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BAT determination in selected industrial fields as a contribution to the fulfilment of the climate protection targets and further immission control legal requirements - Partial Project 02: German contribution to the Review of the Reference Document on Best Available Techniques in the Glass Manufacturing Industry

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BAT determination in selected industrial fields as a contribution to the fulfilment of the climate protection targets and further immission control legal requirements

Final Report

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Partial Project 02:
German contribution to the Review of the Reference Document on Best Available Techniques in the Glass Manufacturing Industry

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The various sectors of the glass industry, such as container glass, flat glass, special glass, domestic glass, glass fibre and mineral wool are significantly different with regard to the used production and processing technologies. For this reason, the individual sections have to be specifically considered in order to investigate and to document the state of the art and recent developments in environmental control.

In coordination with the Federal Office for Environment Protection (UBA), 16 reference plants were selected and examined through company inspections, and both technical and the cost aspects were considered.

Besides the detailed specification on the emission control also the fields of wastes and wastewaters had to be considered. Furthermore, data were specified with respect to current research work of the HVG in the area of the air pollution control.

In particular, glass melting furnaces with oxy fuel firing were investigated, concerning technical improvement, reliability, ecology and economics. The achieved state of the art was comprehensively documented. Apart from the emission situation compared to reference furnaces special attention was put to cost efficiency and the effectiveness regarding the balance between oxygen cost and the energy conservation amount.

In addition, cross media effects e.g. the effects of the filter dust recycling on the sulphur balance of the glass melting furnace were analysed.

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The subdivision of the single systems is always the same!

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1 Introduction:

The results of the exchange of information between the member states of the EU and the affected industry about the best available techniques (BAT) for the realisation of the integrated prevention and control of environmental pollution in the glass industry were for the first time published in the so called IPPC guideline **(I**ntegrated **P**ollution **P**revention and **C**ontrol - Reference Document on Best Available Techniques in the Glass Manufacturing Industry / also called Glass BREF) [1]. The information exchange should help "to counterbalance the imbalance on the technological level in the community, to support the worldwide extension of the limit values set in the community and the used techniques and to support the member states in the effective realisation of this guideline".

The most important general conclusions of the IPPC guideline of the year 2000 for the glass industry are as follows:

- The information exchange was successful, and at the second meeting of the technical working group a high degree of agreement was achieved.
- This branch of industry is extremely diverse, and in most cases it is not advisable to indicate only one technique as BAT.
- In the last years, much was done to improve the environmental impact caused by this branch of industry. Further developments/improvements are expected, in particular with primary techniques, but also through the utilisation of secondary techniques, as already more widely employed in other lines.

The most essential recommendations for the further activities are as follows:

- An evaluation (preferably semiquantitative) of the cross media issues would be helpful.
- A more thoroughgoing consideration of the costs of the techniques for the determination of the BAT would be advisable.
- Reviewing the work achieved, a more detailed evaluation of the techniques for the improvement of the energy efficiency would be purposeful taking into account recent information.
- Reviewing the work achieved, the advance made with primary measures for the emission control should be revalued.
- Reviewing the work achieved, a new evaluation should be done of such techniques where at present certain problems are still unproved or controversial and occur either in the entire glass industry or in some areas of application. This concerns in particular the sulphur dioxide precipitation, the oxy fuel firing and the selective catalytic reduction.

In Seville (Spain) in 2007, the revision (art. 13, 96 /61/EC) of the BAT bulletin for the glass industry will begin.

2 Project definition:

The Research Associaton of the German Glass Industry (HVG) was assigned by the Federal Environment Agency to elaborate a German contribution to the Review of the Reference Document on Best Available Techniques in the Glass Manufacturing Industry.

For this object, well-founded German contributions are important for this international document to reflect the high level of expertise in Germany. For that, new developments as well as the currently best available techniques in the glass and mineral fibre industry were looked into and documented. Special attention was given to comparative cost efficiency considerations as well as the verification of BAT bulletin data that were regarded as not yet completely confirmed.

The different sectors of the glass industry are significantly different with regard to the used production and processing technologies. For this reason, the individual sections have to be specifically considered in order to investigate and to document the state of the art and recent developments in the environmental control.

In coordination with the UBA at least two suitable reference systems per glass sector were selected, examined through company inspections and both the technical and the cost aspects considered.

Besides the detailed specification on the air control also the fields of wastes and wastewaters had to be considered.

Further specifications are made on particulate emissions in the exhaust gas of glass melting plants as well as on the environmental impact in the area of the turnover and the storage of fuel and material components. In addition, the formaldehyde-, phenol-, total C- and NH_3 emissions for the mineral and glass fibre producing plants are stated. In this sector, but also in the special glass field the boron emissions are of interest.

For oxy fuel firing, SCR and SNCR methods, reburning process and cullet/batch preheating the new developments concerning the technical progress, the reliability of the actual reduction potential as well as the pending costs are investigated.

The achieved state of the art of oxy fuel firing is documented exactly. Besides the emissions compared to those of reference furnaces, especially the cost efficiency and the effectiveness with regard to the balance between the cost of the oxygen and the amount of the energy saving are taken into account.

In addition, cross media issues as for example the effects of the filter dust recycling on the sulphur budget are shown.

3 State of knowledge:

The glass industry, glass melting processes, the necessary technologies and the effects on the environment are documented in the literature, in many publications of the HVG and/or the German Society of Glass Technology (DGG), in the IPPC guideline and in the VDI guideline 2578 "Emissionsminderung Glashütten" [2].

The glass industry can roughly be subdivided into the sectors container glass, flat glass, special glass, table ware, glass fibre and/or mineral fibre. The estimated tonnage within the EU is about 30 mill. t_{glass}/a, with about 80 % accounting for container and flat glass. The diversity of the individual sectors can be shown for special glass for instance, accounting e.g. for TV glass, glass-ceramics, optical glass, glass tubes, borosilicate, TFT and borofloat glasses.

In Germany, there are approx. 90 locations of glassworks with a melting capacity of more than 20 t_{glass}/d. In 2004, according to the Federal Association of the Glass Industry (BV GLAS), 7.15 mill. t_{glass} were produced. In 2005, the production declined to 6.71 mill. t_{glass}.

The great number of glass types produced requires a broad palette of raw materials comprised of minerals, manufactured inorganic products and cullet.

The melting techniques differ in energy source, type of heating and oxidation medium as well as method of heat recovery. Used are continuously operated glass melting furnaces with regenerative and recuperative air preheating, furnaces with batch preheater, oxy fuel fired furnaces, electric tanks, plants with a combination of electrical and fossil heating as well as special aggregates for the improvement of environmental compatibility. In addition, there are discontinuously operated furnaces as for example pot furnaces and day tanks. The main energy sources are natural gas, heavy fuel oil, light fuel oil and electric energy.

The environmental problems of the glass industry focus on emissions into the air and the energy consumption. To a smaller extent, emissions into the water as well as solid wastes and residues play a role. The energy intense melting process for the glass production occurs at very high temperatures.

Among the air polluting substances are the particulate emissions including the dust contents passing the filter, nitrogen oxides, sulphur oxides, chlorides and fluorides. Moreover, there is the fuel and raw materials conditioned carbon dioxide release and in some cases carbon monoxide emissions occur.

In Germany, besides the primary emission reduction measures used, all glass melting aggregates are equipped with waste gas treatment plants consisting mostly of electrostatic or filtering precipitators (bag filters) with upstream dry sorption stage and calcium hydroxide as sorption agents.

In the container and flat glass industry and in many cases also in the other sectors, the filter dust is completely recycled and remelted.

On 1st October 2002, the German guideline for emission control (TA Luft) [3] came into force. Subsequently, the most important general limit values as well as those relevant for the glass industry are listed.

Emission limits for the German glass industry

TA-Luft 2002 – (Emission values Germany)

Component	Plants in general [mg/m³]	Glass industry (standardized 8 % O_2) [mg/m³]
		New furnaces
NO_x	**350**	**500** (> 50000 m³/h) **800** (< 50000 m³/h) **1000** (nitrate refining)
		Old furnaces
		800
		1000 (nitrate refining)
		1200 (nitrate refining / < 5000 m³/h)
		The target for all glass melting furnaces is 500 mg/m³
HF	**3**	**5**
HCl	**30**	**30**
NH_3	**30**	**30**
SO_x	**350**	**100 – 1500** (dependent on type of glass and heating)

Transition period for NO_x = 8 years **(2010);** other components = 5 years **(2007)**

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TA-Luft 2002 – (Emission values Germany)

Glass type	Gas fired [g/m³]	Oil fired [g/m³]	Operating conditons
Container/Flat	**0.4**	**0.8**	-
Container glass	**0.8**	**1.5**	Near stoichiometric combustion, complete filter dust recycling, sulphate refining, > 40 % cullet
Flat glass	**0.8**	**1.5**	Near stoichiometric combustion, complete filter dust recycling, sulphate content > 0.45 %
Homeware	**0.2**	**0.5**	-
Homeware	**0.5**	**1.4**	Near stoichiometric combustion, complete filter dust recycling, sulphate content > 0.45 %
Glass fibres	**0.2**	**0.8**	-
Glass fibres	**0.8**	**1.4**	Complete filter dust recycling, sulphate content > 0.45 %
Glass wool	**0.05**	**0.8**	-
Glass wool	**0.1**	**1.4**	Proportion of cullet > 40 %
Special glass	**0.2**	**0.5**	-
Special glass	**0.4**	**1.0**	Complete filter dust recycling
Water glass	**0.2**	**1.2**	-
Glass frit	**0.2**	**0.5**	-

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Emission limits for the German glass industry

TA-Luft 2002 – (Emission values Germany)

Component	Plants in general [mg/m^3]	Glass industry [mg/m^3]
Total dust	**20**	**New plants: 20** **Old plants: 20 (Fabric filter)** **30 (EP)**
No. 5.2.2		
I (Tl, Hg)	**0.05 (0.25 g/h)**	Special regulation: with use of **Pb or Se** for reasons of quality **class II = 3 mg/m^3**, or **class III = 4 mg/m^3**
II (Pb, Co, Ni, Se)	**0.5 (2.5 g/h)**	Special regulation: with use of recycling cullet (container glass) **class II = 1.3 mg/m^3**, (**0.8 mg/m^3 Pb**), or **class III = 2.3 mg/m^3**
III (Sb, Cr, V, Sn)	**1 (5 g/h)**	
No. 5.2.7.1.1		
I (As, Cd)	**0.05 (0.15 g/h)**	Special regulation: **cont. gl. cl. I = 0.5 mg/m^3**
II (Ni)	**0.5 (1.5 g/h)**	Special regulation: **sp. gl. Cd = 0.2 mg/m^3** **As = 0.7 mg/m^3**

The transition period is 5 years **(2007)**

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The emission values refer to an oxygen content of respectively 8 vol.% in the dry exhaust gas for flame heated glass melting furnaces as well as 13 vol.% for pot furnaces and day tanks.

4 Project management:

The major object of the project was to investigate and document on the basis of reference plants the best available techniques of the glass industry in the field of environmental control.

As a basis for the project management, a questionnaire was elaborated allowing the recording of all emission relevant data, detailed investment and operating data costs for the used environmental control measures, and information on wastes and wastewater.

In total, 16 glass melting plants in Germany in the field of container, flat and special glass, domestic glass and glass fibre were examined that according to the knowledge of the HVG use the currently best available techniques in glass production.

Container glass industry:

1: Oxy fuel furnaces with heat recovery system in the raw gas and bag filter

2: Cross fired furnace (natural gas) with raw material preheater and EP

3: Horseshoe furnace (heavy oil) with exhaust gas heat recovery system and EP

4: Horseshoe furnace (natural gas) with SCR and EP

Flat glass industry:

5: Flat glass furnace (heavy oil) with exhaust gas heat recovery system and EP

6: Float glass furnace (heavy oil / natural gas) with exhaust gas heat recovery system and EP

Special glass industry:

7: Electric furnace (borosilicate glass) with bag filter

8: Oxy fuel furnace (borosilicate glass) with bag filter

9: Oxy fuel furnace (borosilicate glass) with bag filter

10: Oxy fuel furnace (borosilicate glass) with bag filter

11: Oxy fuel furnaces (TV glass) with SNCR and EP

12: Regenerative cross fired furnaces with SCR and EP

Domestic glass:

13: Horseshoe furnace (heavy oil) with EP

14: Electric furnaces

Glass fibre and rock wool:

15: Oxy fuel furnace (C-glass) with EP

16: Recuperative heated furnace with EP

The questionnaire to be completed by the respective glassworks was discussed, firmed up and where appropriate complemented or abbreviated on site together with the respective management. In many cases, also a representative of the Federal Environmental Agency was present.

➔ On the instruction of the operators of the glass melting plants only data can be published that do not allow any conclusions onto the site of the plant or the furnace investigated. Intern information of the HVG about emission data or innovative and environment based melting technologies may be documented only upon approval by the respective management.

The HVG thanks all member companies and enterprises that participated in the investigation and documentation. The names of these companies are not given in order to avoid conclusion on the respective site and to guarantee anonymity.

Special thanks are also due to Dipl.-Ing. Gesine Bergmann, scientific employee of the HVG, who has accompanied this project from the beginning with great engagement and to Ms Klaudia Jaenicke for the translation into English.

<u>Note on the market situation:</u>

Unfortunately, the economically strained situation in Germany during the last years did not pass the glass industry without a trace.

In particular, the introduction of the mandatory pledge onto carbonated drink packaging and the substitution of plastic containers for glass bottles resulted in a noticeable downturn of production in the container glass industry causing decommissioning of production lines and furnaces and shutting down of whole factories. Among the affected plants, regrettably there are also BAT plants, as for example an oxy fuel furnace with raw material preheater, a LowNO_X melter and a horseshoe tank also operated with raw material preheater. For this reason, since publication of the IPPC guideline in the year 2000, no essential new developments were introduced into the construction of melting tanks within the container glass industry. Instead, the functional efficiency of the existing plants normally was maintained only with provisional repairs. Only recently does an economic upswing emerge in the field of container glass.

Furthermore, the TV glass market collapsed, leading to a shutdown of five large TV screen and TV funnel tanks in Germany. All these plants were equipped with SCR catalysts.

Therefore, at present only three plants with SCR catalyst technique do exist in Germany. These are two catalyst plants (container and special glass industry) operated for more than ten years, and a further one in the field of the flat glass industry taken into operation at the end of 2006.

For the special glass production, an almost complete conversion from conventional heating to oxy fuel firing occurred. In the sector of the fibre glass industry, there also exist several oxy fuel fired melting tanks. Consequently, the new developments focus on oxy fuel melting technology and its effects particularly in respect of nitrogen oxide emissions.

Therefore, especially the state of the art achieved in oxy fuel firing was considered. Besides the emissions caused in comparison to conventionally heated reference tanks, the cost efficiency and the effectiveness with regard to the balance between the cost of the oxygen and the amount of energy saving were taken into account.

Verification of the data was assured through information of furnace producers and providers of air separation units.

Unfortunately, wastes / wastewater and in particular costs cannot always be dealt with satisfactorily. Information in this respect was considered as sensitive issue and partly only inadequately or not at all answered in the questionnaire by many plant operators.

Efforts are being made by the glass producers in Germany to operate their plants as environment compatible as possible and to go below the legal guidelines for emissions.

The HVG is strongly supporting them in this task on site. Since 1975, HVG has been notified as measuring institute according to § 26 BImSchG for glass related emissions. Since 1991, notification has been in effect for HVG to carry out calibration and functional tests of continuous emission measuring instruments. The competence of HVG with regard to sampling and analysis is confirmed among other things by regular participation in round robin tests. Since July 2006, the HVG laboratory has been accredited according to DIN ISO/IEC 17025:2005.

The competence gained within the framework of emission and calibration measurements as well as research projects in the field of environmental control was intensely used in the past in order to decisively take influence in limit value regulations for emissions in the glass industry (TA-Luft).

The experiences of HVG in the field of environmental control also gained recognition on the European level (IPPC guideline) as well as on the national level VDI-Richtlinie 2578 "Emissionsminderung Glashütten".

The HVG expertise serves as a basis for emission prognosis and expert opinions in the field of air pollution control. In recent evaluations of the emissions of oxy fuel tanks, emission limits were established for many glassworks with positive results for the plant operator, as well as for the co-operation between plant operators and permission authority.

