

7.12 Glass production

7.12.1 Coverage

The sector of glass production includes installations for the manufacture of glass with a melting capacity exceeding 20 tonnes per day. the production of glass fibres and mineral fibres is dealt with in the chapter "Man-Made Fibres" (7-13), this sector includes the manufacture of flat glass and container glass, as well as the production of special glass (TV screen, lighting), domestic glassware and water glass. The production of flat, container and commodity glass is dominated by large multinational companies, whereas the manufacture of table and decorative ware is mainly composed of small- and medium sized enterprises. Unlike the production of technical glass, domestic glass production is characterized by a great diversity of products and processes, including hand forming of glass. [1] [2] [3]

7.12.2 Emission sources

As glass making is an energy intensive activity, the choice of energy source, heating technique and heat recovery are crucial for the environmental performance of an installation. Natural gas, fuel oil and electricity are the three main energy sources. While in the recent decades, fuel oil has been the predominant fuel for glass making, the use of natural gas is increasing due to the ease of control and reduced emissions of SO₂ and CO₂, however generally at higher cost. Many furnaces are today equipped to run on both natural gas and fuel oil with a fuel change-over only requiring a change of burners; a mixing of fuel and gas in the same burner is also found. Electricity (resistive heating, where a current is passed through the molten glass) is the third energy source for glass making; it can be used either as the exclusive energy source or in combination with other fuels. [1]

Manufacturing techniques vary from small electricity heated furnaces to cross-fired regenerative furnaces in the flat glass sector, producing up to 900 tonnes per day [4]. The following list contains the main melting techniques for different classes of capacities:

- Large capacity (>500 t/d) installations: Almost always cross-fired regenerative furnaces
- Medium capacity (100 to 500 t/d) installations: regenerative end-port furnaces are favoured, but cross-fired regenerative, recuperative unit melters and also oxy-fuel and electric melters may be used
- Small capacity (25 to 100 t/d) installations: Recuperative unit melters, regenerative end port furnaces, electric melters and oxy-fuel melters are used [1]

Regenerative furnaces utilize regenerative systems for heat recovery and usually burners in or below combustion air / waste gas ports. Waste gas heat is used to preheat combustion air by passing the waste gas through a heat absorbing chamber. The furnace fires on one side at a time and after about twenty minutes, the firing is reversed and the combustion air is passed through the previously heated chamber. Preheat temperatures up to 1400°C and very high thermal efficiencies may be reached. Regenerative furnaces are either cross-fired (combustion ports and burners along the sides of the furnace, chambers on either side) for rather large installations or end-fired (burners and chambers on one side).

Recuperative furnaces utilize heat exchangers for heat recovery, which continuously preheat the combustion air by the waste gases. Temperatures are limited to around 750°C for metallic recuperators and the specific melting capacity of recuperative furnaces is around 30% lower than for regenerative furnaces. The burners are located along each side of the furnace and fire continuously from both sides. Recuperative furnaces are primarily used when high flexibility of operation is required with minimum initial capital, and when regenerators are not economically viable due to small capacity.

Oxy fuel melting involves the replacement of combustion air with oxygen (>90% purity), by which the volume of waste gas is reduced by about two thirds. As the atmospheric nitrogen has not to be heated to the flame temperature, energy savings are possible, as well as reduction of NO_x formation. This kind of furnace generally has the same design as unit melters (multiple lateral burners, a single waste gas exhaust port), but does not utilize heat recovery systems to pre-heat the oxygen supply.

Electric melting uses a refractory lined box with electrodes inserted either from the top, the sides or, more usually the bottom of the furnace. Energy is provided by resistive heating, as the current passes through the molten glass. The technique is commonly applied in small furnaces (especially for special glass), the upper size limit for the economic viability is determined by the cost of electricity compared to fossil fuels. The replacement of fossil fuels in the furnace eliminates the formation of combustion by-products.

Combined fossil fuel and electric melting can be either fossil fuel firing with electrical boost or (less common) predominantly electrical heating with a fossil fuel support.

Discontinuous batch melting is used when smaller amounts of glass are required, particularly if the glass formulation changes regularly. Pot furnaces or day tanks are used to melt specific batches of raw material, most of them are below the sector threshold of 20 tonnes/day. A pot furnace uses a lower section to preheat the combustion air and an upper section, which holds the pots, serves as the melting chamber. Day tanks are larger and resemble a conventional furnace, but are refilled with batch each day.

