4.4.2.5 - 4.4.2.8.

The emission levels of NO_X given in Table 5.5 are BAT-AELs.

Parameter	BAT	BAT-AEL [1] (daily average values or average over the sampling period)	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Minimisation of nitrate input in the batch formulation combined with primary or secondary techniques	<1000	<3
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.			

Table 5.5: BAT associated emission levels for NO_X from the melting furnace in the container glass sector when nitrates are used in the batch formulation

5.3.3 Sulphur oxides (SO_X) from melting furnaces

General considerations regarding the emissions of sulphur oxides are given in Section 4.4.3.

For the container glass sector, the reduction of SO_X emissions has to be considered in combination with the need to recycle high levels of cullet and the need to minimise the waste stream from filter dust, both of which significantly contribute to the sulphur balance of the melting process. Furthermore, the simultaneous presence in the flue-gases of other gaseous pollutants to be minimised might influence the selection of the absorption agent when a scrubbing system is applied.

14. BAT is to reduce SO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. dry or semi-dry scrubbing stage, in combination with a filtration system (see Section 4.4.3.3)
ii. minimisation of the sulphur content in the batch formulation and optimisation of the sulphur balance (see Sections 4.4.3.2 and 8.2)
iii. use of low sulphur fuels (see Section 4.4.3.1).

The emission levels of SO_X given in Table 5.6 are BAT-AELs.

Parameter	Operating conditions	Fuel	BAT-AEL [1] [2] (daily average values or average over the sampling period)	
			mg/Nm^3	kg/tonne melted glass
SOx expressed as SO_2	No use of external cullet; no filter dust recycling	Natural gas	<200 - 500	<0.3 - 0.75
		Fuel oil [3]	500 - 1200 [4]	0.75 - 1.8 [4]
	Use of external cullet (>40 %); filter dust recycling	Natural gas	<500 - 800	<0.75 - 1.2
		Fuel oil [3]	<1200 - 1500	<1.8 - 2.3

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The ranges take into account the variable sulphur balances associated with the types of glass produced.
3. The associated emission levels are related to the use of 1 % sulphur fuel oil in combination with secondary abatement techniques.
4. The lower levels are associated with conditions where the reduction of SO_X is a high priority over a lower production of solid waste corresponding to the sulphate-rich filter dust.

Table 5.6: BAT associated emission levels for SO_X from the melting furnace in the container glass sector

5.3.4 Hydrogen chloride (HCl) and hydrogen fluoride (HF) from melting furnaces

General considerations regarding the emissions of HCl and HF are given in Section 4.4.4. In general, in the container glass sector, these emissions are related to the quality of the raw materials. In a limited number of cases, materials containing fluorides are intentionally used as raw materials (see Section 2.2.1).

15. BAT is to reduce HCl and HF emissions from the melting furnace (possibly combined with flue-gases from hot-end coating activities) by applying the following measures/techniques individually or in combination:

i. selection of raw materials for the batch formulation with a low content of chlorine and fluorine (see Section 4.4.4.1)
ii. dry or semi-dry scrubbing stage, in combination with a filtration system (see Section 4.4.3.3)

The emission levels of HCl and HF given in Table 5.7 are BAT-AELs.

Parameter	BAT-AEL [1] (daily average values or average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
Hydrogen chloride, expressed as HCl	<10 - 30	<0.02 - 0.05
Hydrogen fluoride, expressed as HF	<1 - 5	<0.001 - 0.008
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.		

Table 5.7: BAT associated emission levels for HCl and HF from the melting furnace in the container glass sector

5.3.5 Metals from melting furnaces

General considerations regarding the emissions of metals are given in Section 3.2.2.1.

In general, in the container glass sector, these emissions are mainly related to the quality of the raw materials, particularly the external cullet used in the batch formulation. However, metal compounds can be used as colouring and decolourising materials (see Section 2.2.1). Another source of emissions may be represented by the fuel oil utilised in the melting process.

16. BAT is to reduce metal emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selecting raw materials for the batch formulation with a low content of metals (see Section 4.8.3)
ii. minimising the use of metal compounds in the batch formulation, where colouring and decolourising of glass is needed (see Section 4.4.1.1)
iii. applying a dry or semi-dry scrubbing, in combination with a filtration system (see Section 4.4.3.3).

The emission levels of metals given in Table 5.8 are BAT-AELs.

Parameter [(5)]	**BAT-AEL** [(1) (2)] **(average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI})	<0.2 - 1 [(3) (4)]	<0.3 - 1.5 x 10^{-3}
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn)	<1 - 5 [(3) (4)]	<1.5 - 7.5 x 10^{-3}
1. Average values refer to spot measurements of at least 30 minutes. 2. The ranges refer to the sum of metals present in the flue-gases in both solid and gaseous phases. 3. The lower levels are BAT-AELs when metal compounds are not intentionally used in the batch formulation. 4. The upper levels are associated with the use of metals for colouring glass or with selenium for decolourising flint glass, or when the flue-gases from the hot-end coating operations are treated together with the melting furnace emissions. 5. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3).		

Table 5.8: BAT associated emission levels for metals from the melting furnace in the container glass sector

5.3.6 Emissions from downstream processes

The main potential source of emissions from downstream processes is hot end coating treatment. General considerations regarding the emissions from hot-end coating operations are given in Sections 3.3.2.3 and 4.5.1. A number of techniques described in Chapter 4 can be used to treat emissions and the techniques chosen will depend on installation specific issues.

17. When tin, organotin or titanium compounds are used for hot-end coating operations, BAT is to reduce emissions by applying the following measures/techniques individually or in combination:

i. minimising the losses of the coating product by ensuring a good sealing of the application system and applying a state-of-the-art extracting hood
ii. combining the flue gas from the coating operations with the waste gas from the melting furnace, when a secondary treatment system is applied (filter and dry or semi-dry scrubber) (see Section 4.5.1)
iii. applying a secondary technique, e.g. wet scrubbing or dry scrubbing and filtration (see Sections 4.4.3.3 and 4.4.3.4).

The emission levels of metals and HCl given in Table 5.9 are BAT-AELs.

Parameter	**BAT-AEL** [(1)] **(average over the sampling period)**
	mg/Nm^3
Particulate matter	<10
Titanium compounds expressed as Tin	<5
Tin, inorganic compounds expressed as Sn	<5
Organotin, expressed as Sn	<1
Chlorides, expressed as HCl	<30
1. Average values refer to spot measurements of at least 30 minutes.	

Table 5.9: BAT associated emission levels from hot-end coating activities in the container glass sector

18. When SO_3 is used for surface treatment operations, BAT is to reduce SO_X emissions by applying the following measures/techniques individually or in combination:

i. minimising the product losses by ensuring a good sealing of the application system
ii. applying a secondary technique, e.g. wet scrubbing (see Sections 3.3.2.3 and 4.4.3.4).

The emission levels of SO_X given in Table 5.10 are BAT-AELs.

Parameter	**BAT-AEL [(1)] (average over the sampling period)**
	mg/Nm^3
Sulphur oxides, expressed as SO_2	<100 - 200
1. Average values refer to spot measurements of at least 30 minutes	

Table 5.10: BAT associated emission levels for SO_X from downstream activities when SO_3 is used for surface treatment operations in the container glass sector

5.4 BAT for flat glass manufacturing

5.4.1 Dust emissions from melting furnaces

This section presents BAT for dust emissions arising from the glass melting furnaces applied by the flat glass sector.

19. BAT is to reduce dust emissions (particulate matter) from the waste gases of the melting furnace by applying an electrostatic precipitator or a bag filter system.

The emission levels of dust given in Table 5.11 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL [(1)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
Particulate matter	Flue-gas cleaning by filtration for new or upgraded installations	<5 - 10	<0.01 - 0.025
	Flue-gas cleaning by filtration for existing installations	<10 - 30	<0.03 - 0.075

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The lower levels are associated with the use of bag filters.

Table 5.11: BAT associated emission levels for dust from the melting furnace in the flat glass sector

General considerations regarding the nature of particulate matter and the reported techniques are presented in Sections 4.4.1, 4.4.1.2 and 4.4.1.3.

5.4.2 Nitrogen oxides (NO_X) from melting furnaces

General considerations regarding the origin of NO_X emissions and the measures/techniques considered as BAT are presented in Sections 4.4.2.

In the flat glass sector, almost all furnaces are cross-fired regenerative furnaces. Due to the large capacity of the furnaces used within the sector, the selection of techniques which may be applicable for the reduction of NO_X emissions is limited. Techniques such as electric melting, recuperative furnaces and other furnaces designed for low NOx levels, e.g. LowNO$_X$ Melter® are not applied within the sector due to technical limitations (see Sections 4.2.1 and 4.4.2.3).

20. BAT is to reduce NO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

I. primary measures/techniques, such as:

  i. combustion modifications (see Section 4.4.2.1)
  ii. Fenix process (see Section 4.4.2.4)
  iii. oxy-fuel melting (see Section 4.4.2.5)

II. secondary measures/techniques, such as:

  i. chemical reduction by fuel (see Section 4.4.2.6)
  ii. selective catalytic reduction, SCR (see Section 4.4.2.7)

21. By applying primary techniques and chemical reduction by fuel, BAT is to achieve the highest efficiency of NO_X emissions reduction, while limiting the associated emissions of CO.

22. By applying the SCR technique, BAT is to achieve the highest efficiency of NO_X emissions reduction, while minimising the ammonia slip to concentrations of <30 mg/Nm^3, as the daily average value, or average over the sampling period (spot measurements).

The emission levels of NO_X given in Table 5.12 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL (1) (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Combustion modifications and oxy-fuel melting	800	2.0
	Fenix process	<700 - 800	1.75 - 2.0
	Secondary techniques (2)	<500 - 800	<1.25 - 2.0

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The higher levels of the range are associated with a minimisation of the ammonia slip (SCR technique) with the control of energy consumption and CO emissions (3R technique).

Table 5.12: BAT associated emission levels for NO_X from the melting furnace in the flat glass sector

23. When nitrates are used in the batch formulation, BAT is to reduce NO_X emissions by minimising the use of these raw materials, in combination with primary or secondary measures/techniques.