Know-how and experiences of HVG are introduced for example into the execution of research projects with environment related topics. There are regular progress reports on the HVG research projects before the HVG advisory board, in the project related working groups and in lectures at the sessions of the DGG Technical Committee “Umweltschutz” as well as at the DGG annual meeting. In addition, the research results are published in international technical journals as well as presented at national and international conferences. HVG employees give lectures on glass technology at various universities in which the students, besides the state of the art, will also learn about the current research results.

Within the framework of this project, the HVG expertise will also be used to provide information that does not follow from the questionnaires. For example, this refers to data on additional furnaces in anonymous form and results on current research projects (emissions of gaseous boron compounds – particulate quartz emissions).

5 Results of the project:

First of all the available data of the reference systems are documented for each industry sector in detail. Then an evaluation of the research occurs according to the plants of the same branch of industry each. With that, the bandwidth of the installed glass melting plants and the influence of for example the plant size and/or the melting technology, the quality requirements and the fuel onto environment relevant aspects should be shown.

Furthermore, cost estimates are made that are used as verification of data of the IPPC guideline and on the other hand reflect the current state of the evolution in particular of oxy fuel melting tanks and tanks with SCR and/or SNCR technology.

In addition, recent results are presented about current and/or recently finished research projects of HVG in the environmental sector, for example about particulate matter (PM 10 or PM 2.5) and silica particulate or boron emissions.

All information on costs refers to estimates that presumably do not meet finance-technical or fiscal requirements. Therefore, they have only informing character.

Due to the great number of the tables assigned to the respective reference systems, these are not numbered and/or listed.

5.1 Container glass:

Container glasses are melted in Germany mainly in regenerative horseshoe fired furnaces with air preheating. Furthermore, there are regenerative heated sideport furnaces, some oxy fuel tanks and two LowNO_X melters. In the field of the container glass industry no plants with SNCR technology exist, as for example they can be used for recuperative heated furnaces or for melting furnaces with multistage chamber system. There is only one plant with SCR technology downstream of the electrostatic precipitator.

Within the framework of the project four reference plants of the container glass industry were investigated for which the emissions are partially clearly below the limits of the 2002 TA-Luft.

5.1.1 Plant 1:

Oxy fuel furnaces with heat recovery system (raw gas) and bag filter

5.1.1.1 Melting plant:

	Furnace 1	Furnace 2
Type	Oxy fuel furnace	
Melting area / Length / Width	108 m^2 / L: 15 m / W: 7.2 m	
Height of crown above glass	3.36 m	
Fuel type	Natural gas, H_u = 31470 kJ/m^3	
Electric boosting (installed)	None	
Glass colour	Brown/Green	Brown
Max. allowed melting output	300 t/d	350 t/d
Last main repair	year 2000	year 1996
Intended runtime	11 years	12 years
NO_x reduction measures	Near stoichiometric combustion, sealing measures, furnace geometry,	
Other measures	Raw materials and fuel poor in sulphur/ filter dust recycling	
Coating material	MBTC	
Path of emission hot end coating	Furnace waste gas treatment plant	

Operating data	**Current Average value**	
Melting output	222 t/d	280 t/d
Cullet amount, referred to melting output	75 %	57 %
Batch humidity, referred to entire batch	3.3 %	3.3 %
Gas consumption	1200 m^3/h	1600 m^3/h
Oxygen consumption	1950 m^3/h	2700 m^3/h
Max. crown temperature	1590 °C	1585 °C
Specific melting output	2.06 t/m^2d	2.59 t/m^2d
Specific energy consumption	4083 kJ/kg_{glass}	4316 kJ/kg_{glass}

(Volume data are referred to standard conditions)

The specific energy consumption depends on the efficiency and the cullet content. At full load conditions and after a runtime of 4 years, a specific energy consumption of about 3350 kJ/kg_{glass} was detected.

As criteria for the decision to build oxy fuel furnaces, the following points were made at the site of a glassworks:

a) Small NO_X emissions (less than 500 mg/m³ and/or 0.7 kg/t_{glass})

b) Reduction of the melting costs

c) Installation of melting furnaces in existing buildings

d) Reduction of the CO_2 emissions.

Both furnaces had a very high crown. One expects advantages through smaller vaporisation rates and in particular lower caustic soda concentrations in the field of the silica crown. This considerably reduces the corrosion so that a runtime of 12 years can be expected.

In a lecture given in 2005 (title, time, energy carriers, and place of the presentation are not given in order to protect anonymity), the concept of an oxy fuel furnace (350 t/d / 3412 kJ/kg_{glass}) with high crown, with raw gas heat recovery and bag filter was compared with a conventionally heated furnace (3995 kJ/ kg_{glass}) with regenerative air heating and electrostatic precipitator.

Data assumed in the lecture:

Electric energy cost:	€ 0.05/kWh	Gas price: 0.0193/kWh €
Oxygen price:	€ 0.04/m³	O_2/gas ratio: 2:1
Interest rate:	6 %	Service life: 12 years

With total costs of 40.2 €/t_{glass} (including the redemption for the entire plant), the lecturer estimated for the regenerative heated plant an around 18 % higher amount compared to the oxy fuel tank for which € 34.2/t_{glass} must be invested.

The smaller capital expenditure of an oxy fuel furnace compared to a conventional furnace is contrasted to the energy expenditure and thus the delivery cost of the oxygen. Thus, the cost of electric energy significantly determines the economic effectiveness.

The air separation unit for the production of cryogenic oxygen is on the site of the glassworks. According to the management, the current delivery cost of oxygen is € 0.046/m³.

Allocated to tonnage, for furnace 1 € 9.70/t_{glass} and for furnace 2 € 10.23/t_{glass} must be paid for oxygen.

5.1.1.2 Waste gas heat recovery:

Plant	Furnace 1	Furnace 2
Type of heat exchanger	Pipe bundle	
Heat carrier	Water / Steam	
Use of energy gained	Electric energy / Compressed air	
Place of installation	Raw gas before bag filter	
Type of dedusting	Manual	
Dedusting	Online	
Dust disposal	Batch admixing	
Availability	98.6 %	
Efficiency	approx. 94 %	
O_2 content of exhaust gas – entry	5 %	
O_2 content of exhaust gas – exit	5.5 %	
Temperature of exhaust gas – entry	1380 °C	
Temperature of exhaust gas – exit	200 °C	
Efficiency	approx. 94 %	
Recovered energy	2876 kWh/h	3596 kWh/h

Information on the costs is not available.

Thus, 0.31 kWh/kg_{glass} of exhaust gas heat is recovered on the average.

The power station efficacy has to be considered in the electrification so that in the form of electric energy about 0.1 kWh/kg_{glass} of exhaust gas heat can be used.

Exhaust gas heat use systems in the waste gas of oxy fuel furnaces are not widely employed. In the present case, the exhaust gas consisting of about 1/3 of CO_2 and 2/3 of water vapour is passed through the heat exchanger. Referred to dry exhaust gas, the concentrations of exhaust gas components are correspondingly high. Therefore, in the construction and operation of heat exchangers and oxy fuel firing it has to be taken into account that water or acid dew points must not be gone below.

5.1.1.3 Waste gas treatment plant of the furnaces:

Type of filter	Bag filter
Filter material	M3GR needled felt
Temperature before filter	max. 150 °C
Type of sorbent	$Ca(OH)_2$
Amount of sorbent	20 kg/h
Injection of water	None
Amount of filter dust	approx. 220 t/a
Use of filter dust	100 % recycling (batch)
Compressor - nominal output	127 kW
Service interval	Monthly

Emission limits – Emission data (year 2005)

Component	Limit value [mg/m^3]	**Limit value Spec. emissions [kg/t$_{glass}$]**	**Measured value [kg/t$_{glass}$]**
Total dust	50	**0.070**	**0.0015**
NO_x		**0.7**	**0.23**
SO_x	1500	**2.1**	**0.40**
HF	5	**0.007**	**0.0010**
HCl	30	**0.042**	**0.0082**
Heavy metals:			
Group II TA-Luft1986	1	**0.0014**	**$0.125 \cdot 10^{-3}$**
Group III TA-Luft 1986	5	**0.007**	**$0.666 \cdot 10^{-3}$**

The emission limits were derived from the concentrations of a well-functioning conventionally heated glass melting furnace at the request of the glassworks/ authority. For the nitrogen oxides there were requirements of the authority already at the time of the limit value determination.

For all emission components, the specific emissions clearly fall below the emission limits. Note the exceptionally low NO_x emissions that converted to a conventionally heated plant are below 200 mg/m^3.

A cost estimate of the emission control plant is not available.

5.1.1.4 Dust filters for batch handling: For the preparation, storage and the transport of batch and cullet there are in total nine precipitators, onto which a piping system with approximately 40 suction devices is connected. Three representative filter plants have to be monitored; they comply with the required dust limit values of 20 mg/m^3 and/or those of the dust components.

The occurring filter dusts are added to the batch.

There is no information on the cost situation.

5.1.1.5 Forming / Coating:

The exhaust gases of hot end coating are fed to the furnace exhaust gas through a piping system and cleaned by the treatment plant of the furnace.

The cost situation was not considered.

5.1.1.6 Wastewater

Process water is recirculated.

Wastewaters from machine and mould cleaning as well as elutriating water from the boiler field are subjected to continuous wastewater processing. The wastewaters are discharged indirectly.

For the wastewater processing the methods of sedimentation, precipitation of light substances and neutralisation are used.

The sludge from wastewater recirculation is added to the batch as well as partly disposed.

The fresh water requirement for the entire plant is met by an amount of 174 122 m^3/a of municipal water and 74 459 m^3/a of water from plant fountains.

The wastewater amounts to 77 580 m^3/a.

5.1.1.7 Wastes

There is no detailed information on the waste situation. The filter dust from the glass melting tanks to the amount of approx. 170 t/a is added to the batch and melted down. The filter dust in the batch house of about 180 t/a of faulty batches and sweepings are also melted down.

5.1.1.8 Evaluation of reference plant 1

The two oxy fuel fired melting furnaces mark the state of the art in the container glass sector in Germany. Oxy fuel fired furnaces achieve a level in the reduction of nitrogen oxide emissions that can be obtained with conventional furnace engineering only by secondary measures (SNCR and/or SCR).

The expected corrosion in the superstructure causing a short campaign obviously does not occur on both reference systems due to the height of the superstructures. Similar as with plants conventionally fired the specific consumption of energy goes up during a campaign and thus the energy costs are increased as well as the mass flows of the emissions due to firing.

For profitability studies of oxy fuel furnaces compared to conventionally regenerative or recuperative fired furnaces especially the oxygen delivery costs play an important role besides the furnace campaign, the capital expenditure, the specific energy consumption and/or the repair and maintenance costs. The capital expenditure and the energy consumption (without O_2 generation) of oxy fuel furnaces are lower than those of conventional furnaces, whereas the operational costs are higher taking the oxygen cost into account.

Through the heat exchangers for energy and compressed air generation, a considerable part of the energy contained in the exhaust gas can be recovered and used.

Due to the bag filter with dry sorption stage all emissions fall below the respective limit values.

5.1.1 Plant 2:

Cross fired furnace (natural gas) with raw material preheater and electrostatic precipitator (EP)

5.1.1.1 Melting plant

	Plant 2
Type	Cross fired furnace
Air preheating	Regenerative
Melting area	108 m^2
Burner per firing side	4 pairs of burner
Type of vaporisation	Air
Fuel	Natural gas, H_u = 31867 kJ/m^3
Electric boosting (installed)	-
Glass colour	Flint
Max. approved capacity	350 t/d
Last main repair	Year 2005
Campaign as planned	Year 2017
NO_x reduction measures	Near stoich. combustion, sealing measures, furnace geometry, burner assembly
Other measures	Filter dust recycling / sulphur-poor fuels
Coating material	TC 100
Path of emission hot end coating	Furnace waste gas treatment plant

Operating data	**Current Average value**
Melting output	275 t/d
Cullet amount, referred to melting output	60 %
Batch humidity, referred to entire batch	1.5 %
Gas consumption	1360 m^3/h
Max. crown temperature	1580 °C
Specific melting output	2.55 t/m^2d
Specific energy consumption	3782 kJ/kg_{glass}

(Volume data are referred to standard conditions)

In 2005, the furnace was subjected to a main repair and reconstructed with the same melting area. Comparing the specific energy consumption of the old furnace after an 11 year campaign of term and to that of the reconstructed furnace yields an annual increase of about 2.1 %, referred to the rebuild.

5.1.2.2 Waste gas heat recovery:

Type of heat exchanger	Raw material preheater with direct exhaust gas contact to melted glass
Place of installation	Raw gas after regenerator
Dedusting	None
Availability	100 %
Exhaust gas volume flow	17 000 m^3/h
Exhaust gas temperature – entry / exit	approx. 450 / 200 °C
Raw material temperature – entry / exit	approx. 20 / 300 °C
Amount of recovered energy	approx. 900 kWh/h

The recovered amount of energy was estimated. Allocated to the ton of produced glass this corresponds to about 78 kWh/t_{glass}.

Cost estimate (Writing-off time: 12 years / No depreciated value / Interest rate: 6 %)	**Heat exchanger incl. accessories** **[€]**
Investment / replacement costs	1000 000.-
Annual redemption	**113 333.-**
Operating costs Maintenance, energy, personnel, other	**10 000.-**
Annual total costs	**123 333.-**

This corresponds to an expenditure of 0.016 €/kWh of recovered energy.

Allocated to the tonnage the investment/ operating costs are € 1.23/t_{glass}.

5.1.2.3 Waste gas treatment plant of the furnace:

Type of filter	Electric filter with 3 fields
Temperature before filter	200 °C
Sorbent	None
Injection of water	None
Amount of filter dust	613 t/a
Use of filter dust	100 % recycling (batch)
Electrical energy	194 kWh/h
Service interval	As required

Emission limits - emission data (year 2005)

Component	Limit value [mg/m^3]	Measured value, standardised to 8 % O_2 [mg/m^3]	Measured value [kg/t_{glass}]
Total dust	50	23.8	0.0371
NO_x	3000	909	1.42
SO_x	1200	386	0.60
HF	5	3.0	0.0047
HCl	30	4.8	0.0075
Heavy metals:			
Group I TA Luft 1986	0.2	0.003	$0.005 \cdot 10^{-3}$
Group II TA Luft 1986	1.0	0.76	$1.2 \cdot 10^{-3}$
Group III TA Luft 1986	5.0	1.01	$1.6 \cdot 10^{-3}$

It is striking to note the small concentrations of exhaust gas components. All of them – partially even considerably – fall below the required limit values although no additional sorption agent is injected. Besides the function of heat recovery, the raw material preheater takes over the role of a sorption stage.

The good reaction conditions (long dwell time of the exhaust gases in the preheater and high loading of the exhaust gas with glass abrasion and batch) is contrasted by an increased wear in the exhaust gas system (redirections, blowers, deflectors).

Cost estimate (Writing-off time: 10 years / No depreciated value / interest rate: 6 %)	**Filter plant incl. accessories, blower, pipeline, …** **[€]**
Investment / replacement costs	1500 000.-
Annual redemption	**199 500.-**
Operating costs Maintenance / repair, electric energy, personnel, emission measurement, monitoring	**120 000.-**
Annual total costs	**319 500.-**

Allocated to the produced amount of glass, the estimated costs for the waste gas cleaning are € 3.18/t_{glass}.

5.1.2.3 Dust filters for batch handling:

In the batch house a central dedusting plant is installed; the silos are equipped with silo adaptor filters. Information on the costs was not given due to the connection of the reference system with additional furnaces.

5.1.2.5 Forming/ coating:

In the field of forming, there are no environmental control measures. Emissions of the manufacturing machines are released via the roof ventilators.

The exhaust gases of the hot end coating are fed to the furnace exhaust gases. A cost estimate of the pipeline construction is not available.

5.1.2.6 Wastewater:

Industrial water is discharged indirectly. Process wastewaters are recycled.

According to the operator, it is not possible to consider the wastewater situation particularly.

The wastewater amount for the entire factory is 60 000 m^3/a. The fresh water requirement is near 30 000 m^3/a.

Roughly 25 % of the respective total amount can be allocated to the reference system.

5.1.2.7 Wastes:

The main repairs cause the lion's share of the wastes. In total, this is about 2200 tons of refractory per main repair.

Detailed information is not available.

5.1.2.8 Evaluation of reference plant 2:

Due to their design, sideport furnaces have a higher energy demand compared to horseshoe fired furnaces. With the installation of a raw material preheater, the specific heat consumption can be reduced. In the present case, the specific energy demand of the regenerative natural gas fired sideport furnace with raw material preheater for the production of white container glass amounts to 3782 kJ/kg_{glass} for the rebuild. Due to electric boosting, the specific energy consumption can be further reduced. However, in this context the energy efficiency has to be taken into account.