Special melter designs were developed to improve efficiency and environmental performance. [1]

The major environmental challenges for the glass industry are emissions to air and energy consumption. Glass making is a high temperature, energy intensive activity, resulting in the emission of combustion products and the high temperature oxidation of atmospheric nitrogen, i.e. in particular sulphur dioxide, carbon dioxide, and oxides of nitrogen. Furnace emissions also contain dust, which arises mainly from the volatilisation and subsequent condensation of volatile batch materials. [4]

7.12.3 BAT, Associated Emission Levels (AEL)

7.12.3.1 SO₂

The main techniques for controlling SO₂ emissions are fuel selection, batch formulation and acid gas scrubbing. For oil-fired processes, the main source of SO₂ is the oxidation of sulphur contained in the fuel. SO₂ emissions from the batch vary depending on the use of mainly sodium sulphate for glass oxidation and in some cases sulphite/sulphide in raw materials, but are lower than those from fuel whenever oil-firing is used. The most obvious way for reducing SO₂ emissions is thus to reduce the sulphur content of the fuel or to switch to gas-firing (essentially sulphur free). While the use of fuel with lower sulphur content does not necessarily lead to higher cost (except higher fuel price), the switch to gas-firing requires different burners and several other modifications. It is considered BAT to use gas or oil with a sulphur level of 1% or lower, burning higher sulphur content fuel may also represent BAT if abatement is used to achieve equivalent emission levels. [1] [9]

Concerning emissions from batch materials, sulphates are the main source for conventional glass making, as they are the most widely used fining agents and are also important oxidising agents. In most modern glass furnaces, batch sulphates have been reduced to the minimum practicable level.

Concerning scrubbing, the principles of dry and semi-dry scrubbing are the same: the absorbent is introduced to, and dispersed in the waste gas stream, the absorbents chosen for SO₂ are also effective for other acidic gases. The absorbent can be a dry powder (dry process), a suspension or solution with the water-cooling the gas stream (semi-dry process). The recycling of filter dust (including sulphate waste) is often considered reasonable, when technically applicable. This measure can reduce sulphur overall emissions up to the technically feasible substitution in raw materials by filter dust; external disposal routes for the filter dust may be additionally necessary. Thus site-specific

solutions may include a balancing of potentially conflicting waste minimisation and sulphur emissions reduction, a process sulphur balance will be essential in this case.

The majority of installed SO₂ scrubbers operate with dry-lime scrubbing at around 400°C, at this temperature a SO₂ reduction of about 50% can be achieved (higher reduction rates possible for around 200°C and humid atmosphere). [1] [5]

For **container glass, flat glass, domestic glass and special glass**, secondary abatement for dust with dry or semi-dry acid gas scrubbing where appropriate is considered as BAT. Different values are given for BAT depending on the fuel and (for container glass and flat glass) on the emission reduction priority of the installation, as waste minimisation by filter dust and cullet recycling may lead to higher SO₂ emissions.

For **frits**, BAT for SO₂ is considered to be fuel selection (where practicable) and control of batch composition. [1]

Table 1: SO₂ emission levels associated with BAT for furnaces in glass production [1]

Emission source	BAT associated emission levels ¹ mgSO ₂ /Nm ³ or (kg/tonne)		Comments
	gas-firing	oil-firing	
Container glass with SO ₂ reduction as priority	200 – 500 (0.3-0.75)	500 – 1200 (0.75-1.8)	
Container glass with waste minimisation as priority	< 800 (1.2)	< 1500 (2.25)	Where mass balance does not allow the figures above to be achieved.
Flat glass with SO ₂ reduction as priority	200 – 500 (0.5-1.25)	500 – 1200 (1.25-3)	
Flat glass with waste minimisation as priority	< 800 (2)	< 1500 (3.75)	Where mass balance does not allow the figures above to be achieved.
Domestic glass	200 – 500 (0.5-1.25)	500 - 1300 (1.25-3.25)	If low sulphate in batch, then <200 for gas-firing. Figures in upper part of ranges relate to dust recycling.
Special glass (including water glass)	200 – 500	500 - 1200	Figures in upper part of ranges relate to dust recycling.
Frits	< 200 (0.1-0.5)	500 - 1000	Oil firing is rare.
<p>¹ The BAT associated emission levels are based on a daily average, standard conditions and represents a typical load situation. For peak load, start up and shut down periods, as well as for operational problems of the flue gas cleaning systems, short-term peak values, which could be higher, have to be regarded.</p> <p>For combustion gases: dry, 8 % oxygen by volume (continuous melters), 13 % oxygen by volume (discontinuous melters). For oxy-fuel fired systems the expression of the emissions corrected to 8 % oxygen is of little value, and emissions from these systems should be discussed in terms of mass.</p>			