General considerations regarding batch formulations are presented in Section 4.4.2.2. Considerations concerning primary and secondary measures/techniques considered as BAT are presented in Sections 4.4.2.1, 4.4.2.4, 4.4.2.6, and 4.4.2.7.

The emission levels of NO_X given in Table 5.13 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL (1) (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NO_X expressed as NO_2	Minimisation of nitrate input in the batch formulation combined with primary techniques	<1200	<3.0
	Minimisation of nitrate input in the batch formulation combined with secondary techniques	<500 - 800	<1.25 - 2.0
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.			

Table 5.13: BAT associated emission levels for NO_X from the melting furnace in the flat glass sector when nitrates are used in the batch formulation

5.4.3 Sulphur oxides (SO_X) from melting furnaces

General considerations regarding the emissions of sulphur oxides are given in Section 4.4.3.

For the flat glass sector, the priority of reducing SO_X emissions is often combined with the need to minimise the waste stream from filter dust. Furthermore, the simultaneous presence in the flue-gases of other gaseous pollutants to be minimised might influence the selection of the absorption agent when a scrubbing system is applied. In this context, an integrated approach is anticipated.

24. BAT is to reduce SO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. dry or semi-dry scrubbing, in combination with a filtration system (see Section 4.4.3.3)
ii. minimisation of the sulphur content in the batch formulation and optimisation of the sulphur balance (see Sections 4.4.3.2 and 8.2)
iii. use of low sulphur fuels (see Section 4.4.3.1).

The emission levels of SO_X given in Table 5.14 are BAT-AELs.

Parameter	**Fuel**	**BAT-AEL** (1) (2) **(daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
SOx expressed as SO_2	Natural gas	<200 - 500	<0.5 - 1.25
	Fuel oil (3) (4)	<500 - 1200	<1.25 - 3.0

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The higher levels of the range are associated with the recycling of filter dust in the batch formulation, where feasible, based on the quality of the glass.
3. The associated emission levels are related to the use of 1 % sulphur fuel oil in combination with secondary abatement techniques.
4. The lower levels are associated with conditions where the reduction of SO_X is a priority over a lower production of solid waste corresponding to the sulphate-rich filter dust. In this case, the lower levels are associated with the use of a bag filter.

Table 5.14: BAT associated emission levels for SO_X from the melting furnace in the flat glass sector

5.4.4 Hydrogen chloride (HCl) and hydrogen fluoride (HF) from melting furnaces

General considerations regarding the emissions of HCl and HF are given in Section 4.4.4. In general, in the flat glass sector, these emissions are exclusively related to the quality of the raw materials.

25. BAT is to reduce HCl and HF emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selection of raw materials for the batch formulation with a low content of chlorine and fluorine (see Section 4.4.4.1)
ii. dry or semi-dry scrubbing, in combination with a filtration system (see Section 4.4.3.3).

The emission levels of HCl and HF given in Table 5.15 are BAT-AELs.

Parameter	**BAT-AEL** (1) (2) **(daily average values or average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Hydrogen chloride, expressed as HCl	<10 - 30	<0.03 - 0.08
Hydrogen fluoride, expressed as HF	<1 - 5	<0.003 - 0.01

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The higher levels of the range are associated with the recycling of filter dust in the batch formulation, where feasible based on the quality of glass.

Table 5.15: BAT associated emission levels for HCl and HF from the melting furnace in the flat glass sector

5.4.5 Metals from melting furnaces

General considerations regarding the emissions of metals are given in Section 3.2.2.1. In general, in the flat glass sector, these emissions are related to the quality of the raw materials used in the batch formulation and the fuel oil utilised in the melting process. However, metal compounds can be used for colouring the glass (see Section 2.2.1). In particular, the production of bronze glass requires the use of significant amounts of selenium.

26. BAT is to reduce metal emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selecting the raw materials for the batch formulation with a low content of metals (see Section 4.4.1.1)
ii. applying a dry or semi-dry scrubbing stage, in combination with a filtration system (see Section 4.4.3.3).

The emission levels of metals given in Table 5.16 are BAT-AELs.

Parameter	BAT-AEL (1) (average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
Metals group 1 (As, Co, Ni, Cd, Se, Cr$_{VI}$) (2)	<0.1 - 0.2 (3)	<0.03 - 0.5 x 10^{-3}
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr$_{VI,}$ Sb, Pb, Cr$_{III}$, Cu, Mn, V, Sn) (2)	0.1 - 1 (3)	0.25 - 2.5 x 10^{-3}

1. The average values refer to spot measurements of at least 30 minutes.
2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3).
3. The ranges refer to the sum of metals present in the flue-gases in both solid and gaseous phases.

Table 5.16: BAT associated emission levels for metals from the melting furnace in the flat glass sector

27. When selenium compounds are used for colouring the glass, BAT is to reduce selenium emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. minimising the evaporation of selenium from the batch composition by selecting raw materials with a higher retention efficiency in the glass (see Section 4.4.1.1)
ii. applying a dry or semi-dry scrubbing stage, in combination with a filtration system (see Section 4.4.3.3).

The emission levels of selenium given in Table 5.17 are BAT-AELs.

Parameter	BAT-AEL (1) (2) (average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
Selenium compounds, expressed as Se (3)	1 - 3	2.5 - 8 x 10^{-3}

1. The average value refers to spot measurements of at least 30 minutes.
2. The values refer to the sum of selenium present in the flue-gases in both solid and gaseous phases.
3. The lower levels correspond to conditions where the reduction of Se emissions is a priority over a lower production of solid waste from filter dust. In this case, a high stoichiometric ratio (reagent/pollutant) is applied and a significant solid waste stream is generated.

Table 5.17 BAT associated emission levels for selenium from the melting furnace in the flat glass sector, when used for colouring the glass

5.4.6 Emissions from downstream processes

General considerations regarding the emissions from non-melting activities in the flat glass sector are given in Section 4.5.2, particularly regarding the surface treatment with SO_2 and coating processes.

In general, these emissions are very low and might not require the application of secondary measures.

A number of techniques described in Chapter 4 can be used to treat emissions and the techniques chosen will depend on installation-specific issues.

28. BAT is to reduce emissions to air from the downstream processes by applying the following measures/techniques individually or in combination:

i. minimising the losses of coating products applied to the flat glass by ensuring a good sealing of the application system
ii. minimising the losses of SO_2 from the annealing lehr, by maintaining the operating system well controlled
iii. combining the SO_2 emissions from the lehr with the waste gas from the melting furnace, when technically feasible, and where a secondary treatment system is applied (filter and dry or semi-dry scrubber)
iv. applying a secondary technique, e.g. wet scrubbing or dry scrubbing and filtration (see Sections 4.4.3.3 and 4.4.3.4).

The emission levels of pollutants given in Table 5.18 are BAT-AELs.

Parameter	**BAT-AEL (1) (2) (average over the sampling period)**
	mg/Nm^3
Particulate matter	<20
Chlorides, expressed as HCl	<30
Fluorides, expressed as HF	<5
SO_X, expressed as SO_2	<200
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI})	<1
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn)	<5

1. Average values refer to spot measurements of at least 30 minutes.
2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3).

Table 5.18: BAT associated emission levels from downstream processes in the flat glass sector

5.5 BAT for continuous filament glass fibre manufacturing

5.5.1 Dust emissions from melting furnaces

This section presents BAT for dust emissions arising from the glass melting furnaces applied by the continuous filament glass fibre sector.

In the production of continuous filament glass fibre, the nature of the dust and its formation phenomena related to the presence of high levels of boron compounds in the flue-gases (see Sections 3.5.2.2 and 4.4.1) need to be taken into account when selecting an abatement system. In particular, the cooling of the waste gas and the positioning of the abatement system are very important in optimising abatement efficiency. Especially in the production of E-glass, some boron compounds condensate at very low temperatures (see Section 3.5.2.2).

In those cases, where existing abatement equipment may have been installed and positioned regardless of the particular characteristics of the particulate matter present in the flue-gases, an improvement of the abatement performances might be possible only during a major rebuild of the installation.

29. BAT is to reduce dust emissions (particulate matter) from the waste gases of the melting furnace by applying the following measures/techniques individually or in combination:

i. reduction of the volatile components by raw material modifications (see Section 4.4.1.1)
ii. filtration system: electrostatic precipitator or bag filter (see Sections 4.4.1.2 and 4.4.1.3
iii. wet scrubbing system (see Section 4.4.3.4).

The emission levels of dust given in Table 5.19 are BAT-AELs.

Parameter	**Conditions**	**BAT-AEL (1) (2)** **(daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
Particulate matter	New or upgraded installations	<5 - 10	<0.02 - 0.05
	Existing installations	<10 - 30	<0.05 - 0.14

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The lower levels are associated with the use of bag filters.

Table 5.19: BAT associated emission levels for dust from the melting furnace in the continuous filament glass fibre sector

5.5.2 Nitrogen oxides (NO_X) from melting furnaces

General considerations regarding the origin of NO_X emissions and the measures/techniques considered as BAT are presented in Section 4.4.2.

In general, gas-fired recuperative furnaces or oxy-fuel fired furnaces are used for the production of continuous filament glass fibre; other types such as electric melting and regenerative furnaces are not applied because of technical limitations. For this reason, the selection of techniques which may be applicable to this sector for the reduction of NO_X emissions is limited. Furthermore, the presence of high concentrations of boron compounds in the flue-gas limits the potential applicability of the SCR technique, due to a possible negative effect on the catalyst. There are no known examples of the SNCR technique being used in this sector.

30. BAT is to reduce NO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. combustion modifications (see Section 4.4.2.1)
ii. oxy-fuel melting (see Section 4.4.2.5)

The emission levels of NO_X given in Table 5.20 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL [1] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Primary techniques	<600 - 1000 [2]	<0.5 - 4.5 [2]

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The lower levels of the range are associated with the application of oxy-fuel combustion.

Table 5.20: BAT associated emission levels for NO_X from the melting furnace in the continuous filament glass fibre sector

5.5.3 Sulphur oxides (SO_X) from melting furnaces

General considerations regarding the emissions of sulphur oxides are given in Section 4.4.3. For the continuous filament glass fibre sector, emissions of SO_X may arise from the fuel (oil-fired furnaces) and/or from the sulphates used in the batch composition for refining the glass. The simultaneous presence in the flue-gases of other gaseous pollutants to be minimised might influence the selection of the scrubbing system and/or the absorption agent. However, it should be considered that the presence of high concentrations of boron compounds in the flue-gases may limit the abatement efficiency of the reagent used in the dry or semi-dry scrubbing systems.