Besides the energetic advantages of a raw material preheating system, further benefits result during the waste gas cleaning since normally a sorption stage is not necessary in order to keep the emission limit values. The dust concentrations in the raw gas after the preheating system are about 3000 mg/m^3. Abrasion of the exhaust gas components has to be considered in the design of the exhaust gas system.

In a presentation at Technical Committee VI of DGG, a furnace producer described a real sideport fired furnace with large chamber volume and fired with a very high portion of electric energy. The specific energy consumption inclusive electricity amounts to 3400 kJ/kg_{glass}. According to the experiences of HVG, this plant represents an exception.

5.1.3 Plant 3:

Horseshoe furnace (heavy oil)
with exhaust gas heat recovery system and EP

5.1.3.1 Melting plant

	Plant 3
Type	Horseshoe furnace
Air preheating	Regenerative
Melting area	100 m^2
Burner number per firing side	2
Type of vaporisation	Compressed air / Gas
Fuel type	Heavy oil (1% S), H_u = 41018 kJ/m^3; Natural gas, H_u = 35964 kJ/m^3
Electric boosting (installed)	2010 kVA
Glass colour	Amber
Max. approved melting capacity	300 t/d
Last main repair	Year 1997
Planned length of campaign	12 years
NO_x reduction measures	Near stoich. combustion, sealing measures, lambda adjustment, furnace geometry, burner assembly
Other measures	filter dust recycling / sulphate reduction
Coating material	$TiCl_4$ / $SnCl_4$
Emission path - hot end coating	Furnace waste gas treatment plant

Operating data	Current Average value
Melting output	297 t/d
Cullet portion, referred to melting output	72 %
Batch humidity, referred to entire batch	3 %
Oil consumption	920 kg/h
Gas consumption	300 m^3/h
Electric boosting power	1000 kW
Max. crown temperature	1605 °C
Spec. melting output	2.97 t/m^2d
Spec. energy consumption (incl. electric boosting)	4212 kJ/kg_{glass}

(Volume data are referred to standard conditions)

A cost estimate of the primary NO_X reduction measures was classified as difficult by the operator since these measures were consequently carried out by intern staff in the past years. Compared to regenerative sideport fired furnaces the investment and operating data costs of a horseshoe fired furnace are clearly lower, for example for the installation of ZrO_2 probes for the oxygen measurement in the chamber head or the fuel / air adjustment. For all measures in total, a benchmark of € 0.3/t_{glass} can be indicated.

Note: The current data represent the state of the furnace after a campaign of 8 years. For the same plant in the past years the operating data were also recorded in the course of emission measurements. With comparable limiting conditions the specific energy consumption (incl. electric boosting) increased as follows:

Year	**Spec. energy consumption [kJ/kg_{glass}]**
1997	3397
2000	3770
2003	4070
2005	4212

This corresponds to an annual increase of about 2.7 % of specific energy consumption.

The enormous rise in energy prices is becoming clearly more seriously noticeable than the increase in the specific energy consumption.

5.1.3.2 Waste gas heat recovery:

Type of heat exchanger	Pipe bundle
Heat carrier	Water / steam
Use of gained energy	Electric current / industrial water
Place of installation	Clean gas after EP
Type of dedusting	Compressed air
Dedusting	Online
Dust disposal	Added to batch
Availability	99 %
Temperature difference	approx.. 150 °C
Waste gas volume flow	approx. 25 500 m^3/h
Recovered energy	approx. 1 500 kWh/h

The recovered energy was estimated.

Cost estimate (Writing-off time: 10 years / No depreciated value / interest rate: 6 %)	**Heat exchanger incl. accessories** **[€]**
Investment / replacement costs	1670 000.-
Annual redemption	**222 111.-**
Operating costs incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**33 500.-**
Annual total costs	**255 611.-**

This corresponds to an expenditure by 0.0195 €/kWh of recovered energy.

Allocated to the tonnage, the investment/operating data costs are € 2.36/t_{glass}.

5.1.3.3 Waste gas treatment plant of the furnace:

Type of filter	EP with 2 fields
Temperature before filter	400 °C
Type of sorption agent	$Ca(OH)_2$
Amount of sorption	28 kg/h
Water injection	As required
Amount of filter dust	300 t/a
Use of filter dust	100 % recycling (batch)
Energy demand of blower	125 kWh/h
Energy demand of filter	65 kWh/h
Service interval	Annually

Emission limits – emission data

Component	**Limit value** [mg/m³]	**Measured value, standardised to 8 % O_2** [mg/m³]	**Measured value** [kg/t_{glass}]	**Reduction** [%]
Total dust	20	1.2	0.0019	99.9
NO_x	800	507	0.82	-
SO_x	1400	829	1.34	53
HF	5	3.3	0.0053	88
HCl	30	25.0	0.0405	71
Heavy metals:				
Group I TA Luft 1986	0.2	$1.2 \cdot 10^{-3}$	$1.9 \cdot 10^{-6}$	n.d.
Group II TA Luft 1986	1.0	$124 \cdot 10^{-3}$	$201 \cdot 10^{-6}$	n.d.
Group III TA Luft 1986	5.0	$29 \cdot 10^{-3}$	$47 \cdot 10^{-6}$	n.d.

n.d.: not determined

The lowest standardised NO_x concentrations within the framework of emission measurements according to § 28 BImSchG were 446 mg/m^3, however together with CO concentrations of 82 mg/m^3.

The value given in the table was determined without CO concentrations.

Cost estimate (Writing-off time: 10 years / No depreciated value / interest rate: 6 %)	**Filter plant incl. accessories, blower, pipeline, …** **[€]**
Investment / replacement costs	2100 000.-
Annual redemption	**279 300.-**
Operating costs Maintenance / repair: 10 000.- Electr. current: 93 000.- Sorption agent: 20 000.- Personnel: 15 000.- Cont.- / emission measurement: 14 000.-	**152 000.-**
Annual total costs	**431 300.-**

Allocated to the produced amount of glass, € 3.98/t_{glass} have to be invested for the exhaust emission control system.

5.1.3.4 Dust filters for batch handling:

For the preparation, storage and the transport of batch and cullet flows, a central dust collector exists as well as 20 individual top piece silo filters. The plants are not subject to monitoring.

At the top piece silo filters the precipitated dust accumulating during pneumatic filling falls back into the silo. The dust precipitated by the central dust collector is added to the batch and melted down.

Cost estimate (Writing-off time: 10 years / No depreciated value / interest rate: 6 %)	**Dust collectors** **[€]**
Investment / replacement costs	190 000.-
Annual redemption	**25 270.-**
Operating costs incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**8 500.-**
Annual total costs	**33 770.-**

The dedusting in the batch house accordingly costs € 0.31/t_{glass} allocated to the tonnage.

5.1.3.5 Forming / Coating:

In the forming section, no environmental control measures exist. Emissions in the field of the manufacturing machines are released via the roof ventilators.

The exhaust gases of the hot end coating are carried to the furnace waste gases via a piping system and cleaned by the emission control plant of the furnace. The investment requirement for pipelines of high-grade steel amounted to about € 20 000. The maintenance requirement is negligible.

The cost estimate amounts to annual total costs of € 2660.

Allocated to the tonnage this is € 0.02/t_{glass}.

5.1.3.6 Wastewater:

The wastewaters are discharged both directly and indirectly.

There are the following wastewaters:

a) Industrial water as in household (canteen, toilet,…)
b) Industrial water as in household (canteen, toilet,…)
c) Cooling water (with product contact)
d) Cooling water (without product contact)
e) Process water (shears cooling)
f) Cleaning water (machine cleaning, mould cleaning,…)

The wastewaters from b) and d) are recycled.

The water for the shears cooling is continuously carried to an oil filter.

The wastewater from d) together with the cleaning water from e) is added to the batch and burned.

For wastewater processing the methods of sedimentation, filtration, light material deposit and combustion are used.

Wastewater requirements and limit values:

Wastewater amount:	max. 1 m^3/h
Temperature:	max. 35 °C
pH value:	6 – 9.5
Precipitable substances:	1 ml/l
Undissolved substances:	50 g/m^3
Colour:	Decolourisation in local wastewater processing has to remain guaranteed
Odour:	Without bothering odours
Toxicity:	No influencing of the biological processes in the wastewater treatment plant - no adverse effect on the sludge treatment

Al	10 g/m^3	370 mol/m^3	F	50 g/m^3	2650 mol/m^3
Pb	2 g/m^3	10 mol/m^3	Cu	2 g/m^3	30 mol/m^3
Cd	1 g/m^3	10 mol/m^3	Ni	3 g/m^3	50 mol/m^3
Cr	2 g/m^3	40 mol/m^3	Hg	0.05 g/m^3	0.25 mol/m^3
Cr VI	0.5 g/m^3	10 mol/m^3	Zn	5 g/m^3	75 mol/m^3
Fe	10 g/m^3	180 mol/m^3	Öl	20 g/m^3	

Cost estimate (Writing-off time: 10 years / No depreciated value / interest rate: 6 %)	**Wastewater** **[€]**
Investment / replacement costs	330 000.-
Annual redemption	**43 890.-**
Operating costs Including maintenance, energy, resources, personnel, measurements, other: 33 000.- Residues (30 m^3): 15 000.- Wastewater (indirectly / 6000 m^3/a): 15 000.-	**63 000.-**
Annual total costs	**106 890.-**

This corresponds to an amount of € 0.99/t_{glass}.

The directly discharged wastewater (clear of all charges) amounts to 16 700 m^3/a.

The fresh water requirement is covered by an amount of 1750 m^3/a of municipal water and 17 000 m^3/a of water from the company owned fountain.

5.1.3.7 Wastes:

Great amounts of wastes accumulate on completion of a furnace campaign in the course of a main repair. Specialised firms carry out all demolition and disposal activities.

The drained glass is recycled to the melting process.

Fireclay is normally used in road construction.

Fusion cast materials (ZAC) are reprocessed. At the demolition, about 400 t of ZAC material accumulate, which is remunerated with € 65/t.

The deposit of building rubble costs € 25.-/ t . The costs for the deposit of "half contaminated" and "contaminated" refractory amount to € 55.-/t and € 100.-/t, respectively.

In total, 30 % of the wastes are reused and 70 % are disposed.

Altogether, demolition costs arise at the level of approx. € 150 000. - and disposal costs of approx. € 130 000.-.

For a furnace campaign of 10 years, the demolition and disposal costs are about € 0.26/t_{glass}.

The waste balance for the entire factory in the year 2005 is as follows (1/3 of the mentioned amounts are allotted to the reference plant 3):

Type	AVV no.		Tons	€/ton	Transport €	Charge €	Sum €
PE foil	150102	V	131.23	-344.51	2.070.00	-	-45210.25
Brass	170401	V	11.65	-1421.12	0.00	-	-16557.15
Mould cast	170405	V	71.46	-155.48	0.00	-	-11110.30
Scrap iron	170405	V	164.97	-64.97	416.18	-	-10718.92
Copper	170401	V	1.94	-2590.11	0.00	-	-5030.00
Nickelous	?	V/E	0.88	-3435.98	377.50	80.56	-3016.79
Carton	150101	V	169.57	-12.59	2764.00	-	-2134.48
Electrocord	170411	V	1.51	-900.00	0.00	-	-1355.40
Aluminium	170402	V	0.86	-587.04	0.00	-	-507.20
Batteries	160601	E	0.50	0.00	0.00	-	0
Mixed paper	150101	V	43.43	3.73	1035.00	-	162.12
Cullet, unrelevant	101112	V	1.97	111.03	48.50	-	218.73
Bases	06XXXX	E	0.03	7558.62	65.70	110.00	219.20
Mineral fibre	170604	E	1.07	215.00	0.00	-	230.05
Fluorescent tubes	060404	E	0.23	1122.25	22.09	-	254.75
Colours, lacquers	080111	E	0.28	1100.23	38.34	55.00	308.08
Grease trap, canteen	020204	V	4.50	71.11	0.00	5.00	320.00
Solvent	14060X	E	0.70	983.65	63.90	110.00	684.62
Scrap electronics	200135	V	7.86	118.72	122.00	-	933.11
Spray cans	160504	E	0.57	2754.39	973.50	55.00	1570.00
Chemicals	?	E	1.55	1094.00	43.80	190.00	1693.51
Building rubble	170107	V	61.82	29.47	568.41	-	1821.94
Machine oil, chlorine-free	130205	V	40.43	49.55	65.56	140.00	2003.17
Old wood A1	170201	V	85.76	24.27	1653.00	-	2081.80
Oleaginous resources	150202	V	11.98	257.89	94.50	-	3089.50
Elutriates	130503	V	19.56	176.94	646.74	1777.47	3460.99
Rubbish	200303	V/E	66.47	60.13	681.50	-	3996.80
Chamber waste	161105	V	60.41	141.91	3527.00	393.92	8572.49
Sortable waste	150106	V	114.08	140.38	1101.00	-	16015.08
Glass sludge	101114	V/E	162.89	241.63	8158.70	114.00	39359.70
			1240.15	**6.97**	**24536.92**	**3030.95**	**-8645.19**

V: Utilisation E: Disposal

The gains from the waste amount to € 95640.84. Thus, they are about € 8645.19 above the expenditure of € 86955.64.

5.1.3.8 Evaluation of the reference plant 3:

The plant has been known to the HVG for decades. It is one of the first glass melting furnace to be equipped with continuous emission measurement technology.

In the years dating back, primary NO_x reduction potentials were consistently employed and permanently proved. The efforts of the management were orientated in this case not only on existing emission limit values, but also on the strict implementation of the available primary reduction measures.

With a standardised NO_x value of about 500 mg/m^3 and/or 0.8 kg/t_{glass}, the reference system marks the lowest value of all container glass furnaces conventionally fired with regenerative air preheating in Germany even after a campaign of 8 years. At the beginning of the furnace campaign, the specific NO_x emission was actually 0.65 kg/t_{glass}. While in the year 2005 the specific energy consumption was 4212 kJ/$kg_{glass,}$ it was 3397 kJ/kg_{glass} after the rebuild. The annual increase in the specific energy demand of about 2.7 % is representative for the aging process of glass furnaces with regenerative air preheating. With the rise of the energy consumption, also the firing related emissions are increased.

The exhaust gas heat use compensates the energy amount of the electric boosting inserted in the melt. If one considers the energy amount gained from the exhaust gas, the specific energy demand is 3921 kJ/kg_{glass} after a furnace campaign of 11 years.

Besides the nitrogen oxides, also the other emission components fall below the required limit values, including those of the current 2002 TA Luft.

If one adds the costs for primary and secondary environmental control measures in respect of air and wastewater, an amount of € 5.80/t_{glass} results. In addition, there is the cost of the heat recovery of € 2.36/t_{glass} which, however, has to be offset against the gained energy.

The emission control plant is designed on a large scale. The dust emissions of 1.2 mg/m^3 are exceptionally low for an EP. In the past, the HF and HCl concentrations were on a clearly lower level with 0.8 and 4 mg/m^3, respectively; however, with higher sorption agent amount being used. The amount of sorption agent was increased to the former level, after the results of the 2005 measurements became known.

Energy, exhaust gas, waste and wastewater management can be characterised as exemplary.

5.1.4 Plant 4:

Horseshoe furnace (natural gas) with SCR and EP

5.1.4.1 Melting plant:

Focus of the investigation of this system configuration was the combination of exhaust gas cleaning with the selective catalytic reduction (SCR plant). The topics wastes and wastewater as well as the melting plants were not considered.

The exhaust gases consist of the common exhaust gas fume of four natural gas fired horseshoe furnaces with regenerative air preheating.

5.1.4.2 Waste gas heat recovery:

Besides the regenerative air preheating system no waste gas heat recovery system is installed.

5.1.4.3 Waste gas treatment plant of the furnaces:

Filter type	EP with 5 fields
Temperature before filter	380 °C
Sorbent	$Ca(OH)_2$
Amount of sorption agent	35 kg/h
Water injection	None
Amount of filter dust	550 t/a
Use of filter dust	100 % recycling (batch)
Energy demand	545 kWh/h
Service interval	Annually
Exhaust gas volume flow, dry	57 000 m^3/h

(Volume data are referred to standard conditions.)