7.12.3.2 NO_x

In glass production, nitrogen oxides are mainly generated as thermal NO_x caused by high furnace temperatures, as a product from decomposition of compounds in the batch materials, and from the nitrogen contained in the used fuels. Thus several parameters have a significant influence on the NO_x emission levels: the type and amount of fuel used (natural gas, heavy fuel oil), the furnace type (cross-fired, end-fired furnaces; regenerative, recuperative air preheating), the melting temperature and the type of glass produced [6] [7]. The most appropriate techniques for controlling NO_x emissions are in general: primary measures, oxy-fuel melting, chemical reduction by fuel, selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR). When using oxycombustion, special care has to be taken with regard to energy efficiency so as not to reduce the NO_x emission abatement potential. [1] [6]

Primary process modifications are based on the following techniques or combinations: reduction of the air/fuel ratio (near stoichiometric combustion), staged combustion¹, low NO_x and sealed burners and fuel change. Further measures include the running of furnaces under slightly reducing conditions and to minimize the combustion air supply. The latter is done in order to enhance energy efficiency and to prevent NO_x formation. It is generally recommended to maintain 0,7-1 % O₂ in unit melters and 1-2% O₂ in end-port furnaces (measured at combustion chamber exit) and to keep the CO level as low as possible (200-300 to 1000 ppm CO maximum). [8] [9]

Secondary techniques for reducing NO_x emissions in glass manufacturing should be implemented where primary measures do not achieve necessary NO_x levels. They include the chemical reduction by fuel, the use of selective catalytic reduction (SCR) and, not widely adopted, the use of selective non-catalytic reduction (SNCR). [9]

For **container glass**, the main techniques likely to be considered BAT are primary measures (combustion modifications), oxy-fuel firing, SNCR or SCR (other techniques that achieve the emission levels may also represent BAT). Technically, low NO_x levels can be achieved using for example the special melters or electric melting. However, these techniques may only be economically applicable in certain circumstances. More widely applicable but options, which may not represent the most appropriate option in all circumstances are oxy-fuel firing and batch/cullet preheating.

Where these secondary techniques require a delay until the next rebuild, many air fuel fired furnaces are expected to achieve emission levels of 600-850 mg/Nm³ with primary measures only.

For **flat glass** BAT are primary measures. When other techniques (e.g., SCR,) can be used to achieve the given levels, they can also be considered BAT. Where these techniques require a delay until the next rebuild, many air fuel fired furnaces are expected to achieve emission levels of <850 mg/Nm³ with combustion modifications only.

For **domestic glass**, BAT statements are more difficult, as in the sector high product quality requirements, lower production volumes and more oxidising conditions (higher levels of nitrate) increase the potential for NO_x emissions. For smaller installations, electrically heated furnaces are an option and are considered BAT for lead crystal, crystal glass and opal glass.

In the short time, using primary combustion measures, emission reductions of up to 40% compared to the current levels are expected. As a medium term proposal, values in the range of 500-700 mg/Nm³ are expected using the following measures (or combinations thereof) that are considered BAT: primary measures, oxy-fuel-firing or SCR (if costs are acceptable).

For **special glass**, the BAT values are based primarily on the use of oxy-fuel melting and SNCR or SCR. The sector is very diverse and the appropriate technique will depend on site-specific issues.

For **frits**, BAT is the use of oxy-fuel melting or alternatively the use of air-gas systems and primary or secondary measures, that are able to achieve the given levels. [1]

¹ This measure is expected to be phased out with the installation of new low-NO_x burners

Table 2: NO_x emission levels associated with BAT for furnaces in glass production [1]

Emission source	Combination of control measures	BAT associated emission levels ¹ mg/Nm ³ (kg/tonne)	Comments
Flat glass	BAT techniques (see text)	500-700 (1.5-1.75)	Transition until next rebuild or substantial use of nitrate compounds: < 850 (2.2)
Container glass	BAT techniques (see text)	500-700 (0.5-1.1)	Transition until next rebuild: 500-850 (0.9-1.3)
Special glass	BAT techniques (see text)	500-700	
Domestic Glass (Lead crystal, crystal glass, opal glass)	Electrical heating	(0.2-1.0)	
	Short term modifications: Air-fuel fired	1000-1500 (2.5-3.5)	
	Medium term limit values: Primary measures, 3R/Reburning, oxy-fuel, SNCR, SCR	500-700 (0.5-1.75)	
Frits	Oxy-fuel melting	(0.5-1.5)	
	Air-gas systems and primary / secondary measures	500-700	

¹ The BAT associated emission levels are based on a daily average, standard conditions and represents a typical load situation. For peak load, start up and shut down periods, as well as for operational problems of the flue gas cleaning systems, short-term peak values, which could be higher, have to be regarded.