31. BAT is to reduce SO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. minimisation of the sulphur content in the batch formulation and optimisation of the sulphur balance (see Sections 4.4.3.2 and 8.2)
ii. use of low sulphur fuels (see Section 4.4.3.1)
iii. dry or semi-dry scrubbing, in combination with a filtration system (see Section 4.4.3.3)
iv. wet scrubbing (see Section 4.4.3.4).

The emission levels of SO_X given in Table 5.21 are BAT-AELs.

Parameter	**Fuel**	**BAT-AEL[1] [2] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
SOx expressed as SO_2	Natural gas	<200 - 800	<0.9 - 3.6
	Fuel oil [3] [4]	<500 - 1200	<2.2 - 4.5

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The higher levels of the range are associated with the use of sulphates in the batch formulation for refining the glass.
3. The associated emission levels are related to the use of 1 % sulphur fuel oil in combination with secondary abatement techniques.
4. The lower levels correspond to conditions where the reduction of SO_X is a priority over a lower production of solid waste corresponding to the sulphate-rich filter dust. In this case, the lower levels are associated with the use of a bag filter.

Table 5.21: BAT associated emission levels for SO_X from the melting furnace in the continuous filament glass fibre sector

5.5.4 Hydrogen chloride (HCl) and hydrogen fluoride (HF) from melting furnaces

General considerations regarding the emissions of HCl and HF are given in Section 4.4.4. In general, in the continuous filament glass fibre sector, the emissions of HCl are exclusively related to the quality of the raw materials. Emissions of HF may not only arise from impurities in the raw materials, but also from the use of compounds which contain fluorine in the batch formulations (see Section 3.5.2.2).

32. BAT is to reduce HCl and HF emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selection of raw materials for the batch formulation with a low content of chlorine and fluorine (see Section 4.4.4.1)
ii. minimisation of the fluorine content in the batch formulation (see Section 4.4.4.1)
iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3)
iv. wet scrubbing (see Section 4.4.3.4).

The emission levels of HCl and HF given in Table 5.22 are BAT-AELs.

Parameter	**BAT-AEL (1) (daily average values or average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Hydrogen chloride, expressed as HCl	<10	<0.05
Hydrogen fluoride, expressed as HF	<5 - 15 (2)	<0.02 - 0.07 (2)

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The higher levels of the range are associated with the use of fluorine compounds in the batch formulation.

Table 5.22: BAT associated emission levels for HCl and HF from the melting furnace in the continuous filament glass fibre sector

5.5.5 Metals from melting furnaces

General considerations regarding the emissions of metals are given in Section 3.2.2.1.

In general, in the continuous filament glass fibre sector, these emissions are related to the quality of the raw materials used in the batch formulation and tend to be low.

33. BAT is to reduce metal emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selecting the raw materials for the batch formulation with a low content of metals (see Section 4.4.1.1)
ii. applying a dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of metals given in Table 5.23 are BAT-AELs.

Parameter (2)	**BAT-AEL** (1) **(average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI})	<0.2 (3)	<0.9 x 10^{-3}
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, $Cr_{VI,}$ Sb, Pb, Cr_{III}, Cu, Mn, V, Sn)	<1 (3)	<4.5 x 10^{-3}

1. Average values refer to spot measurements of at least 30 minutes.
2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3).
3. The levels refer to the sum of metals present in the flue-gases in both solid and gaseous phases.

Table 5.23: BAT associated emission levels for metals from the melting furnace in the continuous filament glass fibre sector

5.5.6 Emissions from downstream processes

General considerations regarding the emissions from non-melting activities in the continuous filament glass fibre sector are given in Sections 3.5.2.3 and 4.5.3.
The emissions may arise from coating applications of the glass filaments and from cutting and milling of the products.

34. BAT is to reduce emissions from downstream processes by applying the following measures/techniques individually or in combination:

i. wet scrubbing systems (see Section 4.5.6.1.2)
ii. wet electrostatic precipitator (see Section 4.5.6.1.3)
iii. filtration system: bag filter (see Section 4.4.1.3)

The emission levels of pollutants given in Table 5.24 are BAT-AELs.

Parameter	**BAT-AEL** (1) **(average over the sampling period)**
	mg/Nm^3
Emissions from forming and coating	
Total particulate matter	<5 - 20
Formaldehyde	<10
Ammonia	<30
Total volatile organic compounds, expressed as C	<20
Emissions from cutting and milling	
Total particulate matter	<5 - 20

1. Average values refer to spot measurements of at least 30 minutes.

Table 5.24: BAT associated emission levels from downstream processes in the continuous filament glass fibre sector

5.6 BAT for domestic glass manufacturing

This sector presents a wide variety of products, with significant differences in the formulation of the batch compositions. For these reasons, a wide range of furnace types and sizes is utilised. The high quality standards generally required in domestic glass production may limit the application of some techniques that are potentially valid for the sector.

5.6.1 Dust emissions from melting furnaces

This section presents BAT for dust emissions arising from the glass melting furnaces applied by the domestic glass sector.

35. BAT is to reduce dust emissions (particulate matter) from the waste gases of the melting furnace by applying the following measures/techniques individually or in combination:

i. reduction of the volatile components by raw material modifications (see Section 4.4.1.1)
ii. electric melting (see Section 4.2.1)
iii. filtration system: electrostatic precipitator or bag filter (see Sections 4.4.1.2 and 4.4.1.3)
iv. wet scrubbing system (see Section 4.4.3.4).

The emission levels of dust given in Table 5.25 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL (1) (2) (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
Particulate matter	New or upgraded installations	<5 - 10	<0.02 - 0.03
	Existing installations	<10 - 30	<0.03 - 0.1
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The lower levels are associated with the use of bag filters.			

Table 5.25: BAT associated emission levels for dust from the melting furnace in the domestic glass sector

General considerations regarding the nature of particulate matter and the reported techniques are presented in Sections 4.4.1, 4.4.1.2 and 4.4.1.3.

For glasses containing significant amounts of metals or other substances of potentially high environmental concern (e.g. lead for crystal glass and fluorine for opal glass), the priority for reducing the emissions of these components is, in general, directly associated with the use of an efficient system for controlling dust emissions.

36. When producing domestic glass which in the batch formulation contains significant amounts of lead, fluorine or other substances of potentially high environmental concern, BAT is to reduce dust emissions (particulate matter) by applying the following measures/techniques individually or in combination:

i. electric melting (see Section 4.2.1)
ii. bag filter (see Section 4.4.1.3)
iii. electrostatic precipitator (see Section 4.4.1.2)

The emission levels of dust given in Table 5.26 are BAT-AELs.

Parameter	**Conditions**	**BAT-AEL [(1)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
Particulate matter	New and existing installations	1 - 10	0.003 - 0.03
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.			

Table 5.26: BAT associated emission levels for dust from the melting furnace in the domestic glass production, when containing lead, fluorine or other substances of high environmental concern

5.6.2 Nitrogen oxides (NO_X) from melting furnaces

General considerations regarding the origin of NO_X emissions and the measures/techniques considered as BAT are presented in Section 4.4.2.

In general, the domestic glass sector presents low production volumes and high quality requirements, which normally lead to higher potential NO_X emissions. For ensuring the necessary quality standards of the final product, the use of more oxidising combustion conditions, in the case of conventional furnaces, and the presence of nitrates in the batch formulation are often required.

The nature of the sector gives rise to a number of issues that can affect the options for NO_X control. For example, in the domestic glass sector compared to the container glass sector, furnaces are, on average, substantially smaller (<160 tonnes/day) and, in general, only internal cullet is used. Moreover, the furnace is usually run slightly hotter and residence time is up to 50 % longer (higher specific energy consumption). All of these factors lead to a potential increase of NO_X formation. Among the potentially applicable techniques described in Section 4.4.2, some have not yet been applied in the domestic glass sector due to technical or economic limitations (e.g. SCR, SNCR, chemical reduction by fuel). In this context, the selection of the most appropriate BAT will depend on the features of the particular installation.

37. BAT is to reduce NO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

I. primary measures/techniques, such as:

i. combustion modifications (see Section 4.4.2.1)
ii. special furnace designs (see Section 4.4.2.3)
iii. electric melting (see Section 4.2.1)
iv. oxy-fuel melting (see Section 4.4.2.5).

38. By applying primary techniques, BAT is to achieve the highest efficiency of NO_X emissions reduction, while limiting the associated emissions of CO.

The emission levels of NO_X given in Table 5.27 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL** [1] **(daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Primary techniques	<500 - 800 [2]	<0.5 - 2.0 [2]
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The lower levels are associated with the use of oxy-fuel combustion and electric melting.			

Table 5.27: BAT associated emission levels for NO_X from the melting furnace in the domestic glass sector

39. When nitrates are used in the batch formulation and/or special oxidising combustion conditions are required in the melting furnace for ensuring the quality of the final product, BAT is to reduce NO_X emissions by applying the following measures/techniques individually or in combination:

I. primary measures/techniques, such as:

i. minimisation of the nitrate content in the batch formulation (see Section 4.4.2.2)
ii. combustion modifications (see Section 4.4.2.1)
iii. special furnace designs (see Section 4.4.2.3)
iv. electric melting (see Section 4.2.1)
v. oxy-fuel melting (see Section 4.4.2.5)

II. secondary measures/techniques, such as:

i. chemical reduction by fuel (see Section 4.4.2.6)
ii. selective catalytic reduction, SCR (see Section 4.4.2.7)
iii. selective non-catalytic reduction, SNCR (see Section 4.4.2.8).

40. By applying primary techniques and chemical reduction by fuel, BAT is to achieve the highest efficiency of NO_X emissions reduction while limiting the associated emissions of CO.

41. By applying the SCR or SNCR techniques, BAT is to achieve the highest efficiency of NO_X emissions reduction while minimising the ammonia slip to concentrations of <30 mg/Nm^3, as the daily average value, or average over the sampling period (spot measurements).