The downstream 2-layer honeycomb catalyst was installed in 1994 and is cleaned quasi-continuously with preheated compressed air. Reducing agent is 25 % NH_3 solution.

Emission limits - emission data (year 2001)

Component	**Limit value** [mg/m³]	**Measured value, standardised to 8 % O_2** [mg/m³]	**Measured value** [kg/t_{glass}]	**Reduction** [%]
Total dust	50	5.4	0.0094	> 99
NO_x	500	389	0.68	78
SO_x	1800	291	0.51	42
HF	5	2.1	0.0036	83
HCl	30	19,4	0.0342	52
NH_3	30	8.4	0.0149	-
Heavy metals:				
Group I TA Luft 1986	0,2	< 0.02	$< 0.04 \cdot 10^{-3}$	n.b.
Group II TA Luft 1986	1,0	0.88	$1.55 \cdot 10^{-3}$	88
Group III TA Luft 1986	5,0	0.30	$0.53 \cdot 10^{-3}$	96

n.d.: not determined

The amount of the emissions of the substances of Group II is to be put down basically to gaseous selenium compounds.

The tonnage was about 640 t/d. At the time of the measurements, 110 l/h of ammonium hydroxide were injected.

The emission measurements in 2004 were on the same level. The NH_3 slip was clearly higher with 19.5 mg/m³, however, and the standardised NO_x concentrations were 456 mg/m³.

The entire electric energy demand of the filter and SCR plant, including ammonia, proportioning, compressed air and other consumers, was indicated with 547 kW.

An electricity tariff of € 0.065/kWh was assumed.

For ammonium hydroxide (25 %) 110 €/m³ were estimated.

Writing-off time of 13 years was indicated by the plant operator. For comparison with other plants writing off 10 years, this period was considered also in this case.

The entire financing occurred within the framework of a publicly financed promotion project.

Cost estimate (Writing-off time: 10 years / No depreciated value / interest rate: 6 %)	**Filter plant incl. accessories, blower, pipeline, …** **[€]**	**SCR incl. storage, proportioning...** **[€]**
Investment / replacement costs	3950 000.-	2350 000.-
Annual redemption	**525 350.-**	**312 550.-**
Operating costs Maintenance / repair: 10 000.- Electr. current: 311 460.- Sorbent: 25 000.- Personnel: 15 000.- Cont. / emission measurement (5000.-) Ammonium hydroxide (106 000.-)	**472 460.-**	
Annual total costs	**1310 360.-**	

Allocated to the glass produced, an amount of € 5.61/t_{glass} has to be invested accordingly for the emission control including SCR.

The amount for the catalyst is about € 2.00/t_{glass}.

Points 5.1.4.4 to 5.1.4.7 were not considered within the framework of this project.

5.1.4.8 Evaluation of reference plant 4:

Reference system 4 is equipped with an electrostatic precipitator incl. exhaust gas dry sorption stage ($Ca(OH)_2$ as sorption agent) and downstream SCR plant with 25 % ammonia solution as reducing agent. It has been constantly in operation for 12 years without catalyst exchange. Thus, it produced evidence that nitrogen oxides in the exhaust gas of natural gas fired glass furnaces can be efficiently reduced with the method of selective catalytic reduction used after the filter plant.

Therefore, mainly economical grounds speak against this technology. Under the limiting conditions found, about 2 €/t_{glass} have to be spent additionally in order to realise NO_x values of less than 500 mg/m^3. Attention has also to be paid to added environmental pollution through the additional ammonia slip and the energy consumption necessary for the ammonia generation.

Operating an SCR plant, the firing conditions of the furnaces have to be taken into account. The experiences of HVG showed that primary NO_x reduction measures now tend to be less used. This leads to an increase in the ammonia and, in general, in the specific energy consumption.

Besides the nitrogen oxides also the other emission components fall below the required limit values, incl. those of the 2002 TA Luft.

5.1.5 Further information on the container glass industry:

As already mentioned, between 2000 and 2005 there were considerable economical difficulties in the container glass sector, with the result of production closures and factory shutdowns. The consolidation measures did not exclude plants that are to be classified as BAT plants (oxy fuel furnace with raw material preheating – LowNO$_X$ melter – horseshoe fired furnace with raw material preheating).

Note the following concerning furnaces closed down:

LowNO$_X$ melter

Operating data of existing LowNO$_X$ melter could not be established. For this reason, only information on a deactivated plant obtained during emission measurements in 2000 can be made:

	LowNO$_X$ melter
Melting area	194 m^2
Number of burner per firing side	10
Type of the vaporisation	Compressed air / gas
Type of fuel	Fuel oil S (max. 1 % S) H_u = 40 300 kJ/m^3
Electric boosting (installed)	2860 kVA
Glass colour	Green
Max. approved melting output	390 t/d
Year of manufacture	1997

Operating data	**Year 2000**
Melting output	358 t/d
Cullet fraction, referred to melting output	80 %
Oil consumption	1429 kg/h
Gas consumption	300 m^3/h
Max. crown temperature	1560 °C
Spec. melting output	1.85 t/m^{2}d
Spec. energy consumption (incl. electric boosting)	4008 kJ/kg$_{glass}$

(Volume data are referred to standard conditions)

The plant was equipped with a raw material preheater. Information on the exhaust gas heat use is not available.

Data of the emission control plant:

Type of filter	EP with 2 fields
Temperature before filter	180 °C
Sorption agent	Ca(OH)2
Amount of sorbent	30 kg/h
Use of filter dust	100 % recycling (batch)

Emission limits - emission data (year 2000)

Component	Limit value [mg/m³]	Measured value, standardised to 8 % O_2 [mg/m³]
Total dust	40	2.7
NO_x	650	336
CO	-	58
SO_x	1600	1326
HF	5	0.6
HCl	15	10.2
Heavy metals:		
Group I TA Luft 1986	0.2	-
Group II TA Luft 1986	1.0	0.014
Group III TA Luft 1986	5.0	0.017

Oxy fuel furnace with raw material preheating

At the beginning of 2005 a mixed fired (heavy oil - natural gas) oxy fuel furnace with raw material preheater for the production of container glass was taken out of operation. The furnace was designed for a melting rate of 415 t/d and at the beginning of the campaign was operated with a specific heat consumption (incl. electric boosting) of 3020 kJ/kg_{glass}. Including the energy demand for the oxygen production (VSA oxygen), a remarkably advantageous value of about 3238 kJ/kg_{glass} was stated corresponding to an energy demand for the oxygen production of approx. 60 kWh/t_{glass}. The triple of the reported value was observed by other sources.

The NO_x emissions were in the range of 0.25 kg/t_{glass}, accompanied by CO emissions of 0.08 kg/t_{glass}, however.

The difficulties with handling and wear of the raw material preheater resulted in the plant being taken out of operation. After a campaign of seven years, the energy consumption of 3618 kJ/kg_{glass} without VSA oxygen generation was found, i.e. an annual increase of 2.6 %.

The oxy fuel furnace together with two conventionally fired furnaces was connected to an electrostatic precipitator with dry sorption stage. The required limit values of the notice of approval were kept.

Horseshoe fired furnace with raw material preheating

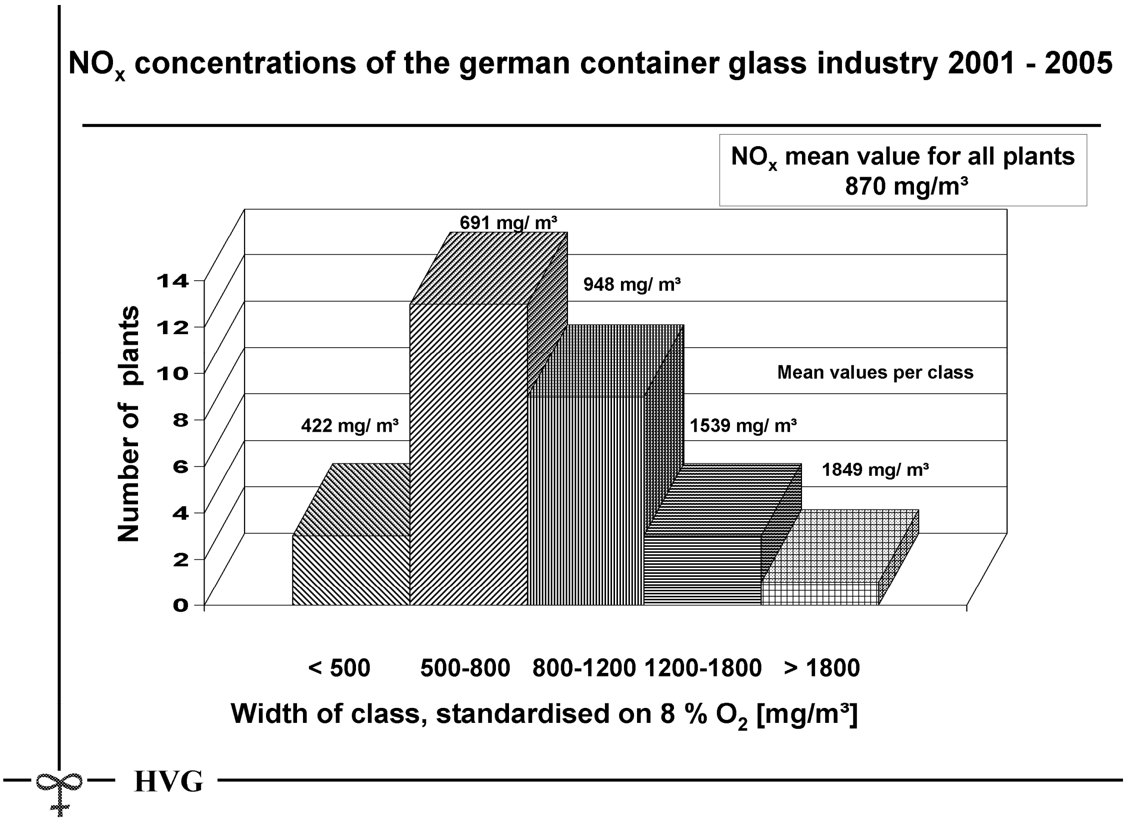
The specific energy consumption of the deactivated furnace had been 4027 kJ/kg_{glass} after a campaign of 11 years..

The treated BAT plants are certainly not representative for the entire container glass industry with regard to their energy demand and the effects on the environment. The recording of all plants would exceed the scope of this project.

In Germany, container glasses are mainly melted in horseshoe furnaces with regenerative air preheating. The melting area is between 16 m^2 and 120 m^2. The specific energy consumption depends on many factors, such as size and utilisation of the plant, furnace and chamber construction, quality requirements, cullet content and type of molten glass, age of furnace, firing management and fuel.

A specific energy consumption of 3200 kJ/kg (incl. electric boosting) can be achieved for a heavily loaded large horseshoe fired furnace in the state of reconstruction. In new condition, the value is 4000 kJ/kg for smaller, efficient plants with a melting area of 40 m^2.

The NO_x concentrations of 29 plants, established by HVG emission measurements from 2000 to 2005 in the container glass industry, are in the following graphs.



Note that for about half of the plants, already today the emissions fall below the limit value of 800 mg/m^3 valid from 2010. On the other hand, there are a number of plants for which this limit value still represents a target value.

A conventional horseshoe fired furnace (Reference plant 3), a plant with SCR technology (Reference plant 4) as well as a now deactivated LowNO_X melter are among the plants with concentrations below 500 mg/m^3.

The indicated average value is an arithmetic value from the number of the plants, i.e. it is not referred to the melting capacity.

5.2 Flat glass:

In Germany, eleven float glass lines as well as three cast glass furnaces exist at present.

All float glass aggregates use sideport furnaces with regenerative air preheating and are equipped with electrostatic precipitators and dry sorption stage. Both natural gas and heavy fuel oil are used as energy source. The maximum tonnages are between 550 t/d and more than 800 t/d according to furnace and glass.

The quality requirements for the melted glass are clearly higher compared to the container glass industry. All measures for the reduction of environment polluting emissions are subjected to the quality requirements. As a matter of course, all operators use the known possibilities of the primary measures for the NO_x reduction. Nevertheless, the used primary methods for the reduction of the nitrogen oxide emissions are different.

In 2006, a completely new float line equipped with an SCR plant was set up near Magdeburg. According to the 2002 TA Luft, new systems of this size must keep an NO_x limit value of 500 mg/m^3. HVG has no knowledge so far about measured values and/or operational experiences.

For cast glass furnaces the maximum approved melting capacities are 350 t/d. Also for this sector the melting aggregates are sideport fired furnaces. Since 1996, however, a cast glass furnace has been operated with VSA oxygen as oxidising agent and heavy oil as fuel. Under point 5.2.3, some information on this plant is given.

Unfortunately, it has not been achieved to establish data on a natural gas fired float line using the 3R process within the framework of this project.

As reference systems, a cast and a float glass furnace have been investigated both of which are heavy fuel oil fired, use additional exhaust gas heat and are equipped with extensive measures for primary NO_x reduction.

5.2.1 Plant 5:

Flat glass furnace (heavy oil)

with exhaust gas heat recovery system and EP

5.2.1.1 Melting plant

	Plant 5
Type	Sideport furnace
Air preheating	Regenerative
Melting area	136 m^2
Type of vaporisation	Compressed air
Fuel type	Fuel oil S, H_u = 40 700 kJ/kg
Electric boosting (installed)	1000 kVA
Glass colour	White, extrawhite, bronce, yellow
Max. approved melting capacity	350 t/d
Last main repair	Year 2000
Planned campaign	Year 2010
NO_x reduction measures	Near stoich. combustion, sealing measures, adjustable burners, lambda adjustment, burner assembly
Other measures	Filter dust recycling / sulphate reduction
Exhaust gas heat use	Raw gas heat exchanger

Operating data	**Average value**
Melting capacity	259 t/d
Cullet fraction, referred to melting capacity	30 %
Batch humidity, referred to total batch	4.6 %
Oil consumption	1515 kg/h
Capacity of electric boosting	-
Max. crown temperature	1550 °C
Spec. melting capacity	2.35 t/m^2d
Spec. energy consumption	5710 kJ/kg_{glass}

(Volume data are referred to standardised condition)

The mentioned values represent the state of the plant after a 5 year campaign with the production of conventional cast glass.

Currently a glass is melted which must suffice special quality requirements (application in photovoltaic solar panels) and has a higher specific energy demand (6145 kJ/kg_{glass}).

Besides the furnace and chamber construction, the insulation, the fuel/air ratio, the firing management, etc., the specific energy consumption depends on the melting capacity of the furnace, in particular.

High utilisation favours specific energy consumption since the heat losses in the superstructure and in the area of the chamber decrease referred to the tonnage. In the present case, the tonnage is strongly product and market dependent so that temporarily only two of the three production lines are in operation. Thus, the utilisation varies between 200 and 320 t/d.

For the rebuild, the specific energy consumption was 5050 kJ/kg_{glass} in the case of high utilisation. The increase in the energy consumption due to ageing of the furnace is 2.5 % per annum.

The furnace has a separate chamber system with partition walls in the regenerators, i.e., each of the six chambers per firing side has separate switching units for exhaust gas and combustion air (sliding valves and channels), single blower with regulation equipment and ZrO_2 probes for the oxygen measurement in the chamber head. Besides, elaborate measuring and control equipment is available. All measuring and control quantities, energy consumption, oxygen content in the chamber heads and emissions are monitored and documented. The continuous emission measurement technology allows the recording of the emission components NO_x, SO_2 and dust as well as that of the exhaust gas limiting conditions of O_2 and temperature. The exhaust gas volume flow and the emission mass flows are deduced from the recording of the oil amount.

All these measures and the willingness of the management to continuously optimise the process in a way that is energy efficient and compatible to the environment are necessary, in order to be able to permanently keep the NO_x emission limit value of 800 mg/m^3 (operating data parameters without nitrate fining) already fixed in the permission notice. Again, a cost estimate of all installations understood as primary NOx reduction measures in the sum turns out to be difficult.

Compared to a regenerative horseshoe furnace, investment expenditure and operating data costs are clearly higher. Since for the main repair no offer for a furnace without separate chamber system was invited, the cost estimate is based on statements from furnace producers, the management and other specialists. Nevertheless, it remains an estimate with a relatively great insecurity.

Partition walls, sliding valves, waste gas channels are designed for an operating time of 20 years. In addition to the installation costs, the necessary measuring and control technology and the continuous emission control have to be taken into account. The installation and maintenance of the ZrO_2 probes is done on leasing basis.

The cost estimate considers the additional expenditure compared to a plant without reduction measures.