For combustion gases: dry, 8 % oxygen by volume (continuous melters), 13 % oxygen by volume (discontinuous melters). For oxy-fuel fired systems the expression of the emissions corrected to 8 % oxygen is of little value, and emissions from these systems should be discussed in terms of mass.

7.12.3.3 Dust

Dust is emitted by all sub-sectors of glass manufacturing in different process steps. Dust emissions in glass manufacturing industry stem mainly from furnaces and to a lesser extent from batch mixing (use of powdered, granular, or dusty raw materials) and finishing and blasting of glass products. Dust is emitted by the batch plant as volatile components that evaporate and condensate from the batch and the glass melt (mainly sodium sulphate), by combustion of some fossil fuels, in low quantities by materials transportation, handling, storage, and mixing. Dust emissions depend notably on the type of fuel used, the furnace type, and the type of glass produced. Besides end-of-pipe measures, possibilities to slightly reduce direct dust emissions are: pelleting the glass batch, changing the heating system from oil/gas-firing to electrical heating, charging a larger share of glass returns in the batch, and applying a better selection of raw materials (size distribution). [2]

Dust emissions arising through transportation, storage and mixing are typically coarser than those from the high temperature processes, which are generally $< 1\mu\text{m}^2$. Emissions from storage can be reduced by using enclosed silos, which are vented to suitable dust abatement equipment. During transportation 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 "carry-over" of fine particles out of the furnace, a percentage of water can be maintained in the batch, usually 3 - 4 %. [2]

During the melting cycle using discontinuous furnaces, the dust emission varies greatly. The dust emissions from crystal glass tanks (<5 kg/tonne melted glass) are higher than from other tanks (<1 kg/tonne melted soda and potash glass). Oxy-fuel burners can reduce waste gas volume and flue dust production by 60%. The most significant means for reducing dust emissions from furnaces is the use of either an electrostatic precipitator or a bag filter system, were appropriate in combination with a dry or semi-dry acid gas scrubbing system. Installation of electrostatic precipitators (ESP) can reduce dust emissions to 30 mg/m³ and fabric (baghouse) filters can reduce the emissions below 10 mg/m³. The BAT emission level with these techniques is 5-30 mg/Nm³ (equates to 0.1 kg/tonne of glass melted), based on a typical averaging period between 30 minutes and 24 hours. In some cases, BAT for metal emissions may result in lower emission levels for dust. [1] [2]

For **container glass, flat glass, domestic glass, special glass, frits** BAT for dust is considered the use of an electrostatic precipitator or bag filter operating, where appropriate, in conjunction with a dry or semi-dry acid gas scrubbing system. The application of BAT for metals may in some cases result in lower emission levels for dust. [1]

Table 3: Dust emission levels associated with BAT for furnaces in glass production [1]

Emission source	BAT associated emission levels ¹ mg/Nm ³ or (kg/tonne)	Comments
Container glass	5-30 (<0.1)	
Flat glass	5-30 (<0.1)	
Domestic glass	5-30 (<0.1)	
Special glass	5-30	
Frits	5-30 (<0.1)	
¹ The BAT associated emission levels are based on a daily average, standard conditions and represents a typical load situation. For peak load, start up and shut down periods, as well as for operational problems of the flue gas cleaning systems, short-term peak values, which could be higher, have to be regarded. For combustion gases: dry, 8 % oxygen by volume (continuous melters), 13 % oxygen by volume (discontinuous melters). For oxy-fuel fired systems the expression of the emissions corrected to 8 % oxygen is of little value, and emissions from these systems should be discussed in terms of mass.		

7.12.3.4 VOC

VOC emissions from the production of mineral fibres are subject of the section on “man-made fibres” (7-13). For other glass manufacturing operations, minor emissions of VOCs could also arise for example from cold coating operations. These emissions are not considered to be very significant and are not discussed further.

7.12.3.5 Cross Media Effects

For all mentioned emission reduction and abatement techniques, the cross-media transfer of pollutants and the full range of environmental effects and improvements should be considered. For example additional energy consumption and increased quantities of waste or wastewater residuals may result from individual efforts for pollutant prevention, reduction, or removal.