The emission levels of NO_X given in Table 5.28 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL** [1] **(daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Minimisation of nitrate input in the batch formulation combined with primary or secondary techniques	<500 - 1500 [2]	<1 - 4 [2]
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The lower levels are associated with the use of electric melting.			

Table 5.28: BAT associated emission levels for NO_X from the melting furnace in the domestic glass sector when nitrates and/or oxidising conditions are applied

5.6.3 Sulphur oxides (SO_X) from melting furnaces

General considerations regarding the emissions of sulphur oxides are given in Section 4.4.3.

In the domestic glass sector, the use of external cullet, as well as the recycling of filter dust in the batch composition, are normally very limited due to high quality requirements. In general, for gas-fired or electric melting furnaces, SO_X emissions tend to be low.

42. BAT is to reduce SO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. minimisation of the sulphur content in the batch formulation and optimisation of the sulphur balance (see Sections 4.4.3.2 and 8.2)
ii. use of low sulphur fuels (see Section 4.4.3.1)
iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of SO_X given in Table 5.29 are BAT-AELs.

Parameter	**Fuel/melting technique**	**BAT-AEL (1) (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
SOx expressed as SO_2	Natural gas	<100 - 300	<0.2 - 0.7
	Fuel oil (2)	<1000	<2.5
	Electric melting	<100	<0.2
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The associated emission levels are related to the use of 1 % sulphur fuel oil in combination with secondary abatement techniques.			

Table 5.29: BAT associated emission levels for SO_X from the melting furnace in the domestic glass sector

5.6.4 Hydrogen chloride (HCl) and hydrogen fluoride (HF) from melting furnaces

General considerations regarding the emissions of HCl and HF are given in Section 4.4.4. In general, in the domestic glass sector, these emissions are related to the quality of the raw materials. In specific cases, in particular for the production of opal glass, materials containing fluorides are used in the batch formulation (see Section 2.2.1).

43. BAT is to reduce HCl and HF emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selection of raw materials for the batch formulation with a low content of chlorine and fluorine (see Section 4.4.4.1)
ii. minimisation of the fluorine content in the batch formulation and optimisation of the fluorine mass balance (see Section 4.4.4.1)
iii. dry or semi-dry scrubbing, in combination with a filtration system (see Section 4.4.3.3)
iv. wet scrubbing (see Section 4.4.3.4).

The emission levels of HCl and HF given in Table 5.30 are BAT-AELs.

Parameter	BAT-AEL [(1)] (daily average values or average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
Hydrogen chloride, expressed as HCl	<10 - 20 (2)	<0.03 - 0.06 (2)
Hydrogen fluoride, expressed as HF	<1 - 5 (3)	<0.003 - 0.015 (3)
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The lower levels are associated with the use of electric melting. 3. The higher levels are associated with the production of opal glass.		

Table 5.30: **BAT associated emission levels for HCl and HF from the melting furnace in the domestic glass sector**

5.6.5 Metals from melting furnaces

General considerations regarding the emissions of metals are given in Section 3.2.2.1.

In the domestic glass sector, these emissions may be related to the quality of the raw materials. The emission of metals, e.g. nickel and vanadium, may also originate from the fuel oil utilised in the melting process. In addition, metal compounds can be used as colouring and decolourising materials as well as to confer special characteristics to the glass, e.g. crystal and lead crystal glass (see Sections 2.2.1 and 3.6.2.2).

44. BAT is to reduce metal emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selecting raw materials for the batch formulation with a low content of metals (see Section 4.8.3)
ii. minimising the use of metal compounds in the batch formulation through a suitable selection of the raw materials where colouring and decolourising of glass is needed or where specific characteristics are conferred to the glass (see Section 4.4.1)
iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of metals given in Table 5.31 are BAT-AELs.

Parameter	BAT-AEL (1) (average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI}) (2)	<0.2 - 1 (3)	<0.6 - 3 x 10^{-3}
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn) (2)	<1 - 5 (3)	<3 - 15 x 10^{-3}
1. The average values refer to spot measurements of at least 30 minutes. 2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3). 3. The ranges refer to the sum of metals present in the flue-gases in both Solid and gaseous phases.		

Table 5.31: **BAT associated emission levels for metals from the melting furnace in the domestic glass sector**

45. When selenium compounds are used for decolourising the glass, BAT is to reduce selenium emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. minimising the use of selenium compounds in the batch formulation, through a suitable selection of the raw materials (see Section 4.4.1)
ii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of selenium given in Table 5.32 are BAT-AELs.

Parameter	**BAT-AEL [(1) (2)] (average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Selenium compounds, as Se	<1	<3 x 10^{-3}
1. The average value refers to spot measurements of at least 30 minutes. 2. The values refer to the sum of selenium present in the flue-gases in both solid and gaseous phases.		

Table 5.32 BAT associated emission levels for selenium from the melting furnace in the domestic glass sector when used for decolourising the glass

46. When lead compounds are used for the manufacturing of lead crystal glass, BAT is to reduce lead emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. electric melting (see Section 4.2.1)
ii. bag filter (see Section 4.4.1.3)
iii. electrostatic precipitator (see Section 4.4.1.2)
iv. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of lead given in Table 5.33 are BAT-AELs.

Parameter	**BAT-AEL [(1) (2)] (average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Lead compounds,expressed as Pb	<0.5 - 1	<1 - 3 x 10^{-3}
1. The average values refer to spot measurements of at least 30 minutes. 2. The values refer to the sum of lead present in the flue-gases in both solid and gaseous phases.		

Table 5.33 BAT associated emission levels for lead from the melting furnace in the domestic glass sector when used for manufacturing lead crystal glass

5.6.6 Emissions from downstream processes

The main potential sources of emissions from downstream processes in the domestic glass sector are associated with cutting, grinding and polishing operations of the articles, particularly for crystal and lead crystal glasses. Where acid polishing is applied, a specific treatment of the resulting acid gases is required.

General considerations regarding the emissions from downstream processes are given in Sections 3.6.2.3 and 4.5.4.

47. For downstream dusty processes, BAT is to reduce emissions of dust (particulate matter) and metals by applying the following measures/techniques individually or in combination:

i. performing dusty operations (e.g. cutting, grinding, polishing) under liquid (see Section 4.5.4)
ii. applying a bag filter system (see Section 4.4.1.3).

The emission levels of dust (particulate matter) and metals given in Table 5.34 are BAT-AELs.

Parameter	**BAT-AEL (1)** **(average over the sampling period)**
	mg/Nm^3
Particulate matter	<1 - 10
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn) (2)	<1 - 5
Lead compounds, expressed as Pb	<1 - 1.5 (3)
1. Average values refer to spot measurements of at least 30 minutes. 2. The levels refer to the sum of metals present in the waste gas. 3. The levels refer to downstream operations on lead crystal glass.	

Table 5.34: BAT associated emission levels from dusty downstream processes in the domestic glass sector

48. For acid polishing processes, BAT is to reduce HF emissions by applying the following measures/techniques individually or in combination:

i. minimising the losses of polishing product by ensuring a good sealing of the application system
ii. applying a secondary technique, e.g. wet scrubbing (see Sections 3.6.2.3 and 4.4.3.4).

The emission levels of HF given in Table 5.35 are BAT-AELs.

Parameter	**BAT-AEL (1)** **(average over the sampling period)**
	mg/Nm^3
Hydrogen fluoride, expressed as HF	<5
1. Average value refers to spot measurements of at least 30 minutes.	

Table 5.35: BAT associated emission levels for HF from acid polishing processes in the domestic glass sector

5.7 BAT for special glass manufacturing

The special glass manufacturing sector presents a wide range of products, glass formulations and production techniques. Most of the melting techniques described in Section 2.3 are applied to the sector. The specific energy consumption associated with each type of product varies from 5 to 17 GJ/tonne melted glass with a consequent wide range of conversion factors to transform emissions concentration (mg/Nm^3) into kg/tonne melted glass.

Due to these characteristics, BAT-AELs given as emission factors in the next tables may present a wide range of values in order to include all the products of the sector.
However, the extensive use of oxy-fuel firing and electric melting for the manufacturing of special glass requires to associate BAT-AELs given in emission concentrations to emission factors. For a more specific correlation, a reference should be made to Table 5.2 to determine the corresponding mass emission for each product type.

5.7.1 Dust emissions from melting furnaces

This section presents BAT for dust emissions arising from the glass melting furnaces applied by the special glass sector.

49. BAT is to reduce dust emissions (particulate matter) from the waste gases of the melting furnace by applying the following measures/techniques individually or in combination:

i. reduction of the volatile components by raw material modifications (see Section 4.4.1.1)
ii. electric melting (see Section 4.2.1)
iii. filtration system: electrostatic precipitator or bag filter (see Sections 4.4.1.2 and 4.4.1.3

The emission levels of dust given in Table 5.36 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL [(1)] [(2)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
Particulate matter	Flue-gas cleaning by filtration for new or upgraded installations	<5 - 10	<0.01 - 0.07
	Flue-gas cleaning by filtration for existing installations	<10 - 30	<0.07 - 0.2

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The lower levels are associated with the use of bag filters.

Table 5.36: BAT associated emission levels for dust from the melting furnace in the special glass sector

General considerations regarding the nature of particulate matter and the reported techniques are presented in Sections 4.4.1, 4.4.1.2 and 4.4.1.3.

For glasses containing significant amounts of metals or other substances of potentially high environmental concern (e.g. lead for TV funnels or optical glass, fluorine for opaque and optical glass, see Table 2.8), the priority for reducing the emissions of these components is, in general, directly associated with the use of an efficient system for controlling dust emissions.

50. When producing special glass which in the batch formulation contains significant amounts of lead, fluorine or other substances of potentially high environmental concern, BAT is to reduce dust emissions (particulate matter) by applying the following measures/techniques individually or in combination:

i. electric melting (see Section 4.2.1)
ii. bag filter (see Section 4.4.1.3)
iii. electrostatic precipitator (see Section 4.4.1.2).

The emission levels of dust given in Table 5.37 are BAT-AELs.

Parameter	**Conditions**	**BAT-AEL [(1)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
Particulate Matter	New and existing installations	1 - 10	0.003 - 0.07

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.