Cost estimate (Writing-off time: **20 years** / No depreciated value / interest rate: 6 %)	**Primary NO_X measures furnace** **[€]**
Investment / replacement costs	1500 000.-
Annual redemption	**126 000.-**
Operating costs Energy: 5000.- Oxygen measurement: 30 000.- Emission measurement (proportionally): 5000.-	**40 000.-**
Annual total costs	**166 000.-**

The measured values of the emission measurement are necessary as a control mechanism. They are usually assigned to the emission control plant, in this case however, by 50 % to the primary measures.

Thus, for an average tonnage of 259 t/d, an amount of € 1.76 /t_{glass} results for primary NO_X reduction measures. For full utilisation of the furnace, € 1.42/t_{glass} have to be considered.

The larger the plant, the less effect have the cost of primary NO_X reduction on the cost of the ton of produced glass. With an investment requirement of about € 2000 000.- and the same operating data costs, about € 0,80/t_{glass} can be estimated for a float glass plant with a melting capacity of 750 t/d.

5.2.1.2 Waste gas heat recovery:

Type of heat exchanger	Tube register
Heat carrier	Water / steam
Use of gained energy	Industrial water / firing / oil preheating
Installation	Raw gas before EP
Type of dedusting	hail of bullets
Dedusting	Online
Dust disposal	Special disposal
Availability	99 %
Temperature difference	approx. 200 °C
Recovered energy amount	approx. 1500 kWh/h

Allocating the recovered energy amount to the melting capacity, a value of 139 kWh/t_{glass} and 500 kJ/kg_{glass}, respectively, is established.

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Heat exchanger incl. accessories** **[€]**
Investment / replacement costs	500 000.-
Annual redemption	**66 500.-**
Operating costs Incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**60 000.-**
Annual total costs	**126 500.-**

This corresponds to an expenditure of 0.010 €/kWh of regained energy.

The investment/ operating data costs are 1.34 €/t_{glass} allocated onto the tonnage.

5.2.1.3 Waste gas treatment plant of the furnace:

Type of filter	EP with 2 fields
Temperature before filter	Max. 300 °C
Sorbent	$NaHCO_3$
Amount of sorption agent	55 kg/h
Water injection	In the summer: yes In the winter: no
Amount of filter dust	570 t/a
Use of filter dust	100 % recycling (batch)
Energy demand: filter and blower	125 kWh/h
Service interval	Annually

Emission limits - emission data

Component	Limit value [mg/m³]	Measured value, standardised to 8 % of O_2 [mg/m³]	Measured value [kg/t_{glass}]
Total dust	20	3.0	0.0048
NO_x	800	780	1.89
NO_x (use of nitrate)	1600	1150	2.78
SO_x	1200	1150	2.78
HF	5	3.7	0.0089
HCl	30	7.0	0.0169
Heavy metals:			
Group I TA Luft 1986	0.2	$0.6 \cdot 10^{-3}$	$1.5 \cdot 10^{-6}$
Group II TA Luft1986	1.0	$4 \cdot 10^{-3}$	$9.7 \cdot 10^{-6}$
Group III TA Luft 1986	5.0	$25 \cdot 10^{-3}$	$60.5 \cdot 10^{-6}$

During the bronze glass campaign, the amount of sorption agent has to be clearly increased. With 80 kg/h the emissions of gaseous selenium compounds of about 30 mg/m^3 in the raw gas can be reduced to less than 3 mg/m^3 in the clean gas. In order to keep the current limit value of 1 mg/m^3 the amount of sodium bicarbonate has to be increased to about 120 kg/h or 3.5 g/m^3.

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Filter plant incl. accessories, blower, pipeline, …** **[€]**
Investment / replacement costs	2200 000.-
Annual redemption	**292 600.-**
Operating costs	**205 000.-**
Annual total costs	**497 600.-**

Allocated to the produced amount of glass, an amount of € 5.26/t_{glass} has to be invested accordingly for the emission control. In the case of full utilisation of the furnace the amount is reduced to approx. € 4.30/t_{glass}.

The calculation is based on the assumption that the filter plant including proportioning has to be rebuilt. If the plant is older than 10 years and still functional, the annual redemptions are omitted. Thus, only the operating data costs have to be considered for a filter plant written off. Converted to the current tonnage these are € 2.17/t_{glass}.

5.2.1.4 Dust filters for batch handling:

There are two bag filter plants (without requirements by the authorities) for the dedusting during the feeding and weighing of the raw materials and/or the mixer area. In addition, four top piece silo filters are installed.

The top piece silo filters cause the precipitated dust, that accumulates during the pneumatic filling, to fall back into the silo. The precipitated dust of the filter plants is added to the batch and melted down.

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Dedusting plants batch house [€]**	**Top piece filter [€]**
Investment / replacement costs	150 000.-	40 000.-
Annual redemption	**19 950.-**	**5320.-**
Operating costs Incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**20 000.-**	**10 000.-**
Annual total costs	**<u>55 270.-</u>**	

Accordingly, the dedusting in the batch house costs € 0.58/t_{glass} allocated to the tonnage.

5.2.1.5 **Forming / coating:** Not applicable

5.2.1.6 Wastewater:

The wastewaters are discharged indirectly.

There are wastewaters as follows:

a) Industrial water as in household (canteen, toilet,…)
b) Process water (Osmosis water for the full desalination, wastewater from filter backwash when obtaining water from fountain)

The wastewaters from b) are recycled and processed. Moreover, the water is subjected to water processing in the waste heat boiler.

For wastewater processing the methods filtration and ion exchange are employed.

Threshold values and annual freights of components:

Emitted substance (parameter)			Direct discharge		indirect discharge	
No.	Denotation	Threshold value [kg/a]	Freight [kg/a]	Kind of detection	Freight [kg/a]	Kind of detect.

1. Nutrients

01	Nitrogen sum as N	50 000	-	-	4982	M
02	Phosphorus sum as P	5000	-	-	177	M

2. Metals and compounds

03	Arsenic and compounds as As	5	-	-	0.70	M
04	Cadmium and compounds as Cd	5	-	-	0.07	M
05	Chrome and compounds as Cr	50	-	-	0.70	M
06	Copper and compounds as Cu	50	-	-	3.15	M
07	Mercury and compounds as Hg	1	-	-	0.03	M
08	Coin and compounds as Ni	20	-	-	0.85	M
09	Lead and compounds as Pb	20	-	-	2.14	M
10	Zinc and compounds as Zn	100	-	-	4.92	M

3. Chlorous organic substances

11	Dichloroethan-1,2 (DCE)	10	-	-	0.07	M
12	Dichlorine methane (DCM)	10	-	-	0.07	M
13	Chlorine alkanes (C10 - 13)	1	-	-	b. d.	M
14	Hexachlorobenzene (HBC)	1	-	-	0.01	M
15	Hexachlorine butadiene (HCBD)	1	-	-	0.01	M
16	Hexachlorcyclohexan (HCH)	1	-	-	0.01	M
17	Halogen Containing organic combinations as AOX	100	-	-	5.95	M

4. Else. Organic Combinations

18	Benzol, toluol, ethyl benzol, xylenes as BTEX	200	-	-	b.d.	M
19	Bromierte Diphenylether	1	-	-	0.01	M
20	Organic stannic combinations as Sn	50	-	-	0.07	M
21	Carbolic acids as entirely C	5	-	-	0.75	M
22	Polycyclic ones. Aromatic hydrocarbons	20	-	-	8.90	M
23	Organic carbon as Gesamt - C or CSB/3	50 000	-	-	7428	M

5. Other compounds

24	Chloride as Cl	2000 000	-	-	9096	M
25	Cyanide as a cellulose nitcapacity	50	-	-	0.76	M
26	Fluoride as F	2000	-	-	0.01	M

b.d. = below the determination limit M: measured

Cost estimate: (Writing-off time: 15 years / no depreciated value / interest rate: 6 %)	**Wastewater** **[€]**
Investment / replacement costs	1500 000.- (Redevelopment)
Annual redemption	**110 000.-**
Operating costs: Incl. maintenance, energy, resources, personnel, measurements, other: 10 000.- wastewater (indirect / 2000 m^3/a): 5000.-	**15 000.-**
Annual total costs	**<u>125 000.-</u>**

This corresponds to an amount of € 1.32/t_{glass}.

Moreover, there are additonal costs at the level of € 74 000.-, that have to be get together for fall out water. Added up this corresponds to total cost of wastewater of € 2.10/t_{glass}.

The fresh water consumption is 84 408 m^3/a. The costs amount to € 79 000.

5.2.1.7 Wastes:

As for every glass melting furnace, the lion's share of waste occurs in the course of a main repair. Following amounts of refractory occurred in 2000:

Corhart ZAC:	137.68 t
Secondary material LAGA Z 1.2:	958.20 t
Secondary material TASi 2:	990.36 t
Misalignment material:	612.70 t

The costs were not considered.

The waste balance for reference plant 5 for 2005 is as follows:

Waste designation	New AbfSchl. (Krw-/AbfG) from 2002	Internal	External	Utilisation	Elimination	Landfill over surarea area	Landfill below surarea area	Chemical, Physical Processing	Combustion	Identification	Amount 05 [in t]	Costs [in EURO]
Fluorescent tubes	200121		X		x					R 4	0.2	333.94
Glass waste (break glass)	101112		X	x		X				D 1	367.74	12012.33
Construction site waste concrete	170101		X	X						R 5	11.92	159.26
Domestic refuse	200301		X	x					X	D 10	20.93	11393.74
Epoxy	150102		X	X						R 1	6.85	2857.51
Consumed linings and ff. materials	161106			x						D 1	13.14	754.54
Metal scrap	120101		X	X						R 3	48.52	-1593
Nonchlorite machine oils	130205		x	x					X	R 12	16.3	3436.65
Elutriates from loading chambers	130503		x	x					x	R 1	7.5	758.44
Paper and pasteboard	150101		X	X						R 3	11.5	3382.09
Wood	150103		x	x						R 1	95.1	3819.16
Wrappings with damaging impurities [colour frit bags]			x		x				x	D 10	0.41	577.73
Wrappings with damaging impurities [aerosol cans]	150110		x		x				x	D 10	0.32	350.1
Absorbing and filtering materials... with damaging impurities	150202		x	x						R 1	0.56	920.62
Construction site waste	170802		x		x	x				D 1	258.57	11493.47
Electronics scrap	160214		x	x						R 1	0.555	268.42
Colour frits disposal (damage caused by water - assurance)	080111		x		x				x	D 10	1.92	2865
Other building-waste	170903		x	x					x	D 10	2.41	2233.52
Ref. plant 5 result											864.4	56023.52

5.2.1.8 Evaluation of reference plant 5:

For heavy fuel oil fired sideport furnace with regenerative air preheating of the reference system 5, the extensive primary measures for the NO_X reduction are to be emphasised, in particular the divided chamber system in combination with the oxygen measurement by means of zirconia dioxide probes and the continuous emission control. While float glass tanks are operated with melting capacities of up to 900 t/d, for a melting capacity of 260 t/d on the average comparably high operating data costs and only a little lower capital expenditure are incurred. For this reason the estimated costs of € 1.78/t_{glass} are relatively high. For highly loaded float glass tanks, the amount should be more than halved.

On the other hand, the measures allow the emission limit value for nitrogen oxides of 800 mg/m^3 to be met definitely.

The dry sorption of the electrostatic precipitator uses sodium carbonate as sorption agent. Employing the proper amount of sorption agent one achieves very good reduction capacities under the prevailing exhaust gas temperatures, in particular for gaseous selenium compounds, HCl as well as at the sulphur oxides. A further advantage of $NaHCO_3$ utilisation compared to $Ca(OH)_2$ injection is that a clearly better precipitation behaviour for the total dust is performed.

Inorganic fluorine compounds on the other hand can be precipitated only inadequately. For this reason, it is important that already before the filter plant the required limit value falls below 5 mg/m^3.

All emissions are below the required limit values.

In addition, it is remarkable that sodium carbonate with a present supply price of about € 220/t is relatively expensive. Considering the filter dust as a sodium carrier for the formation of the glass matrix, the double amount must be spent compared to the cost of traditional soda.

The specific energy demand of 5050 kJ/kg prevailing at the beginning of the furnace campaign is very low for float glass tanks without electric boosting. The annual additional consumption is about 2.5 %. Due to the exhaust gas heat use, an amount of about 139 kWh/t_{glass} and 500 kJ/kg_{glass}, respectively, are recovered allocated to the tonnage.

If one adds together the costs of primary measures (€ 1.76/ t_{glass}), waste heat operation (€ 1.34/ t_{glass}), emission control plant (€ 5.26/ t_{glass} /new plant), batch house dedusting (€ 0.58/ t_{glass}), wastewater (€ 1.32/ t_{glass}) and wastes (€ 0.59/ t_{glass}), an amount of € 10.85/ t_{glass} plus the costs for rainwater of € 0.78/ t_{glass} result.

The estimates are based on new systems. If the plants keep on being functional after the writing-off time, the actual costs are lower.

5.2.2 Plant 6:

Float glass furnace (heavy oil / natural gas) with exhaust gas heat recovery system and EP

5.2.2.1 Melting plant

	Plant 6
Type	Sideport furnace
Air preheating	Regenerative
Melting area	400 m^2
Type of vaporisation	Natural gas
Fuel type	Fuel oil S, H_u = 40 680 kJ/kg
	Natural gas, H_u: 37 080 kJ/m^3
Electric boosting (installed)	1000 kVA
Glass colour	White
Max. approved melting capacity	800 t/d
Last main repair	Year 2002
Planned campaign	Year 2017
NO_x reduction measures	Near stoich. combustion, sealing measures, adjustable burners, lambda adjustment, burner assembly
Other measures	Filter dust recycling / sulphate reduction
Exhaust gas heat use	Raw gas heat exchanger

Operating data	Average value
Melting capacity	700 t/d
Cullet portion, referred to melting capacity	35 %
Batch humidity, referred to total batch	4.2 %
Oil consumption	2910 kg/h
Gas consumption	990 m^3/h
Capacity of electric boosting	1000 kW
Max. crown temperature	1550 °C
Spec. melting capacity	1.75 t/m^2d
Spec. energy consumption (incl. electric boosting)	5204 kJ/kg_{glass}

(Volume data are referred to standard condition.)

The indicated values represent the state of the plant after two years of term. In the new condition, about 5000 kJ/kg_{glass} can be estimated as specific heat requirement.

The furnace has the same primary NO_x reduction measures as reference plant 5.

The cost estimate considers only the additional expenditure compared to a plant without reduction measures.

Cost estimate (Writing-off time: 20 years / no depreciated value / interest rate: 6 %)	**Primary NO_x measures melting tank** **[€]**
Investment / replacement costs	2000 000.-
Annual redemption	**168 000.-**
Operating costs Energy: 8000.- Oxygen measurement: 33 000.- Emission measurement (proportional): 5000.-	**46 000.-**
Annual total costs	**214 000.-**

The measured values of the emission measurement are necessary as a control mechanism. They are usually allocated to the emission control plant, in this case, however, by 50 % to the primary measures.

For **primary NO_x reduction measures € 0.84/**t_{glass} has to be spent.

5.2.2.2 Waste gas heat recovery:

Type of heat exchanger	Tube register
Heat carrier	Water / steam
Use of gained energy	Industrial water / firing / process water / current
Installation site	Raw gas after EP
Type of dedusting	Hail of bullets
Dedusting	Online
Dust disposal	Recycling / in exceptions: special disposal
Availability	97.2 %
Recovered energy	3000 kWh/h

Allocating the amount of recovered energy to the melting capacity, an amount of 102 kWh/t_{glass} and 370 kJ/kg_{glass}, respectively, is generated.

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Heat exchanger incl. accessories** **[€]**
Investment / replacement costs	1000 000.-
Annual redemption	**133 000.-**
Operating costs Incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**70 000.-**
Annual total costs	**203 000.-**

This corresponds to an expenditure of € 0.008/kWh of recovered energy.

The investment/operating data costs are € 0.79/t_{glass} allocated onto the tonnage.