For the sector of glass production, the recycling of filter dust (including sulphate waste) may lead to higher SO_x emissions, thus waste minimisation and sulphur emissions reduction may become conflicting targets (cf. section Sulphur oxides).

7.12.4 Emerging techniques

In the medium term, no major breakthroughs in technology are expected. Techniques that are already beyond the state of **emerging technologies**, but which are likely to undergo further development are low NO_x burner systems, oxy-fuel melting, cullet and batch preheating, developments concerning batch formulations, the integration of frit processes. Innovative long-term techniques still at pilot scale are systems using ceramic filters and catalysts combining in one operation NO_x, SO_x and Dust removal (CERCAT®) and ESP using charged water droplets (TRI-MER®) [1] [10]

7.12.5 Cost data for emission reduction techniques

Table 4: Cost data for different abatement techniques [1]

Abatement Technique	Capital Costs [k€] @ 100/300/600 [Tonnes/d]	Annual Operating Costs [k€] @ 100/300/600 [Tonnes/d]	Specific cost [€/Tonne molten glass] @ 100/300/600 [Tonnes/d]
SCR	615/1000/1800	64/123/330	4.98/2.83/2.99
SNCR	280/450/1350	28/73/225	2.35/1.49/2.16
LowNO _x	100/180/550	21/35/72	1.34/0.72/0.83
Oxy-Fuel	-300/-1350/-4800	190/530/1900	4.06/5.05/5.16
3R incl. Repair etc	- /270/680	- /185/285	2.87/2.28/1.91
3R excluding repair	- /140/260	- /106/267	2.20/1.35/1.50
SCR+filter	1500/2420/4550	108/200/470	10.2/5.75/5.78
Filter+scrubber	875/1420/2750	53/89/186	5.52/3.01/3.06

Values for a capacity of 100 [tonnes/day] Container (11120 m³ flue/h), 300 [tonnes/day] Container (23000 m³ flue/h), 600 [tonnes/day] Float (70000 m³ flue/h)

Table 5: Efficiencies of different NO_x reduction technologies in Glassmaking [5]

	Achieved reduction	Secondary measures	Achieved reduction
Low-NO _x burner	40%	3R process	85%
Staged combustion	35%	SCR	>70%
oxy-fuel firing	<1kg NO _x /tonne glass	SNCR	Up to 70%

Table 6: Specific cost for different combinations of filters (dust) and scrubbers (SO_x) for glass furnaces [11]

Type of glass	Production (Tons melt per day)	ESP & dry scrubber (CaOH) ₂ Filter dust recycle [€/t]	ESP & dry scrubber (CaOH) ₂ Filter dust disposal [€/t]	ESP & dry scrubber (NaHCO ₃) Filter dust recycle [€/t]	ESP & dry scrubber (NaHCO ₃) Filter dust disposal [€/t]	Bag filter & dry scrubber Filter dust recycle [€/t]	Bag filter & dry scrubber Filter dust disposal [€/t]	Bag filter & semi dry scrubber Filter dust recycle [€/t]	Bag filter & semi dry scrubber Filter dust disposal [€/t]	Wet scrubber [€/t]
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		6.7			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	100-120						11			14.4-21.5*
E-glass air	100-120									15.7-20.5*

* higher value for filter dust disposal 400 Euro/ton

Table 7: Specific cost for different DeNOx methods for glass furnaces [11]

Type of glass	Production (Tons melt per day)	SCR [€/t]	3R [€/t]	SNCR (recuperative) [€/t]	Basic Lownox measures** [€/t]	Extended Lownox measures*** [€/t]	All-Oxygen firing (€/Nm ³) with silica crown* [€/t]	All-Oxygen firing (€/Nm ³) with fused cast crown* [€/t]
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					(at 0.10) –4.32	
Tableware (regenerative)	70						(at 0.10) +12.76	
Tableware (regenerative)	100	4.9						
Tableware (regenerative)	150					8 (high E-boost)		
Tableware (regenerative)	190				0.7			
Special glass oxygen fired	250			3.34				
Special glass regenerative fired	700			2.8				
E-glass	100			4.1			6.20 (0.08)	
* Oxygen cost in Euros per Nm ³ given between brackets ** Basic LowNox measures: adjustable burners, oxygen sensors, air-fuel control *** Extended Lownox measures: basic measures plus modifications burner ports & combustion chamber								

7.12.6 References used for chapter 7.12

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