Table 5.37: BAT associated emission levels for dust from the melting furnace in the special glass production when containing lead, fluorine or other substances of high environmental concern

5.7.2 Nitrogen oxides (NO_X) from melting furnaces

General considerations regarding the origin of NO_X emissions and the measures/techniques considered as BAT are presented in Section 4.4.2.
In general, the special glass sector presents a wide range of furnace types and sizes, together with a large variety of products, most of them with high quality requirements. For ensuring the necessary quality standards of the final article, the presence of significant amounts of nitrates in the batch formulation is often required. In this context, the selection of the most appropriate BAT will depend on the features of the particular installation.

There are a number of techniques that can potentially achieve low NO_X emission levels, but may not be applicable to all installations and other techniques that are applicable only at the time of the furnace rebuild (e.g. oxy-fuel or revised furnace geometry).

Where high levels of nitrates need to be used, consideration should also be given to minimising their use as far as is practicable within the constraints of the process and product requirements.

51. BAT is to reduce NO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

I. primary measures/techniques, such as:

- i. combustion modifications (see Section 4.4.2.1)
- ii. electric melting (see Section 4.2.1)
- iii. oxy-fuel melting (see Section 4.4.2.5)

II. secondary measures/techniques, such as:

- i. chemical reduction by fuel (see Section 4.4.2.6)
- ii. selective catalytic reduction, SCR (see Section 4.4.2.7)
- iii. selective non-catalytic reduction, SNCR (see Section 4.4.2.8).

52. By applying chemical reduction by fuel, BAT is to achieve the highest efficiency of NO_X emissions reduction, while limiting the associated emissions of CO.

53. By applying the SCR or SNCR techniques, BAT is to achieve the highest efficiency of NO_X emissions reduction, while minimising the ammonia slip to concentrations of <30 mg/Nm^3, as the daily average value or average over the sampling period (spot measurements).

The emission levels of NO_X given in Table 5.38 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL [(1)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NOx expressed As NO_2	Combustion modification	600 - 850	1.5 - 6
	Eelectric melting	<100	0.2 – 0.6
	Oxy-fuel melting		1 - 3
	Secondary techniques	<500	1 - 3
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.			

Table 5.38: BAT associated emission levels for NO_X from the melting furnace in the special glass sector

54. When nitrates are used in the batch formulation to ensure the quality of the final product, BAT is to reduce NO_X emissions by applying the following measures/techniques individually or in combination:

I. primary measures/techniques, such as:

- i. minimisation of the nitrate content in the batch formulation (see Section 4.4.2.2)
- ii. electric melting (see Section 4.2.1)
- iii. oxy-fuel melting (see Section 4.4.2.5)

II. secondary measures/techniques, such as:

- i. chemical reduction by fuel (see Section 4.4.2.6)
- ii. selective catalytic reduction, SCR (see Section 4.4.2.7)
- iii. selective non-catalytic reduction, SNCR (see Section 4.4.2.8).

General considerations regarding the possible presence of nitrates in the batch formulation are presented in Sections 3.7.1, 3.7.2.2 and 4.4.2.2.

The emission levels of NO_X given in Table 5.39 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL [(1)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Minimisation of nitrate input in the batch formulation combined with primary or secondary techniques	<500 - 1000 [(2)]	<1 - 6
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The lower levels are associated with the use of electric melting.			

Table 5.39: BAT associated emission levels for NO_X from the melting furnace in the special glass sector when nitrates are used in the batch formulation

5.7.3 Sulphur oxides (SO_X) from melting furnaces

General considerations regarding the emissions of sulphur oxides are given in Section 4.4.3.

In the special glass sector, the use of raw materials containing sulphur is rather limited. Normally, the main source of SO_X emissions is represented by the impurities of the raw materials and the possible use of fuel oil for the melting process. In general, due to high quality requirements of the final product, the recycling of filter dust and the use of external cullet are not applied.

55. BAT is to reduce SO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. minimisation of the sulphur content in the batch formulation and optimisation of the sulphur balance (see Sections 4.4.3.2 and 8.2)
ii. use of low sulphur fuels (see Section 4.4.3.1)
iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of SO_X given in Table 5.40 are BAT-AELs.

Parameter	Fuel/melting technique	BAT-AEL (1) (2) (daily average values or average over the sampling period)	
		mg/Nm^3	kg/tonne melted glass
SO_X expressed as SO_2	Natural gas, electric melting	50 - 200 (3)	0.1 - 0.5 (3)
	Fuel oil (4)	500 - 1000	1.5 - 2.5

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The ranges take into account the variable sulphur balances associated with the type of glass produced.
3. The lower levels are associated with the use of electric melting and batch formulations without sulphates.
4. The associated emission levels are related to the use of 1 % sulphur fuel oil in combination with secondary abatement techniques.

Table 5.40: BAT associated emission levels for SO_X from the melting furnace in the special glass sector

5.7.4 Hydrogen chloride (HCl) and hydrogen fluoride (HF) from melting furnaces

General considerations regarding the emissions of HCl and HF are given in Section 4.4.4.

In the special glass sector, in addition to the emissions related to the quality of the raw materials, the production of some types of glass require the use of materials containing fluorine, in particular for optical glasses and lighting glasses (see Section 2.8). In some specific cases, such as the production of borosilicate glass tubes, materials containing chlorine are also used in the batch formulation.

56. BAT is to reduce HCl and HF emissions from the melting furnace by applying the following measures/techniques individually or in combination:

- i. selection of raw materials for the batch formulation with a low content of chlorine and fluorine as impurities present (see Section 4.4.4.1)
- ii. minimisation of the use of fluorine and/or chlorine compounds in the batch formulation, and optimisation of the fluorine and/or chlorine mass balance (see Section 4.4.4.1)
- iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of HCl and HF given in Table 5.41 are BAT-AELs.

Parameter	**BAT-AEL** [(1)] **(daily average values or average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Hydrogen chloride, expressed as HCl	<10 - 30 (2)	<0.03 - 0.1 (2)
Hydrogen fluoride, expressed as HF	<1 - 5 (3)	<0.003 - 0.02 (3)

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The higher levels are associated with the use of materials containing chlorine in the batch formulation.
3. The higher levels are associated with the use of materials containing fluorine in the batch formulation.

Table 5.41: BAT associated emission levels for HCl and HF from the melting furnace in the special glass sector

5.7.5 Metals from melting furnaces

General considerations regarding the emissions of metals are given in Section 3.2.2.1.

In special glass production, emissions of metals are often related to the use of specific substances for colouring or decolourising the glass, and for giving special characteristics to the final product (see Sections 2.8 and 3.7.1). Another potential source of emissions is related to the quality of the raw materials used in the batch formulations and the fuel oil utilised in the melting process.

57. BAT is to reduce metal emissions from the melting furnace by applying the following measures/techniques individually or in combination:

- i. selection of raw materials for the batch formulation with a low content of metals (see Section 4.8.3)
- ii. minimisation of the use of metal compounds in the batch formulation through a suitable selection of the raw materials, where colouring and decolourising of glass is needed or where specific characteristics are conferred on the glass
- iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of metals given in Table 5.42 are BAT-AELs.

Parameter	BAT-AEL (1) (4) (average over the sampling period)	
	mg/Nm³	kg/tonne melted glass
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI})(2)	<0.1 - 1 (3)	<0.3 - 3 x 10^{-3}
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn) (2)	<1 - 5 (3)	<3 - 15 x 10^{-3}

1. The average values refer to spot measurements of at least 30 minutes.
2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3).
3. The ranges refer to the sum of metals present in the flue-gases in both solid and gaseous phases.
4. The lower levels are BAT-AELs when metal compounds are not intentionally used in the batch formulation.

Table 5.42: BAT associated emission levels for metals from the melting furnace in the special glass sector

5.7.6 Emissions from downstream processes

The emissions from downstream processes in the special glass sector are very case specific. In general, they are associated with cutting, grinding and polishing operations which generate dust emissions. Where acid polishing is applied, a specific treatment of the resulting acid gases is required.

General considerations regarding the emissions from downstream processes are given in Sections 3.7.2.3 and 4.5.5.

58. For downstream dusty processes, BAT is to reduce emissions of dust (particulate matter) and metals by applying the following measures/techniques individually or in combination:

i. performing dusty operations (e.g. cutting, grinding, polishing) under liquid (see Section 4.5.5)
ii. applying a bag filter system (see Section 4.4.1.3).

The emission levels of dust (particulate matter) and metals given in Table 5.43 are BAT-AELs.

Parameter	BAT-AEL (1) (2) (average over the sampling period)
	mg/Nm³
Particulate matter	1 - 10
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn) (3)	<1 - 5

1. Average values refer to spot measurements of at least 30 minutes.
2. The levels refer to the sum of metals present in the waste gas.

Table 5.43: BAT associated emission levels for particulate matter and metals from downstream processes in the special glass sector

59. For acid polishing processes, BAT is to reduce HF emissions by applying the following measures/techniques individually or in combination:

i. minimisation of the losses of the polishing product by ensuring a good sealing of the application system
ii. application of a secondary technique, e.g. wet scrubbing (see Section 4.4.3.4).

The emission levels of HF given in Table 5.44 are BAT-AELs.

Parameter	BAT-AEL (1) (average over the sampling period)
	mg/Nm^3
Hydrogen fluoride, expressed as HF	<5
1. Average value refers to spot measurements of at least 30 minutes.	

Table 5.44: BAT associated emission levels for HF from acid polishing processes in the special glass sector

5.8 BAT for mineral wool manufacturing

5.8.1 Dust emissions from melting furnaces

This section presents BAT for dust emissions arising from the glass melting furnaces applied by the mineral wool sector (glass wool and stone wool).
In glass wool production the nature of the dust and its formation phenomena, related to the presence of high levels of boron compounds in the flue-gases (see Section 4.4.1), need to be taken into account when selecting an abatement system. In particular, the cooling of the waste gas and the positioning of the abatement system are very important in optimising abatement efficiency.

Existing abatement equipment may have been installed and positioned without considering the specific characteristics of the particulate matter present in the flue-gases; therefore, an improvement of the abatement performances might be possible only during a major rebuild of the installation.

60. BAT is to reduce dust emissions (particulate matter) from the waste gases of the melting furnace by applying an electrostatic precipitator or a bag filter system.

The emission levels of dust given in Table 5.45 are BAT-AELs.