5.2.2.3 Waste gas treatment plant of the furnace:

Type of filter	EP with 4 fields
Temperature before filter	300 °C
Sorbent	$Ca(OH)_2$
Sorbent amount	15 kg/h
Water injection	None
Amount of filter dust	240 t/a
Use of filter dust	Refining agent
Energy demand filter + blower	320 kWh/h
Service interval	Annually

Emission limits - emission data

Component	**Limit value** [mg/m^3]	**Measured value, standardised to 8 % of O_2** [mg/m^3]	**Measured value** [kg/t_{glass}]
Total dust	20	1.5	0.0031
NO_x	800	750*)	1.54
SO_x	1500	1327	2.72
HF	5	0,5	0.0010
HCl	30	25	0.0512
Heavy metals:			
Group I TA Luft 1986	0.2	n.d.	n.d.
Group II TA Luft1986	1.0	$< 2 \cdot 10^{-3}$	$< 4 \cdot 10^{-6}$
Group III TA Luft 1986	5.0	$5 \cdot 10^{-3}$	$10 \cdot 10^{-6}$

n.b.: not determined

*) This is valid for the normal production. With considerable influencing of the glass quality mostly a short-run higher level is operated in order to start up the condition under 800 mg/m^3 again after dying out of the quality situation.

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Filter plant incl. accessories, blower, pipeline, …** **[€]**
Investment / replacement costs	2500 000.-
Annual redemption	**331 500.-**
Operating costs	**238 000.-**
Annual total costs	**569 500.-**

Allocated to the glass produced, an amount of € 2.23/t_{glass} have to be invested for the emission control system.

5.2.2.4 Dust filters for batch handling:

Two bag filter plants exist (without requirements by the authorities) for the dedusting during the loading and weighing of the raw materials and the mixer field, respectively. In addition, 10 top piece silo filters are installed.

With the top piece silo filters the precipitated dust, that accumulates during the pneumatic filling, falls back into the silo. The precipitated dust of the filter plants is added to the mixture and melted down.

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Dedusting plants batch house** **[€]**	**Top piece filter** **[€]**
Investment / replacement costs	160 000.-	40 000.-
Annual redemption	**21 280.-**	**5320.-**
Operating costs incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**15 000.-**	**5000.-**
Annual total costs	**46 600.-**	

Accordingly, the dedusting in the batch house costs € 0.18/t_{glass} allocated to the tonnage.

5.2.2.5 Forming / coating: Not applicable.

5.2.2.6 Wastewater:

The wastewaters are discharged both directly and indirectly.

There are the following wastewaters:

a) Industrial water similar to water for domestic use (canteen, toilet,…)
b) Cooling water (without product contact)
c) Process water (Osmosis water for the full desalination, wastewater from filter backwash when using fountain water).

The wastewaters from b) are recycled and processed. In addition, the water is subjected to processing in the waste heat boiler.

The methods of filtration and the ion exchange are used for the wastewater processing. The amount of precipitable substances and the CSB, respectively, fall below the required limit value of 30 mg/l each.

Cost estimate (Writing-off time: 15 years / no depreciated value / interest rate: 6 %)	**Wastewater** **[€]**
Investment / replacement costs	900 000. - (redevelopment)
Annual redemption	**75 600.-**
Operating costs	**50 000.-**
Annual total costs	**125 600.-**

This corresponds to an amount of € 0.49/t_{glass}.

The fresh water consumption is covered with 40 000 m^3/a of municipal water and 150 000 m^3/a of fountain water. The costs amount to € 85 000 in each case.

The wastewater amount for the entire plant is 220 000 m^3/a with annual waste-water charges of € 459 000. Adding the costs of the wastewater charges to the cost estimate for the wastewater, € 2.29/t_{glass} have to be spent allocated to the tonnage.

5.2.2.7 Wastes:

Information on the wastes during a main repair is not available.

The waste balance of reference system 6 for the year 2005 is as follows:

Waste designation	New AbfSchl. (Krw-/AbfG) from 2002	Intern	External	Utilisation	Elimination	Landfill over surarea area	Landfill below surarea area	Chemical, Physical Processing	Combustion	Identification	Amount 05 [in t]	Costs [in EURO]
Wood	150103		x	x						R 1	57.06	2225.16
Used paper	2000101		x	x						R 3	49.36	-631.71
Used paper (files)	2000101		x	x						R 3	4.21	589.40
Batch residues	1011122		x	x						R 5	1058.69	46521.28
Glass waste (cullet)	101112		x	x						R 5	15.40	985.60
Glass waste (mixed- mirror glass)	120101		x	x							3627.58	-125996.46
Building rubble	170904		x	x		x				R 5	52.63	6289.63
Furnace outbreak	161106		x	x						R 5	4.20	168.00
Scrap iron	170405		x	x						R 4	76.41	-9551.29
Solid grease and oil dirtied resources	150202		x		x				x	D 10	1.42	296.36
Halog. org. solvent	070203		x		x					D 13	0.22	125.15
Enamel and colour sludge	080113		x	x					x		2.37	1341.98
PE foil	150102		x	x						R 5	0.96	44.16
Mixed settlement waste	200301		x	x					x	D 10	31.63	5156.56
Solvent	200113		x		x			x		D 13	0.22	125.15
Electronics scraps	200136		x	x						R 4	3.47	1225.28
Fluorescent tubes	200121		x		x		x			R 11	0.18	400.00
Nonchlorine oils	130205		x	x						R 3/R1	6.20	740.00
Inorg. chemicals	160507		x		x				x	D9/10	0.22	467.05
Bricks	170102		x	x						R 5	6.50	50.05
Aerosols	150110		x		x					R13/D13	0.35	187.50
Div. chemicals	200127		x	x					x	D 10	0.06	117.79
Copper cables	120101		x	x						R 4	0.44	-322.26
Video terminals	160213		x	x						R3/4/5	0.79	657.91
Mixed wrappings (40ies)	150106		x	x					x	D 10	0.32	350.1
Ref. plant 6 result											5123.97	-65665.46

The glass waste represents the greatest amount of the waste balance of mixed and mirror glass. They are used as a raw material in the optical fibre industry.

The profit from the waste balance is € 0.26/t_{glass}.

5.2.2.8 Evaluation of reference plant 6:

For reference system 6 (heavy fuel oil and natural gas fired sideport furnace with regenerative air preheating for the production of float glass), the expenditures for primary measures for the NO_x reduction are on a clearly lower level compared to a similarly constructed furnace with half the melting capacity (€ 0.84/t_{glass} and € 1.78/$t_{glass,}$ respectively.)

The required emission limit value for nitrogen oxides of 800 mg/m^3 can surely be kept, however, short-run transgressions are necessary for high-quality reasons. Nevertheless, for the future further reduction of the NO_x concentrations is not to be excluded from the viewpoint of the operator.

All the emissions of the individual components also fall below the additionally required limit values.

For the new condition of the furnace, the specific energy consumption was about 5000 kJ/kg_{glass}, a value, very favourable for float tanks.

Through the *raw gas sided arranged* heat exchanger, an amount of heat of 102 kWh/t_{glass} and 370 kJ/kg_{glass}, respectively, is recovered.

With the costs for primary measures (€ 0.84/ t_{glass}), waste heat operation (€ 0.79/ t_{glass}), emission control plant (€ 2.23/ t_{glass}), batch house dedusting (€ 0.18/ t_{glass}), wastewater (€ 0.49/ t_{glass}) and the profit from the waste balance (€ 0.26/ t_{glass}), an amount of € 4.27/ t_{glass} results. If one adds the wastewater charges for the whole plant, the amount increases to € 6.07/ t_{glass}.

5.2.3 Further information on the flat glass industry:

In Germany, exclusively conventionally fired sideport furnaces with regenerative air preheating exist in the float glass field. As to the two reference systems with extensive primary NO_x reduction measures, these are heavy fuel oil and heavy fuel oil/ natural gas heated furnaces, respectively. For both plants, the NO_x emissions fall already now below the limit value of 800 mg/m^3 valid from the year 2010.

The HVG has no current data available representing the state of the art for exclusively natural gas fired sideport furnaces with regenerative air preheating.

It is known that effective measures for the reduction of the NO_x emissions are favoured by extensive furnace constructions with separate chambers. With that exact fuel-air conditions at the individual burner ports can be adjusted and monitored and controlled through zirconia dioxide probes for the O_2 measurement in the corresponding chamber heads.

In the Pilkington 3R process, secondary fuel (5 - 9 % of total fuel consumption) is injected into the regenerator on the side of the released gas at the entry of the burned out waste gases in addition to the near-stoichiometric operation. The fuel becomes pyrolysed under oxygen deficiency with the arising hydrocarbon radicals splitting nitrogen oxides into nitrogen and water. The unburned fuel parts are then largely oxidised to carbon dioxide by leak air intrusion or intended air supply.

A simple and favourable installation expenditure is counterbalanced essentially by additional fuel consumption.

An additional expenditure of € 3.21/t_{glass} for fuel is calculated, assuming the following:

- Spec. energy consumption without 3R: 6000 kJ/kg_{glass} / tonnage: 700 t/d
- Natural gas, H_u: 37 350 kJ/m^3 and 10.42 kWh/m^3, respectively
- Additional consumption 3R: 8 %
- Natural gas price: € 0.25/m^3

For additional consumption of only 5 %, further € 2.01/t_{glass} have to be spent, i.e., a level which is similar to the operation of an SCR plant (reference plant 4). Furthermore, the disadvantages of the CO_2 emission market have to be taken into account. Note that a part of the added additional amount of heat can be recovered in a downstream heat exchanger.

Float tank with open chamber system

Within the framework of an investigation project, emission measurements were carried out in the chamber head of a natural gas fired float tank.

Chamber head		standardised			Emission			Exhaust gas volume flow dry standard condition
	O_2 [%]	CO [mg/m^3]	SO_2 [mg/m^3]	NO_x [mg/m^3]	CO [kg/h]	SO_2 [kg/h]	NO_x [kg/h]	[m^3/h]
Port 1	0.1	1183	1282	1575	18.20	19.71	24.22	9561
Port 2	0.1	1314	1058	1665	19.94	16.06	25.26	9456
Port 3	0.0	5000	871	1355	63.58	11.18	17.36	7947
Port 4	0.5	938	348	1803	16.08	5.96	30.87	10884
Port 5	3.8	3	178	2714	0.02	0.92	14.31	3917
Port 6	4.6	0	162	2789	0	0.84	11.43	4099

The ports 5 and 6 were not charged with fuel. The CO concentrations were largely oxidised again. The standardised NO_x concentrations were 1630 mg/m^3 and the SO_2 concentrations 570 mg/m^3 in the clean gas.

The measurement results demonstrated the difficulties involved in the fuel distribution of an open chamber system. The air distribution to the individual burner ports is defined by the design; the fuel must be adapted according to the amount of air. Control mechanisms for the air distribution are difficult to devise and to a small extent can be realised for example through so-called blocking air lances in the chamber foot.

Whether the NO_x limit value of 800 mg/m^3 for old plants mentioned in the TA Luft can be achieved with natural gas fired flat glass tanks in the year 2010 is currently still open. In particular, with open chamber system and standard burner and adjustment systems the installation of secondary reduction measures may possibly become necessary.

Depending on the NaCl content of the used soda, the HCl content is frequently below 30 mg/m^3 already in the raw gas.

The HF content in the exhaust gas is also below the emission limit value of 5 mg/m^3 in the cleaned gas, partly also clearly below this value. Due to the type of the raw material used, already in the raw gas concentrations are often below the emission limit value.

<u>Oxy fuel fired glass tank (cast glass)</u>

Since 1996 a cast glass furnace with VSA oxygen as oxidising medium and heavy oil as fuel is operated in Germany. The melting area is 65 m^2, the melting capacity about 140 t/d on the average. The oxygen is supplied by a VSA plant which is adjacent to the glass melting plant. VSA oxygen is produced with the aid of molecular sieves in the form of zeolite.

The exhaust gases are diverted to the recuperators to the left and to the right side of the furnace. The heated recuperator air is used on the right side for the defrosting of the oxygen production plant and released via the roof on the left side. The two exhaust gas partial flows are merged after the recuperator and channelled to an electrostatic precipitator plant with dry sorption stage.

The emissions are all lower than the limit value determined as specific emission limit. The specific NO_x emission is about 0.7 kg/t_{glass}. The exhaust gases are not cooled down with inflowing ambient air so that the concentrations of the individual emission components are very high. On leaving the melting furnace the SO_x concentrations for example are 9300 mg/m^3.

5.3 Special glass industry:

Special glass furnaces are operated today increasingly with oxy fuel firing or designed as electric furnaces.

The four conventionally heated special glass tanks for TV glass production in Germany were until the closure equipped with secondary reduction technology (SCR and SNCR) so that using NO_X emission values < 500 and < 1000 mg/m^3 respectively, were achieved. At present, in the special glass field only one catalyst plant exists after conventionally fired sideport furnaces (reference plant 12).

As to the special glass industry, four reference plants with oxy fuel firing, a plant with two electrical heated furnaces and a plant with SCR technology were examined.

5.3.1 Plant 7:

Electric furnace (borosilicate glass) with bag filter

5.3.1.1 Melting plant Plant 7

	Furnace 1	Furnace 2
Type	Elecrical heated furnace	
Glass colour	White	
Max. approved melting capacity	38 t/d	48 t/d
Planned campaign	60 months	

Operating data	**Current Average value**	
	Furnace 1	Furnace 2
Melting capacity	35 t/d	45 t/d
Cullet fraction, referred to the melting capacity	70 %	70 %
Electric power	1700 kW	1990 kW
Max. crown temperature	230 °C	230 °C
Spec. energy consumption	4451 kJ/kg$_{glass}$	3908 kJ/kg$_{glass}$

For the initiation (heating up) of fully electrically heated glass melting furnaces the refractory has to be heated up to operating data temperature and the content of the furnaces (cold cullet or batch) has to be melted first of all with fossil energy carriers so that the electric energy can be conducted via the electrodes arranged in the fluid glass. In the fluid state the electric conductance of the glass melt is exploited in order to realise the energy application through the electric current.

During the melting operation, the batch is fed via a traversing belt conveyor so that a closed batch blanket is formed above the glass melt. The batch layer on the glass melt is melted from below and simultaneously shields the space against the radiation of the melted glass. This strongly restricts the vaporisation mainly causing the dust and corrosive gas emissions. Thus, the batch blanket takes over the function of a sorption stage since the released batch gases arising while melting the glass raw materials must flow through the batch charge. The acidic exhaust gas components can now react from the vapour phase through reaction with the alkalis and/or alkaline earths in the batch to solids as for example NaCl. Plants of this type are also called electric furnaces with cold superstructure (cold top).

Before the adaptation to electric heated furnaces the furnaces were operated as regenerative sideport furnaces. The energy consumption was above 20 000 kJ/kg_{glass} due to the system size.

According to the documents of the HVG the most favourable particular heat consumption of regenerative sideport furnaces in the special glass sector with a melting capacity of less than 50 t/d is 17 260 kJ/kg_{glass}. This value was found in January 2001. Thus, the adaptation to a different melting technology was reasonable from the viewpoint of energy demand.

5.3.1.2 **Waste gas heat recovery:** Not applicable.

5.3.1.3 Waste gas treatment plant of the furnaces:

The exhaust gases are cleaned over two separate bag filter plants.

Type of filter	Bag filter
Temperature before filter	80 °C
Sorbent	$Ca(OH)_2$
Amount of sorbent	3 kg/h
Amount of filter dust	35 t/a
Use of filter dust	Landfill (underground)
Electric energy	20 kWh/h

Emission limits – emission data

Component	Limit value [mg/m³]	Measured value Tank 1 [mg/m³]	Measured value Tank 2 [mg/m³]	Measured value Tank 1 [kg/t_{glass}]	Measured value Tank 2 [kg/t_{glass}]
Total dust	30	1.2	0.8	0.0017	0.0008
NO_x	500	72	103	0.39	0.29
SO_x	100	0.7	4.7	0.0037	0.0131
HF	5	0.3	0.3	0.0018	0.0009
HCl	30	5.1	22.0	0.0279	0.0614

Compared to flame heated furnaces, the emissions of electrically molten glasses in cold-top furnaces are on a lower level. NO_x emissions result only from the nitrate decomposition.

The oxygen content of the exhaust gases corresponds to the oxygen content of ambient air. Emission limit values can not be standardised to a reference oxygen content.

Through variation of the sucking conditions any concentrations of the individual emission components are possible as a function of the power spectrum of the installed fan.

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Bag filter, fan, duct …** **[€]**
Investment / replacement costs	440 000.-
Annual redemption	**58 520.-**
Operating costs Incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**50 000.-**
Annual total costs	**108 520.-**

Allocated to the glass produced, an amount of € 3.71/t_{glass} has to be invested for the exhaust emission control system.