Parameter	BAT	BAT-AEL (1) (daily average values or average over the sampling period)	
		mg/Nm^3	kg/tonne melted glass
Particulate matter	Flue-gas cleaning by filtration for new or upgraded installations	<5 - 10	<0.01 - 0.02
	Flue-gas cleaning by filtration for existing installations	<10 - 30	<0.02 - 0.06
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.			

Table 5.45: BAT associated emission levels for dust from the melting furnace in the mineral wool sector

General considerations regarding the nature of particulate matter and the reported techniques are presented in Sections 4.4.1, 4.4.1.2 and 4.4.1.3.

Cupola furnaces will be fitted with bag filters rather than electrostatic precipitators due to the risk of explosion from the ignition of carbon monoxide produced within the furnace.

5.8.2 Nitrogen oxides (NO_X) from melting furnaces

General considerations regarding the origin of NO_X emissions and the measures/techniques considered as BAT are presented in Section 4.4.2.

In the mineral wool sector, a limited range of furnace types is applied for the melting process. In general, gas-fired and electric furnaces are used for glass wool production, and cupola or immersed electric arc furnaces for stone wool manufacturing (see Section 3.8.2.2). For this reason, the selection of techniques which may be applicable to the sector is limited.In many circumstances, the use of high levels of recycled material in the melting process, with high levels of organic components, requires the addition of nitrates in the batch composition. In this context, higher levels of NO_X are anticipated.

61. BAT is to reduce NO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. combustion modifications (see Section 4.4.2.1)
ii. electric melting (see Section 4.2.1)
iii. oxy-fuel melting (see Section 4.4.2.5).

The emission levels of NO_X given in Table 5.46 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL [(1)] (daily average values or average over the sampling period)**	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Primary techniques	<300 – 500 (2)	<0.5 - 1.0 (2)
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The lower levels of the ranges are associated with the application of oxy-fuel melting.			

Table 5.46: BAT associated emission levels for NO_X from the melting furnace in the mineral wool sector

62. When nitrates are used in the batch formulation, BAT is to reduce NO_X emissions by applying the following measures/techniques individually or in combination:

i. minimisation of the nitrate content in the batch formulation (see Section 4.4.2.2)
ii. electric melting (see Section 4.2.1)
iii. oxy-fuel melting (see Section 4.4.2.5).

The emission levels of NO_X given in Table 5.47 are BAT-AELs.

Parameter	BAT	BAT-AEL (1) (daily average values or average over the sampling period)	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Minimisation of nitrate input in the batch formulation, combined with primary techniques	<500 – 700 (2)	<1.0 - 1.4 (2)

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The lower levels of the ranges are associated with the application of oxy-fuel melting.

Table 5.47: BAT associated emission levels for NO_X from the melting furnace in the mineral wool sector when nitrates are used in the batch formulation

5.8.3 Sulphur oxides (SO_X) from melting furnaces

General considerations regarding the emissions of sulphur oxides are given in Section 4.4.3.

In general, for glass wool production, emissions of sulphur oxides (expressed as SO_2) tend to be very low. Almost all furnaces are gas fired or electrically heated and only very low levels of sulphate are used (see Section 3.8.2.2).

Most of the stone wool production is made with coke-fired cupola furnaces operated under strong reducing conditions.

Production waste, processed into cement briquettes, and blast furnace slag are often recycled in the batch formulation. The combination of these aspects results in variable charges of sulphur compounds and, consequently, variable emission levels (see Section 3.8.2.1).

For stone wool production, where a "waste briquetting" system is in place, the priority of reducing SO_X emissions is often combined with the need to minimise the waste stream from the fiberising process and from filter dust. In this context, an integrated approach is anticipated (see Section 3.8.4).

63. BAT is to reduce SO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. minimisation of the sulphur content in the batch formulation and optimisation of the sulphur balance (see Sections 4.4.3.2 and 8.2)
ii. use of low sulphur fuels (see Section 4.4.3.1).
iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3)
iv. wet scrubbing system (see Section 4.4.3.4).

The emission levels of SO_X given in Table 5.48 are BAT-AELs.

Parameter	Product/conditions	BAT-AEL [(1)] (daily average values or average over the sampling period)	
		mg/Nm^3	kg/tonne melted glass
SO_X expressed as SO_2	Glass wool - gas-fired and electric furnaces	<50 - 150 (2)	<0.1 - 0.3 (2)
	Stone wool - gas-fired and electric furnaces	<350	<0.7
	Stone wool - cupola furnaces, 0 % briquettes recycling	300 - 600 (3)	0.6 - 1.2 (3)
	Stone wool - cupola furnaces, <45 % briquettes recycling	600 - 1200 (4)	1.2 – 2.4 (4)
	Stone wool - cupola furnaces, >45 up to 100 % briquettes recycling	1200 - 1500 (5)	2.4 - 3.0 (5)

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The lower levels of the ranges are associated with the use of electric melting.
3. The levels of the ranges are associated with initial emission concentrations of 500 - 1000 mg/Nm^3 and a removal efficiency of 40 % achieved with secondary abatement techniques.
4. The levels of the ranges are associated with initial emission concentrations of 1000 - 2000 mg/Nm^3 and a removal efficiency of 40 % achieved with secondary abatement techniques.
5. The levels of the ranges are associated with initial emission concentrations of 2000 - 2500 mg/Nm^3 and a removal efficiency of 40 % achieved with secondary abatement techniques.

Table 5.48: BAT associated emission levels for SO_X from the melting furnace in the mineral wool sector

5.8.4 Hydrogen chloride (HCl) and hydrogen fluoride (HF) from melting furnaces

General considerations regarding the emissions of HCl and HF are given in Section 4.4.4. In general, in the mineral wool sector, these emissions are exclusively related to the quality of the raw materials.

64. BAT is to reduce HCl and HF emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selection of raw materials for the batch formulation with a low content of chlorine and fluorine (see Section 4.4.4.1)
ii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of HCl and HF given in Table 5.49 are BAT-AELs.

Parameter	BAT-AEL [(1)] (daily average values or average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
Hydrogen chloride, expressed as HCl	<5 - 30	<0.01 - 0.06
Hydrogen fluoride, expressed as HF	<1 - 5	<0.002 - 0.01

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.

Table 5.49: BAT associated emission levels for HCl and HF from the melting furnace in the mineral wool sector

5.8.5 Hydrogen sulphide (H_2S) and carbon monoxide (CO) from stone wool melting furnaces

General considerations regarding the emissions of H_2S and CO are given in Section 3.8.2.2. In general, in the mineral wool sector, these emissions are mainly related to stone wool production, where the melting process is operated under strong reducing conditions.

65. BAT is to reduce H_2S emissions from the melting furnace by applying a waste gas incineration system to oxidise hydrogen sulphide to SO_2 (see Section 3.8.2.2).

The emission levels of H_2S given in Table 5.50 are BAT-AELs.

Parameter	**BAT-AEL (1) (daily average values or average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Hydrogen sulphide, expressed as H_2S	<2	<0.004
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.		

Table 5.50: BAT associated emission levels for H_2S from the melting furnace in stone wool production

66. BAT is to reduce CO emissions from the melting furnace by applying a waste gas incineration system to oxidise carbon monoxide to CO_2 (see Section 3.8.2.2).

The emission levels of CO given in Table 5.51 are BAT-AELs.

Parameter	**BAT-AEL (1) (daily average values or average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Carbon monoxide, expressed as CO	<200	<0.4
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.		

Table 5.51: BAT associated emission levels for CO from the melting furnace in stone wool production

5.8.6 Metals from melting furnaces

General considerations regarding the emissions of metals are given in Section 3.2.2.1. In general, in the mineral wool sector, these emissions are related to the quality of the raw materials used in the batch formulation. Manganese (IV) oxide may be used as an oxidising agent when large amounts of recycled cullet are used in the batch formulation (see Section 3.8.2.2).

67. BAT is to reduce metal emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. Selection of the raw materials for the batch formulation with a low content of metals (see Sections 4.4.1)
ii. Application of a filtration system (see Sections 4.4.1.2 and 4.4.1.3).

The emission levels of metals given in Table 5.52 are BAT-AELs.

Parameter [(2)]	**BAT-AEL** [(1)] **(average over the sampling period)**	
	mg/Nm^3	kg/tonne melted glass
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI})	<0.2 [(3)]	<0.4 x 10^{-3}
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn)	<1 - 2 [(3)]	<2 - 4 x 10^{-3}
1. Average values refer to spot measurements of at least 30 minutes. 2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3). 3. The ranges refer to the sum of metals present in the flue-gases in both solid and gaseous phases.		

Table 5.52: BAT associated emission levels for metals from the melting furnace in the mineral wool sector

5.8.7 Emissions from downstream processes

General considerations regarding the emissions from downstream processes in the mineral wool sector are given in Sections 3.8.2.3 and 4.5.6.

Emissions are generated from the forming area, curing ovens and cooling of the products. In many cases, it is common procedure to combine emissions from the different areas before treatment. A number of techniques are applicable in all areas; other techniques are more suitable for treatment of the flue-gases from the forming area or the curing oven alone.

68. BAT is to reduce emissions from downstream processes by applying the following secondary measures/techniques individually or in combination:

i. impact jets and cyclones (see Sections 4.5.6.1.1 and 4.5.6.1.2)
ii. wet scrubbers (see Sections 4.5.6.1.2 and 4.5.6.2.2)
iii. wet electrostatic precipitators (see Sections 4.5.6.1.3 and 4.5.6.2.3)
iv. stone wool filters (see Sections 4.5.6.1.4 and 4.5.6.2.5)
v. waste gas incineration (see Section 4.5.6.2.4).

The emission levels of pollutants given in Table 5.53 are BAT-AELs.

Parameter	**BAT-AEL** [(1)] **(daily average values or average over the sampling period)**
	mg/Nm^3
Forming area - Combined forming and curing emissions - Combined forming, curing and cooling emissions	
Total particulate matter	<20 - 50
Phenol	<5 - 10
Formaldehyde	<2 - 5
Ammonia	30 - 60
Amines	<3
Total volatile organic compounds	10 - 30
Curing oven emissions	
Total particulate matter	<5 - 30
Phenol	<2 - 5
Formaldehyde	<2 - 5
Ammonia	<20 - 60
Amines	<2
Total volatile organic compounds	<30
NO_X, expressed as NO_2	<100 - 200
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.	