5.3.1.4 Dust filters for batch handling:

The raw materials are mixed in a common batch house together with many other batch types. A differentiation is not possible.

5.3.1.5 Forming / coating: Not applicable.

5.3.1.6 Wastewater:

The plants are to be seen in the context of the entire factory. Detailed information is not available. Industrial water as well as cooling water arises with and without product contact. Cooling water is recirculated. Only surplus cooling and cullet water is discharged.

5.3.1.7 Wastes:

There is no information available.

5.3.1.8 Evaluation of reference plant 7:

Special glass furnaces normally need very high crown temperatures. For this reason, they require very high specific energy consumption compared to traditional soda lime furnaces. In the present case the energy consumption could be lowered drastically through the conversion of conventional firing to electric melting. One has to consider, however, that the indicated value has to be divided by the power station efficacy, i.e. it is higher by around the factor 3.

The emissions of electrical heated furnaces are often an order of magnitude below the conventional melting technology. Emissions result only from raw material related batch reactions. NO_X emissions occur only for nitrate containing batch compositions from the nitrate disintegration.

As to the so-called chloride refining, special attention has to be paid to the hydrochloric acid concentrations since the predominating exhaust gas temperatures do not allow an effective precipitation with dry sorption technique at the waste gas treatment plant.

Through variation of the sucking conditions, arbitrary concentrations of the individual emission components result within the spectrum of performance of the installed blowers. Nevertheless, concentrations as emission limits were defined in this case. This approach should be chosen together with limitation of the minimum and maximum exhaust gas volume flow.

Note on the emission value determination of electrical heated furnaces and oxy fuel furnaces

Compared to conventional fuel air fired glass furnaces, at fully electrically heated furnaces completely other conditions arise *exhaust gas sided* with regard to exhaust gas volume flow, emission and pollutant concentration. Until the 2002 TA- Luft, there was no regulation that took the special features of these furnaces into account. In this TA-Luft of 1 October 2002, which is currently valid, the following stipulation, however, was inserted under section 5.4.2.8:

"For fuel air fired and electrically heated glass melting tanks special arrangements are to be made. The specific energy consumption of comparable modern fuel air fired glass furnaces and the capability of exhaust emission control systems are to be considered. The VDI guideline 2578 (Edition November 1999) is pointed out."

Thus, a product related emission equivalent to an NO_x emission value of 500 mg/m^3 (target value) is derived for glass furnaces with oxy fuel firing and electric furnaces, considering the specific energy consumption of modern fuel air fired furnaces.

As far as for product quality reasons a nitrate use is necessary, the emission should not exceed this value by a factor of 2.

The above arrangement should guaranty that an electrical heated glass melting furnace with regard to the NO_x emission should not be judged more unfavourably than a conventional fossil fuel fired furnace which for NO_x emission has already reached the target value of 500 mg/m^3 and the limit value of 800 and/or 1000 mg/m^3 with nitrate use.

The derivation of product-related emission limits proved of value, for example in [$kg_{pollutant}/t_{glass}$].

By determining specific product-related emission limit values the fact is taken into account that the conversion of measured NO_x emission values to definite reference oxygen content is not possible.

5.3.2 Plant 8:

Oxy fuel fired furnace (borosilicate glass) with bag filter

5.3.2.1 Melting plant

	Plant 8
Type	Oxy fuel furnace
Fuel type	Natural gas, H_u: 31147 kJ/m^3
Electric boosting (installed)	700 kVA
Max. approved melting capacity	50 t/d
Last main repair	Year 2005
Planned campaign	Year 2010
NO_x reduction measures	O_2 as oxidising medium
Waste gas heat recovery	None

Operating data	Average value
Melting capacity	40 t/d
Cullet fraction, referred to melting capacity	60 %
Batch humidity, referred to total batch	1 %
Gas consumption	327 m^3/h
Oxigen consumption	636 m^3/h
Capacity of electric boosting	283 kW
Max. crown temperature	1650 °C
Spec. energy consumption (without oxygen generation)	6722 kJ/kg_{Glas}

(Volume data are referred to standardised condition)

Up to 2000, the glasses were melted in a regenerative fired sideport furnace with light fuel oil and natural gas. A specific heat consumption of 17 300 kJ/kg_{glass} was found for the new state of this furnace compared to the conventionally fired plant with the same melting face (without electric boosting, but lower melting rate).

Thus, it is proved unambiguously that one can achieve high reductions of the specific energy consumption with the conversion to oxy fuel technique on small melting aggregates. The needed energy for the production of fluid oxygen is not considered.

The oxidising medium is delivered as fluid oxygen.

With a profitability study in the course of a rebuild, besides the capital expenditure also the operating costs for the furnace play an exceptional role of course, and with that the energy consumption and the costs for the oxygen.

It is known that, compared to oxy fuel furnaces, regenerative fired glass melting furnaces, especially sideport furnaces, require much more refractory for the heat recovery. The capital expenditure is clearly higher for such furnace types. In addition, secondary reduction measures for the NO_x reduction have to be installed and operated in the special glass field due to the high superstructure temperatures or the saltpetre use. With oxy fuel furnaces, on the other hand, special attention has to be paid to the costs for the oxygen generation or the delivered fluid oxygen.

In this case only the adaptation to the oxy fuel technique and the associated saving of fuel associated should have been the crucial factors.

With an assumed natural gas price for the industry of € 0.025/kWh, an amount € 0.11/m^3 for the fluid oxygen delivery and an electricity tariff of € 0.065/kWh, and the above data taken into consideration, a gas consumption per glass ton for the conventionally heated plant of 555.4 m^3/t_{glass} results. The gas consumption of the oxy fuel furnace of 196.2 m^3/t_{glass}, an electric energy demand of 169.8 kWh/t_{glass} and an oxygen consumption of 381.6 m^3/t_{glass} amount to the following costs:

Conventional furnace:	€ 120.13/t_{glass}
Oxy fuel furnace:	€ 93.46/t_{glass}

Accordingly, the melting energy costs of the oxy fuel furnace are by around 20 % lower than those of the conventionally fired sideport furnace.

➔ The costs were all estimated and are based on verbal information of industry representatives. Information on the costs from the plant operator is not available.

5.3.2.2 Waste gas heat recovery: Not applicable

5.3.2.3 Waste gas treatment plant of the furnace:

Type of filter	Bag filter with heat switching
Temperature before filter	105 °C
Sorbent	$Ca(OH)_2$
Amount of sorbent	15 kg/h
Injection of water	None
Amount of filter dust	184 t/a
Use of filter dust	Agent for neutralisation
Electric energy	34 kWh/h

Emission limits – emission data

Component	**Limit value [kg/h]**	**Measured value [kg/h]**	**Measured value [mg/m³]**	**Measured value [kg/t$_{glass}$]**
Total dust	**0.23**	**0.0044**	0.28	0.0027
NO_x	**8.25**	**2.31**	148	1.42
SO_x	**1.15**	**0.087**	5.6	0.054
HF	**0.058**	**0.0070**	0.45	0.0043
HCl	**0.345**	**0.108**	6.9	0.066

Mass flow limits were defined as emission limit values. In addition, the measured values and the specific emissions were indicated for information.

The amounts of all emission components fall clearly below the respective required limit values.

For the old conventionally heated furnace, the specific NO_x emissions were 16 kg/t$_{glass}$.

Cost estimate (Writing-off time: 15 years / no depreciated value / interest rate: 6 %)	**Bag filter, fan, duct,…** **[€]**
Investment / replacement costs	1500 000.-
Annual redemption	**126 000.-**
Operating costs Incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**83 109.-**
Annual total costs	**209 109.-**

Allocated to the glass quantum produced on the average, an amount of € 14.32/t_{glass} has to be invested accordingly for the exhaust emission control system.

In spite of a writing-off time of 15 years the costs are considerably different from those of large highly loaded furnaces.

5.3.2.4 Dust filters for batch handling: No information available.

5.3.2.5 Forming / Coating: Not applicable.

5.3.2.6 Wastewater: No information available.

5.3.2.7 Wastes: No information available.

5.3.2.8 Evaluation of reference plant 8:

For reference plant 8 a considerable reduction in the special energy consumption could be achieved by the conversion from a regenerative fired sideport furnace to an oxy fuel special glass furnace. The estimate of the costs in respect of the saving of melting energy was about 20 % including the costs for the delivered fluid oxygen.

Due to the conversion, the specific energy consumption could be reduced by 60 % (without expenditure for the fluid oxygen generation). The decrease of more than 90 % in the NO_x emissions is even more remarkable.

With the operation of the bag filter plant, the emissions are clearly below the required limits for all components.

5.3.3 Plant 9:

Oxy fuel fired furnace (borosilicate glass) with bag filter

5.3.3.1 Melting plant

	Plant 9
Type	Oxy fuel furnace
Melting area	51.2 m^2
Fuel type	Natural gas, H_u: 36008 kJ/m^3
Electrical boosting (installed)	Yes
Max. approved melting capacity	50 t/d
Last main repair	Year 2005
Planned campaign	4.5 years
NO_x reduction measures	Near stoich. combustion, sealing measures, adjustable burners, burner assembly
Other measures	Sulfur poor fuels
Heat recovery	None
Kind of coating	Finishing
Coating agent	SO_2
Path of emission (coating)	Via the roof

Operating data	**Average value**
Melting capacity	50 t/d
Cullet fraction, referred to melting capacity	40 %
Batch humidity, referred to total batch	0,1 %
Gas consumption	600 m^3/h
Oxygen consumption	1200 m^3/h
Capacity of electric boosting	Not declared
Max. crown temperature	1690 °C
Spec. energy consumption (without oxygen preparation)	10370 kJ/kg_{glass}

(Volume data are referred to standardised condition)

The oxidising medium is cryogenic oxygen which is produced on the company premises with an air separation unit. According to information of the management, about 25 % of the melting energy costs have to be spent for the oxygen production.

The sideport furnace with regenerative air preheating used before had a specific energy consumption of 20 500 kJ/kg_{glass}. With an assumed natural gas price for the industry of € 0.025/kWh and the above data, the gas consumption per glass ton for the conventionally fired plant of 569.3 m^3/t_{glass} and costs are as follows:

Conventional furnace: € 142.36/$t_{glass.}$

For the calculation of the melting energy costs for the oxy fuel furnace, the data on the power of the electric boosting are missing. Neglecting this portion, for the same melting rate (assumed oxygen costs: € 0.065/m^3) have to be spent:

Oxy fuel furnace: € 90.73/t_{glass} (plus costs for electric boosting).

➔ Also here, an estimate is given rather than information of the management!

5.3.3.2 **Waste gas heat recovery:** Not applicable.

5.3.3.3 Waste gas treatment plant of the furnace:

Type of filter	Bag filter with heat switching
Temperature before filter	120 °C
Sorbent	$Ca(OH)_2$
Amount of sorbent	20 kg/h
Injection of water	None
Amount of filter dust	250 t/a
Use of filter dust	Stowage

Emission limits – emission data

Component	Limit value	Measured value [mg/m³]
Total dust	20 mg/m³	1 mg/m³
NO_x	16.7 kg/h	13.9 kg/h
SO_x	100 mg/m³	5 mg/m³
HF	5 mg/m³	1 mg/m³
HCl	30 mg/m³	1 mg/m³

For nitrogen oxides a mass flow limit and for the other components a concentration were defined as emission limit values. The NO_x limit value of 16.7 kg/h was derived from the emission limit value of 1000 mg/m³ (nitrate refining) of an energetically satisfactory, conventionally heated reference melter.

The emissions of all components fall clearly below the required values.

Allocated to the tonnage 6.67 kg/t_{glass} are emitted. For the old conventional melter, the specific NO_x emission was 33.6 kg/t_{glass}, i.e. a reduction of 80 % was achieved.

For the cost estimate for the operation of the filter plant, sufficient data are not available.

5.3.3.4 Dust filters for batch handling: No information available.

5.3.3.5 Forming / Coating: Not applicable.

5.3.3.6 Wastewater:

The wastewaters are discharged indirectly. Industrial water as well as cooling water with and without product contact arises. The cooling water is recirculated.

The annual amount of wastewater is 120 000 m^3 (€ 157 000 - wastewater charges). Fresh water of 95 953 m^3/a is procured by the city. The remaining amount is obtained from the river.

5.3.3.7 Wastes:

In the course of a main repair, an external firm is charged with the handling of demolition and utilisation and/or disposal. In addition, about 750 t/a of glass waste have to be disposed.

Filter dusts from the exhaust emission control system (250 t/a) are used to fill mined space (stowage).

5.3.3.8 Evaluation of reference plant 9:

On deciding whether a conventional or an oxy fuel melter are to be built, presumably also considerations with regard to the installation of an SCR plant played a role besides the energetic, economic and possibly qualitative reasons for the conversion of the melting technology. The limit value of the TA Luft is 1000 $mg/m^3 NO_x$ for conventional melters with nitrate use. For the special glass to be melted, this value cannot be achieved without secondary measures.

All borosilicate glass melting furnaces are more or less afflicted with a further problem. While the precipitation of particulate boron compounds in the exhaust gas does not cause problems and is basically dependent on the dimensioning of the filter plant, gaseous boron compounds only condense at very low temperatures down to the range of the water dew point. Thus, the exhaust emission control is difficult and even after filter plants with dry sorption stages visible exhaust gas plume can occur.

The HVG currently attends to this problem within the framework of an investigation project. First investigations in the exhaust gas of a recuperative E-glass furnace were successfully carried out and reduction rates of 80 % of gaseous boron compounds were achieved. The activities are supported by thermo-chemical calculations in the run up to and during the measurements.

5.3.4 Plant 10:

Oxy fuel fired furnace (borosilicate glass) with bag filter

5.3.4.1 Melting plant

	Plant 10
Type	Oxy fuel furnace
Melting area	54 m^2
Fuel type	Natural gas, H_u: 36000 kJ/m^3
Electrical boosting (installed)	2.500 kVA
Kind of glass	Glass ceramics
Max. approved melting capacity	40 t/d
Last main repair	Year 2004
Planned campaign	4 years
NO_x reduction measures	Near stoich. combustion, sealing measures, adjustable burners, lambda control
Other measures	Sulfur poor fuels
SNCR Pplant	Switch off
Waste gas heat recovery	Yes

Operating data	Average value
Melting capacity	40 t/d
Cullet fraction, referred to melting capacity	50 %
Batch humidity, referred to total batch	1 %
Gas consumption	550 m^3/h
Oxygen consumption	1100 m^3/h
Capacity of electric boosting	200 kW
Max. crown temperature	1700 °C
Spec. energy consumption (without oxygen production)	12 312 kJ/kg_{glass}

(Volume data are referred to standardised condition)

The furnace is equipped with an SNCR plant with gaseous NH_3 as reducing agent. In the course of optimisation measures, the required mass flow limit value could be kept to for NO_x also without ammonia injection.

Formerly, the glasses were melted in regenerative sideport and recuperative heated furnaces, respectively, with light fuel oil and natural gas. The portion of electric boosting was about five times as high. The specific energy consumption was about 20 000 kJ/kg_{glass} (incl. electric boosting of 1050 kWh).

The energy demand could be reduced by about 38 % through the conversion to oxy fuel firing. However, the energy demand of the oxygen production has to be added.

The oxidising medium is cryogenic oxygen and is produced on the company premises. Information about the energy demand of the air separation unit is not available.

From discussions with oxygen suppliers, a value between 0.4 and 1 kWh/m^3_{oxygen} of electric energy results depending on the size of the plant and the amount of oxygen produced.

Based on the mean value of 0.75 kWh/m^3, specific energy consumption of 14 094 kJ/kg_{glass} results including O_2 generation of reference plant 10. This is almost 30 % less than needed for conventional reference melters.

However, from the viewpoint of the plant operator normally the costs are decisive. In the present case, the cost element of the oxygen production is about 30 % of the melting energy costs.

5.3.4.2 Waste gas heat recovery:

In the raw gas of reference plant 10 a waste gas heat exchanger is installed for the heating of the industrial water. The recovered amount of heat was indicated with 550 kWh/h.

Allocated to the melting rate, a value of 330 kWh/t_{glass} and/or 1188 kJ/kg_{glass} results.

Information about installation and/or company costs is not available.