Table 5.53: BAT associated emission levels for pollutants from downstream processes in the mineral wool sector

5.9 BAT for high temperature insulation wools (HTIW) manufacturing

This sector presents a relatively standardised production process. Only one type of melting technique is applied to the sector and a rather limited range of raw materials is used for the process. Due to these specific characteristics and the limited information available, BAT-AELs are presented only as concentrations.

5.9.1 Dust emissions from melting and downstream processes

In the high temperature insulation wool (HTIW) sector, only cold top electric resistance furnaces are applied for the melting process. Dust emissions are mainly associated with the carryover of the batch composition during charging. General considerations regarding the nature of particulate matter are presented in Section 4.4.1.

69. BAT is to reduce dust emissions (particulate matter) from the waste gases of the melting furnace by applying a filtration system.

The emission levels of dust given in Table 5.54 are BAT-AELs.

Parameter	BAT	BAT-AEL [(1)] (daily average values or average over the sampling period)
		mg/Nm^3
Particulate matter	Flue-gas cleaning by filtration systems	<5 - 20 [(2)]
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The values are associated with the use of a bag filter system.		

Table 5.54: BAT associated emission levels for dust from the melting furnace in the HTIW sector

General considerations regarding the reported filtration techniques are presented in Sections 4.4.1.2 and 4.4.1.3.

Other sources of dust and fibre emissions are associated with the following downstream processes:

- fiberisation and collection
- mat formation (needling)
- lubricant burn-off
- cutting, trimming and packaging of the finished product.

General considerations regarding the sources of dust and fibre emissions from downstream processes are presented in Section 4.5.7.

70. For downstream dusty processes, BAT is to reduce emissions applying the following measures/techniques individually or in combination:

i. minimising the losses of product by ensuring a good sealing of the production line, where technically applicable
ii. operate cutting, trimming and packaging under vacuum, by applying an efficient extraction system in conjunction with a fabric filter (see Section 3.9.2.3)
iii. applying a fabric filter system (see Section 4.4.1.3).

The emission levels of dust (particulate matter) and fibres given in Table 5.55 are BAT-AELs.

Parameter	BAT-AEL [(1)] (average over the sampling period)
	mg/Nm^3
Particulate matter	1 - 5
Particulate matter containing fibres [(2)]	<1
1. Average values refer to spot measurements of at least 30 minutes. 2. The levels refer to the concentration of particulate matter which contains mineral fibres. The count of potential biopersistent fibres may vary significantly depending on the emissions source; therefore, a specific BAT-AEL for fibres could not be indicated.	

Table 5.55: BAT associated emission levels from dusty downstream processes in the HTIW sector

5.9.2 Nitrogen oxides (NO_X) from melting and downstream processes

General considerations regarding the origin of NO_X emissions and the measures/techniques considered as BAT are presented in Section 4.4.2.

In the HTIW sector, electric resistance furnaces are used for the melting process which do not represent a source of NO_X emissions. In general, raw materials containing nitrogen are not used in the batch formulations. In this context, NO_X emissions from the melting furnace are not significant. A significant source of NO_X emissions is represented by the thermal treatment of the product in the oven, for lubricant removal (see Section 2.10).

71. BAT is to reduce NO_X emissions from the lubricant burn-off oven by applying combustion control and/or modifications (see Section 4.4.2.1).

The emission levels of NO_X given in Table 5.56 are BAT-AELs.

Parameter	BAT	BAT-AEL [1] (daily average values or average over the sampling period)
		mg/Nm^3
NOx expressed as NO_2	Combustion control and/or modifications	100 – 200
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.		

Table 5.56: BAT associated emission levels for NO_X from the lubricant burn-off oven in the HTIW sector

5.9.3 Sulphur oxides (SO_X) from melting and downstream processes

General considerations regarding the origin of SO_X emissions are presented in Section 4.4.3.

In general, in the HTIW sector, fuel oil is not used for the production process and sulphur compounds may be present in the batch formulations only as impurities in the raw materials. In this context, SO_X emissions from the melting furnace and other downstream processes are expected to be low.

72. BAT is to reduce SO_X emissions from the melting furnaces and downstream processes by applying the following measures/techniques individually or in combination:

i. selection of the raw materials for the batch formulation with a low content of sulphur (see Section 4.4.1)
ii. use of low sulphur fuels (see Section 4.4.3.1)

The emission levels of SO_X given in Table 5.57 are BAT-AELs.

Parameter	BAT	BAT-AEL [1] (daily average values or average over the sampling period)
		mg/Nm^3
SOx expressed as SO_2	Primary measures	<50
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.		

Table 5.57: BAT associated emission levels for SO_X from the melting furnaces and downstream processes in the HTIW sector

Hydrogen chloride (HCl) and hydrogen fluoride (HF) from melting furnaces

General considerations regarding the emissions of HCl and HF are given in Section 4.4.4. In general, in the HTIW sector, these emissions are exclusively related to the quality of the raw materials.

73. BAT is to reduce HCl and HF emissions from the melting furnace by selecting raw materials for the batch formulation with a low content of chlorine and fluorine (see Section 4.4.4.1).

The emission levels of HCl and HF given in Table 5.58 are BAT-AELs.

Parameter	**BAT-AEL [1]** **(daily average values or average over the sampling period)**
	mg/Nm^3
Hydrogen chloride, expressed as HCl	<10
Hydrogen fluoride, expressed as HF	<5
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.	

Table 5.58: BAT associated emission levels for HCl and HF from the melting furnace in the HTIW sector

5.9.4 Metals from melting furnaces and downstream processes

General considerations regarding the emissions of metals are given in Section 3.2.2.1.

In general, in the HTIW sector, these emissions are related to the quality of the raw materials used in the batch formulation and tend to be low.

74. BAT is to reduce metal emissions from the melting furnace and/or downstream processes by applying the following measures/techniques individually or in combination:

i. selection of the raw materials for the batch formulation with a low content of metals
ii. applying a filtration system (see Section 4.4.1.3).

The emission levels of metals given in Table 5.59 are BAT-AELs.

Parameter [2]	**BAT-AEL [1]** **(average over the sampling period)**
	mg/Nm^3
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI})	<1 [3]
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn)	<5 [3]
1. Average values refer to spot measurements of at least 30 minutes. 2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3). 3. The levels refer to the sum of metals present in the flue-gases in both solid and gaseous phases.	

Table 5.59: BAT associated emission levels for metals from the melting furnace and/or downstream processes in the HTIW sector

5.9.5 Volatile organic compounds from downstream processes

In the HTIW sector, potential emissions of volatile organic compounds are associated with the oven where the lubricant burn-off (polyethylene glycol) is carried out (see Section 3.9.2.3).

75. BAT is to control volatile organic compound (VOC) emissions from the lubricant burn-off oven by applying the following measures/techniques individually or in combination:

i. combustion control, including monitoring the associated emissions of CO (see Section 4.4.2.1)
ii. waste gas incineration (see Section 4.5.6.2.4)
iii. wet scrubbers (see Section 4.5.6.1.2).

The emission levels of VOC given in Table 5.60 are BAT-AELs.

Parameter	BAT	BAT-AEL [(1)] (daily average values or average over the sampling period)
		mg/Nm^3
Volatile organic compounds	Primary and/or secondary techniques	10 - 20
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.		

Table 5.60: BAT associated emission levels for VOC from the lubricant burn-off oven in the HTIW sector

5.10 BAT for frits manufacturing

In the frits sector, it is rather common to find a number of furnaces using different batch formulations and diverse combustion techniques grouped together and collected into a single abatement system. Oxy-fuel combustion and oxygen-enriched fuel-air furnaces are applied, resulting in a combined flue-gas with high concentrations of oxygen. Due to these characteristics, emission concentrations reported in Sections 5.10.1 to 5.10.5 refer to an oxygen content of 15 % in the flue-gas, which represents a typical value for the sector.

The specific energy consumption associated with each type of product varies significantly, depending on the manufacturing conditions and type of furnace, with a consequent wide range of conversion factors to transform emissions concentration (mg/Nm^3) into kg/tonne melted frit. Consequently, BAT-AELs given as emission factors in Tables 5.61 to 5.65 may present a wide range of values, in order to include all the products and manufacturing conditions.

However, the extensive use of oxy-fuel firing and oxygen-enriched fuel-air combustion for the manufacturing of frits requires associating BAT-AELs given in emission concentrations with emission factors.

5.10.1 Dust emissions from melting furnaces

This section presents BAT for dust emissions arising from the melting furnaces applied by the frits sector.

76. BAT is to reduce dust emissions (particulate matter) from the waste gases of the melting furnace by means of an electrostatic precipitator or a bag filter system.

The emission levels of dust given in Table 5.61 are BAT-AELs.

Parameter	**BAT**	**BAT-AEL (1) (2) (daily average values or average over the sampling period)**	
		mg/Nm³	kg/tonne melted glass
Particulate matter	Flue-gas cleaning by filtration for new or upgraded installations	<5 – 10	<0.03 - 0.1
	Flue-gas cleaning by filtration for existing installations	<10 – 30	<0.05 - 0.2
1.The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes. 2. The lower levels are associated to the use of bag filters.			

Table 5.61: BAT associated emission levels for dust from the melting furnace in the frits sector

General considerations regarding the nature of particulate matter and the filtration techniques are presented in Sections 4.4.1., 4.4.1.2 and 4.4.1.3.

5.10.2 Nitrogen oxides (NO_X) from melting furnaces

General considerations regarding the origin of NO_X emissions and the measures/techniques considered as BAT are presented in Section 4.4.2.

In the frits sector, the presence of nitrates in the batch formulation is often required, as well as oxidising combustion conditions. In this context, high NO_X emission levels are anticipated.

General considerations regarding the use of nitrates in the batch formulation and the peculiar operating conditions of the melting furnaces are presented in Sections 2.11.2 and 3.10.2.2.

In general, several furnaces (up to 20 - 30) are present in a single installation, producing a variety of frits, with and without nitrates. The flue-gases of all furnaces or a group of furnaces are conveyed together into a single air pollution treatment system precluding the possibility of establishing different BAT-AELs for different batch formulations.

There are a number of techniques (e.g. SCR, SNCR) that can potentially achieve low NO_X levels which have not been applied to the sector because of technical and/or economic limitations.

77. BAT is to reduce NO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. minimisation of the nitrates content in the batch formulation (see Sections 4.4.2.2)
ii. reduction of the parasitic air entering the furnace (see Section 4.4.2)
iii. combustion modifications (see Section 4.4.2.1)
iv. oxy-fuel melting (see Section 4.4.2.5).

The emission levels of NO_X given in Table 5.62 are BAT-AELs.

Parameter	BAT	BAT-AEL [(1)] [(2)] (daily average values or average over the sampling period)	
		mg/Nm^3	kg/tonne melted glass
NOx expressed as NO_2	Primary techniques	500 - 1600	3 - 12

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.
2. The ranges take into account different melting technologies and a variety of glass types within the sector, with or without nitrates in the batch formulations.

Table 5.62: BAT associated emission levels for NO_X from the melting furnace in the frits glass sector

5.10.3 Sulphur oxides (SO_X) from melting furnaces

General considerations regarding the origin of SO_X emissions are presented in Section 4.4.3.

In general, in the frits sector, fuel oil is not used for the production process and sulphur compounds may be present in the batch composition only as impurities of the raw materials. In this context, SO_X emissions from the melting furnace and other downstream activities are expected to be low.

78. BAT is to control SO_X emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selecting the raw materials for the batch formulation with a low content of sulphur (see Section 4.4.1.1)
ii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of SO_X given in Table 5.63 are BAT-AELs.

Parameter	BAT-AEL [(1)] (daily average values or average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
SO_X, expressed as SO_2	<50 - 200	<0.3 – 1

1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.

Table 5.63: BAT associated emission levels for SO_X from the melting furnace in the frits sector

5.10.4 Hydrogen chloride (HCl) and hydrogen fluoride (HF) from melting furnaces

General considerations regarding the emissions of HCl and HF are given in Section 4.4.4.

In general, in the frits sector, the emissions of HCl are related exclusively to the quality of the raw materials. HF emissions may be generated from both impurities of the raw materials and, in specific cases, from the use in the batch formulation of minerals which contain fluorine (see Sections 2.2.1 and 3.10.1).

79. BAT is to reduce HCl and HF emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selection of raw materials for the batch formulation with a low content of chlorine and fluorine (see Section 4.4.4.1)
ii. minimisation of the fluorine compounds in the batch formulation when used to ensure the quality of the final product (see Section 4.4.4.1)
iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3)

The emission levels of HCl and HF given in Table 5.64 are BAT-AELs.

Parameter	BAT-AEL [(1)] (daily average values or average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
Hydrogen chloride, expressed as HCl	<10	<0.05
Hydrogen fluoride, expressed as HF	<5	<0.03
1. The daily average values refer to continuous monitoring of emissions; for spot measurements, the average values refer to three consecutive measurements of at least 30 minutes.		

Table 5.64: BAT associated emission levels for HCl and HF from the melting furnace in the frits sector

5.10.5 Metals from melting furnaces

General considerations regarding the emissions of metals are given in Section 3.2.2.1.

In the frits sector, these emissions are mainly associated with the use of metal compounds for colouring the vitreous melt and for providing the final products with special appearance (see Sections 2.11 and 3.10.1).

80. BAT is to reduce metal emissions from the melting furnace by applying the following measures/techniques individually or in combination:

i. selection of raw materials for the batch formulation with a low content of metals (see Section 4.8.3)
ii. minimisation of the use of metal compounds in the batch formulation, where colouring is required or other specific characteristics are conferred to the glass
iii. dry or semi-dry scrubbing in combination with a filtration system (see Section 4.4.3.3).

The emission levels of metals given in Table 5.65 are BAT-AELs.

Parameter	BAT-AEL [(1)] (average over the sampling period)	
	mg/Nm^3	kg/tonne melted glass
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI}) [(2)]	<1 [(3)]	$<2.5 \times 10^{-3}$
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn) [(2)]	<5 [(3)]	$<10 \times 10^{-3}$
1. Average values refer to spot measurements of at least 30 minutes. 2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3). 3. The levels refer to the sum of metals present in the flue-gases in both solid and gaseous phases.		

Table 5.65: BAT associated emission levels for metals from the melting furnace in the frits sector

5.10.6 Emissions from downstream processes

General considerations regarding the emissions from downstream processes in the frits sector are given in Sections 3.10.2.3 and 4.5.8.

In the frits sector, emissions of dust and metals are associated with the milling of the frits and the packaging area of dry products.

81. For downstream dusty processes, BAT is to reduce emissions by applying the following measures/techniques individually or in combination:

i. applying wet milling techniques (see Section 4.5.8)
ii. operating dry milling and dry product packaging under an efficient extraction system in conjunction with a fabric filter (see Section 4.5.8)
iii. applying a filtration system (see Section 4.4.1.3).

The emission levels of dust (particulate matter) and metals given in Table 5.66 are BAT-AELs.

Parameter	BAT-AEL [(1)] (average over the sampling period)
	mg/Nm^3
Particulate matter	5 - 10
Metals group 1 (As, Co, Ni, Cd, Se, Cr_{VI}) [(2)]	<1 [(3)]
Metals groups 1 + 2 (As, Co, Ni, Cd, Se, Cr_{VI}, Sb, Pb, Cr_{III}, Cu, Mn, V, Sn) [(2)]	<5 [(3)]
1. Average values refer to spot measurements of at least 30 minutes. 2. Metals are grouped on the basis of their potential environmental impact (see Section 3.2.2.1, Table 3.3). 3. The levels refer to the sum of metals present in the waste gas.	

Table 5.66: BAT associated emission levels from downstream processes in the frits sector

5.11 Emissions to water from glass manufacturing processes

Emissions to water from the activities in the glass industry are generally low, with only a few issues that are specific to the sector. However, a number of activities can give rise to more significant aqueous emissions, particularly from downstream processes.
General considerations regarding emissions to water are presented in Sections 3.2.2.2 and 4.6.

82. BAT is to reduce water consumption by applying process optimisation measures individually or in combination (see Section 4.6):

i. minimisation of spillages and leaks (see Section 4.6)
ii. re-use of cooling and cleaning waters after purging
(see Sections 3.3.3, 3.4.3, 3.6.3, 3.7.3 and 3.9.3)
iii. operate a closed loop water system (see Sections 3.8.3 and 3.10.3).

83. BAT is to reduce the emission load of pollutants in the waste water discharges by applying waste water treatment systems.

A list of possible techniques for waste water treatment is presented in Section 4.6.

More detailed information is available in the CWW BREF (Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector) [123, EC 2003].

The emission levels in waste water discharges given in Table 5.67 are BAT-AELs.

Parameter [1]	Unit	BAT-AEL [2] (composite sample)
pH	-	6.5 - 9
Total suspended solids	mg/l	<50
Chemical oxygen demand (COD)	mg/l	100 - 130 [3]
Sulphates, expressed as $SO_4^=$	mg/l	<1000
Fluorides, expressed as F^-	mg/l	<6 [4]
Total hydrocarbons	mg/l	<15 [5]
Lead, expressed as Pb	mg/l	<0.05 - 0.3[6]
Antimony, expressed as Sb	mg/l	<0.1
Arsenic, expressed as As	mg/l	<0.3
Barium, expressed as Ba	mg/l	<3.0
Zinc, expressed as Zn	mg/l	<0.5
Copper, expressed as Cu	mg/l	<0.1
Chromium, expressed as Cr	mg/l	<0.1
Cadmium, expressed as Cd	mg/l	<0.05
Tin, expressed as Sn	mg/l	<0.5
Nickel, expressed as Ni	mg/l	<0.5
Ammonia, expressed as NH_4	mg/l	<10
Boron, expressed as B	mg/l	2 - 4
Phenol	mg/l	<1

1. The indicated parameters represent the most significant ones for the glass industry.
2. The levels refer to a composite sample taken over a time period of two hours.
3. Depending on the receiving water, these levels may be higher, in particular for the continuous filament glass fibre sector when water is discharged to a sewage treatment.
4. The level refers to treated water coming from activities involving acid polishing.
5. In general, total hydrocarbons are composed of mineral oils.
6. The range is associated with downstream processes in the domestic glass sector. Where lead crystal glass is involved in the process, the higher levels are expected.

Table 5.67: BAT associated emission levels in waste water discharges in the glass industry

Due to the limited information available, the levels reported in Table 5.67 do not necessarily represent currently achieved values within the industry but are based on the expert judgement of the TWG.

In the case of discharge of waste water to a sewage treatment plant or to other off-site treatment plants, higher emission levels may be observed; in this situation, consideration should be given to the suitability of the receiving facility.

5.12 Solid and other wastes from the glass manufacturing processes

General considerations regarding the production of solid waste are given in Sections 3.2.2.3 and 4.7.

84. BAT is to reduce the production of solid waste to be disposed of by applying the following measures individually or in combination:

i. recycling of waste batch materials, where quality requirements allow for it (Section 4.7)
ii. minimisation of material losses during the storage and handling of raw materials (Section 4.3)
iii. recycling of internal cullet from rejected production (see Sections 3.3.4, 3.4.4, 3.6.4, 3.7.4, 3.8.4 and 3.9.4)
iv. recycling of filter dust in the batch formulation where quality requirements allow for it (see Section 4.7)
v. valorisation of solid waste and/or sludge for possible use in other industries (see Sections 3.5.4 and 4.7).

85. In the stone wool production, BAT is to apply cement bonded briquetting of waste for recycling into hot blast cupola furnaces.

General considerations and more specific information concerning the applicability of cement bonded briquetting of waste are given in Sections 3.8.2.1 and 4.7.

5.13 Noise from the glass manufacturing processes

General considerations regarding noise emissions are given in Section 3.2.4.

86. BAT is to reduce/minimise noise emissions by applying a combination of the following measures/techniques:

i. enclosing noisy equipment/operation in a separate structure/unit
ii. using embankments to screen the source of noise
iii. carrying out noisy outdoor activities during the day
iv. using noise protection walls or natural barriers (trees, bushes) between the installation and the protected area, on the basis of local conditions.