5.3.4.3 Waste gas treatment plant of the furnace:

Type of filter	Bag filter
Temperature before filter	82 °C
Sorbent	$Ca(OH)_2$
Amount of sorbent	None
Injection of water	None

Emission limits – emission data

Component	Limit value [kg/h]	Measured value [kg/h]	Measured value [mg/m³]	Measured value [kg/t$_{glass}$]
Total dust	**0.055**	**0.0004**	0.02	0.0002
NO_X	**10.3**	**8.85**	575	5.59
SO_X	**1.1**	**0.041**	2.8	0.026
HF	**0.055**	**0.0032**	0.2	0.0020
HCl	**0.33**	**0.0032**	0.2	0.0020
NH_3	**0.6**	**-**	-	-
Group II TA Luft 1986	**0.0077**	**$< 0.09 \cdot 10^{-3}$**	< 0.091	$< 0.06 \cdot 10^{-3}$
Group III TA Luft 1986	**0.055**	**$< 0.06 \cdot 10^{-3}$**	< 0.0004	$< 0.03 \cdot 10^{-3}$

All emissions fell below the limit values (mass flow limits). For information, also the measured values and the specific emissions were indicated.

For all components, the emissions fall clearly below the required limit values.

For the old conventional melter, the specific NO_X emissions were 29.7 kg/t$_{glass}$. Thus, the conversion to oxy fuel firing resulted in a reduction of about 80 %.

Information about the level of costs is not available.

5.3.4.4 Dust filters for batch handling:

The batch is manufactured in a batch house for several melting aggregates. A differentiation is not possible.

5.3.4.5 Forming / coating: Not applicable.

5.3.4.6 Wastewater: No information available.

5.3.4.7 Wastes: No information available.

5.3.4.8 Evaluation of reference plant 10:

Concerning reference plant 10, there is a clear reduction in the specific energy consumption after the conversion of fuel air to oxy fuel firing. The NO_X emissions could be reduced by about 80 %.

The waste gas treatment plant can be operated without sorption agent. Special attention has to be put to the temperature regime. With exhaust gas temperatures above a certain level, there is the danger that gaseous arsenic compounds pass the filter plant and are emitted.

The SNCR plant is out of operation. Due to optimisation processes, the emissions fall below the required limit value also without additional ammonia injection.

Operating an SNCR plant, the temperature window (950 +/- 100 °C) necessary for reducing nitrogen oxide to nitrogen and water has to be kept and a good mixing of the reducing agent into the exhaust gas flow guranteed. With too low injecting temperatures, the NH_3 slip goes up strongly, with too high temperatures the injected ammonia burns and even increases the NO_X freight. The secure operation of an SNCR plant in the exhaust gas of oxy fuel melters therefore needs extensive control and adjustment mechanisms since load changes affect onto the amount of exhaust gas and very considerably the exhaust gas temperature, with the result that the NH_3 injecting place has to be designed variably.

5.3.5 Plant 11

Oxy fuel fired furnace (television glass) with SNCR und EP

5.3.5.1 Melting plant

	Plant 11	
	Screen furnace	conus furnace
Type	Oxy fuel furnace	
Melting area	240 m^2	109 m^2
Number of burners per side	11	9
Kind of fuel	Natural gas, H_u = 37 200 kJ/m^3	
Electric boosting (installed)	500 kVA	None
Max. approved melting capacity	270 t/d	240 t/d
Year of construction	1995	1996
Last main repair	Year 2001	Year 2002
Planned campaign	Jahr 2008	Jahr 2009
NO_x reduction measures	Near stoich. combustion, sealing measures, furnace geometry	
	SNCR	Without SNCR
Other measures	Sulfur poor materials and fuels / filter dust recycling	

Operating data	Average value	
Melting capacity	270 t/d	170 t/d
Cullet portion, referred to melting capacity	30 %	40 %
Batch humidity, referred to total batch	2 %	2 %
Gas consumption	1500 m^3/h	600 m^3/h
Oxigen consumption	3000 m^3/h	1200 m^3/h
Capacity of electric boosting	500 kW	-
Max. crown temperature	1570 °C	1530 °C
Spec. energy consumption (without oxygen production)	5120 kJ/kg_{glass}	3151 kJ/kg_{glass}

(Volume data are referred to standardised condition)

The specific energy consumptions, in particular the value of the conus melter, are remarkably low. After all, these are values measured after a campaign of 4 and 5 years, respectively.

Following arguments were mentioned as criteria for using the oxy fuel technique:

a) glass quality and process stability

a) NO_x emissions

b) floor space required

c) costs for building and disposal of the melter

The installation of the VSA plant and the safety conditions associated with that were negatively valued by the management of the firm.

The oxygen generation occurs by means of a VSA plant located on the company premises. If necessary fluid oxygen can be resorted to (emergency warehouse). The manufacturing firm operates the air separation unit. The glass manufacturer supplies the necessary energy in the form of electric current and water, the manufacturing firm receives a sum defined by contract.

The annual costs are:

Supplied energy:	€ 1560 000.-
O_2 purchase:	€ 1020 000.-

In the sum, € 2580 000.- have to be spent for the oxygen purchase. Allocated to the needed oxygen amount, this results in

oxygen costs of € 0.070/m^3.

Allocated to the tonnage, for the TV screen melter € 18.67/t_{glass} and for the conus furnace € 11.86/t_{glass} have to be invested.

The energy demand for the oxygen generation was estimated at 0.67 kWh/m^3.

The management is continuously endeavouring to improve processes and environmental effects. Since the year 2002, the requirement of natural gas and electric energy, allocated to the amount of glass produced, has been reduced by 8.5 % and 16.6 %, respectively, for the entire factory incl. the processing and other plants. This was accompanied by a reduction in the CO_2 emissions by 9.2 %.

5.3.5.2 Waste gas heat recovery:

Plant	**TV Screen furnace**
Type of heat exchanger	Tube register
Heat carrier	Water / steam
Use of gained energy	Warm-/ process water
Installation location	Raw gas before EP
Type of dedusting	Hail of bullets
Dedusting	Online
Dust disposal	Landfill underground
Availability	98.3 %
Recovered energy	1300 kWh/h

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Heat exchanger including accessories** **[€]**
Investment / replacement costs	500 000.-
Annual redemption	**66 500.-**
Operating costs: Maintenance / repair: 25 000,- Electricity: 5000,- Dust disposal: 1000,- Personnel: 6000,-	**37 000.-**
Annual total costs	**103 500.-**

This corresponds to an expenditure of 0.01 €/kWh of recovered energy.

Allocated to the tonnage, the investment/operation costs are 1.05 €/t_{glass}.

5.3.5.3 Waste gas treatment plant of the furnaces:

Type of filter	EP with 2 fields
Temperature before / after filter	250 / 220 °C
Sorbent	None
Water injection	None
Amount of filter dust	350 t/a
Use of filter dust	100 % recycling (batch)

Emission limits – emission data

Component	**Limit value [kg/h]**	**Measured value [kg/h]**	**Measured value [kg/t_{glass}]**
Total dust	0.54	0.02	0.0011
NO_X	58.7	47.5	2.59
SO_X	3.2	0.3	0.016
HF	0.032	0.012	0.0007
HCl	0.192	0.095	0.0052

Lead is the crucial dust component with an emission of 0.3 g/h.

The TV screen melter is equipped with an SNCR plant. Urea solution is used as reducing agent. The plant was taken out of operation in 2004, however, it is still functional. In the last 4 years, the NO_X emissions could be lowered by a third due to optimisation measures, so that the compliance to the emission limit is surely guaranteed also without SNCR technique.

While the SNCR plant was operated, NO_X reduction rates of 25 to 40 % were achieved. The NH_3 slip was approx. 50 g/h (3 mg/m^3). Per kg NO_X reduction 1.4 kg of urea are needed.

A cost estimate of the SNCR plant is not available.

The produced filter dust contains 70 % of PbO and, thus, is an important raw material.

Cost estimate (Writing-off time: 10 years / no depreciated value / interest rate: 6 %)	**Filter plant incl. accessories, blower, pipeline, …** **[€]**
Investment / replacement costs	1500 000.-
Annual redemption	**199 500.-**
Operating costs Maintenance / Repair: 8000.- Electricity: 45 000.- Personnel: 12 000.- Emission measurement: 3000.-	**68 000.-**
Annual total costs	**267 500.-**

Allocated to the amount of glass produced, an amount of € 1.67/t_{glass} has to be invested accordingly for the exhaust emission control system. Expenditures for sorption agents are not necessary.

5.3.5.4 Dust filters for batch handling:

For the preparation, storage and the transport of batch and cullet flows, there are 25 filter plants incl. the top piece silo filters. The state of the plants/filter cloths is investigated at intervals of three months. The authorities control three plants for the handling of lead containing raw materials. The dust emissions of all plants are below 1 mg/m^3, with a limit value of 50 mg/m^3.

Cost estimate (Writing-off time: 10 years / No depreciated value / interest rate: 6 %)	**Dust collectors** **[€]**
Investment- / replacement costs	375 000.-
Annual redemption	**49 875.-**
Operating costs incl. maintenance, energy, resources, utilisation / elimination of filter dust, personnel, other	**68 000-**
Annual total costs	**117 875.-**

The dedusting in the batch house costs € 0.73/t_{glass} accordingly, allocated to the tonnage.

5.3.5.5 Forming / coating: Not applicable.

5.3.5.6 Wastewater:

The wastewater processing of the entire factory is very extensive. The wastewaters are discharged directly.

The wastewaters are listed as follows:

a) Industrial water similar to household water (canteen, toilet,…)
b) Cooling water (with product contact)
c) Cooling water (without product contact)
d) Process water
e) Water of further processing (grinding, polishing, washing,…)

All wastewaters are recirculated and subjected to a continuous wastewater processing.

For the wastewater processing all known methods are employed, apart from centrifugal force precipitation and combustion. All system sections for the wastewater processing are located in a gigantic complex of buildings in direct proximity of the production halls.

The different wastewaters are separately sampled (internal and external) and then combined. All limit values are kept. Lead is the most crucial component.

➔ The factory possesses an own clarification plant in addition through which also the wastewater of a 5000 inhabitant municipality is cleared.

Fresh water is taken from a river nearby, prepared and mainly recirculated.

Example of the wastewater situation of the year 2002:

Output water	Allowed	Measured
Cooling water (cullet)	91 104 m^3/a	87 600 m^3/a
Grindery water	163 812 m^3/a	187 346 m^3/a
Electroplating water	8760 m^3/a	3 650 m^3/a
Cooling water	36 792 m^3/a	37 814 m^3/a
Soft water	13 140 m^3/a	9125 m^3/a
Wastewater oxygen production	70 080 m^3/a	3700 m^3/a
Total wastewater	**383 688 m^3/a**	**329 235 m^3/a**

Clarification plant	**35 000 m^3/a**	**24 057 m^3/a**

Amount of fresh water		**427 150 m^3/a**

Cost information on the wastewater processing is very difficult. A capital expenditure for the buildings of € 6 mill., for the treatment plants of € 4 mill. and for pipelines of € 26 mill. was estimated. With the operating costs of about € 400 000.- per year, a writing-off time of 30 years (building) and 10 years (plants), respectively, and 6 % of annual interest, a value of about € 30/t_{glass} results. Since the writing-off times are over to a great extent, an amount of about € 4.50/t_{glass} was stated for instance.

5.3.5.7 Wastes:

During the glass melting, so-called drainage glass arises which is completely added to the circuit of internal cullet and remelted.

Specialised firms carry out all demolition and disposal activities. The costs incurred by oxy fuel melters are by 30 % lower compared to conventional melters with regenerative air preheating.

The filter dusts in the batch house are recycled.

There are about 100 t/a faulty batches (unleaded) for which approx. disposal costs of € 20 000.- have to be spent.

5.3.5.8 Evaluation of reference plant 11:

In the description of the market situation within the glass industry, it was mentioned already that the TV glass market collapsed which led to the closing of five large TV screen and conus melters in Germany. All these plants were equipped with SCR catalysts.

Without SCR technique, standardised NO_x concentrations of up to 5000 mg/m^3 or specific emissions of more than 12 kg NO_x/t_{glass} were found in the field of the TV glass tanks.

In the exhaust gas system of the TV glass tank, an SNCR plant with urea as reducing agent is installed. Through optimisation of the firing operation, the management succeeded in achieving the compliance of the required NO_x limit value also without operation of the selective noncatalytic reduction.

The mean specific NO_x emission of the two oxy fuel melters of the reference plant 11 is 2.59 kg/t_{glass} and with that on a level which is to be achieved only by secondary reduction measures in conventional melters.

The specific energy consumption of the TV screen and the conus tank with 5120 and 3151 kJ/kg_{glass}, respectively, is on a similarly low level as compared to conventional melters. Considering the estimated data of the air separation unit, for the TV screen tank and the conus tank 409 kJ/kg_{glass} (0.11 kWh/kg_{glass}) and 643 kJ/kg_{glass} (0.18 kWh/kg_{glass}), respectively, have to be additionally invested in the form of electric energy for the oxygen generation.

The melting energy costs of a conventional reference melter for TV screen production with a specific heat consumption of 9000 kJ/kg_{glass} (assumed gas price: € 0.025/kWh) amount to € 62.50/t_{glass}. With the costs of the oxygen generation of € 18.67/t_{glass}, the electric boost portion of € 2.89/t_{glass} (assumed electricity tariff € 0.065/kWh) and the gas costs of € 34,44/t_{glass}, an amount of € 56,00/t_{glass} results for example for the TV screen melter of the reference plant 11. Thus, under economical aspects, many things speak for the operation of oxy fuel melters in the TV glass field, especially as smaller investment and demolition costs are to be noted and no of secondary reduction measures for the nitrogen oxide reduction are necessary.

5.3.6 Plant 12:

Regenerative cross-fired furnaces with SCR and EP

5.3.6.1 Melting Plants

The total exhaust gas of the reference plant 12 consists of the partial flows of four differently large sideport furnaces regeneratively fired with natural gas and light fuel oil. Summarised following equipment specific data result:

	Plant 12
Type	Sideport furnace
Air preheating	Regenerative
Melting area	200 m^2 (altogether)
Type of vaporisation	Natural gas
Fuel type	Natural gas, H_u = 35 953 kJ/m^3
	Light fuel oil, H_u: 42 600 kJ/kg
Electric boosting (installed)	3.000 kVA
Type of glass	8412 / 8414 (intern identification)
Max. approved melting capacity	220 t/d
Planned campaign	5 years
NO_x reduction measures	Near stoich. combustion, sealing measures, SCR

Operating data	**Average value**
Melting capacity	170 t/d
Cullet portion, referred to melting capacity	25 %
Batch humidity, referred to total batch	1.5 %
Gas consumption	2600 m^3/h
Oil consumption	570 l/h
Capacity of electric boosting	1000 kW
Max. crown temperature	1650 °C
Spec. melting capacity	0.85 t/m^2d
Spec. energy consumption (incl. electric boosting)	16 440 kJ/kg_{Ggass}

(Volume data are referred to standardised condition.)

5.3.6.2 Waste gas heat recovery:

	Plant 12
Type of heat exchanger	Tube register
Heat carrier	Water / steam
Use of gained energy	Water for domestic
Installation	Clean gas after EP
Type of dedusting	None
Availability	99 %
Recovered energy	1140 kWh/h

Allocated to the tonnage 0.161 kWh/kg_{glass} and 579 kJ/kg_{glass}, respectively, of the energy contained in the exhaust gas are recovered.

Information on the costs is not available.

5.3.6.3 Waste gas treatment plant of the furnaces:

Filter type	EP with 2 fields and SCR
Temperature before filter	350 °C
Sorbent agent	$Ca(OH)_2$
Amount of sorbent agent	22 kg/h
Water injection	None
Amount of filter dust	307 t/a
Use of filter dust	Landfill underground
Electric energy	approx. 250 kWh/h

In the cleaned gas behind the EP, an SCR plant is installed (honeycomb catalyst with 10 m^3 chamber volume) with ammonia solution (25 %) as reducing agent. The dedusting occurs quasi-continuously with compressed air.

Emission limits – emission data

Component	**Limit value** [mg/m³]	**Measured value standardised to 8 % O_2** [mg/m³]	**Measured value** [kg/t_{glass}]
Total dust	25	20	0.127
NO_x	1000	950	6.05
SO_x	-	-	-
HF	5	4	0.015
HCl	30	9	0.057
NH_3	30	20	0.127
Heavy metals:			
No. 5.2.7.1.1 TA Luft 2002	0.7	0.088	$0.6 \cdot 10^{-3}$
Group II TA Luft 2002	0.5	0.004	$0.03 \cdot 10^{-3}$
Group III TA Luft 2002	1	0.007	$0.05 \cdot 10^{-3}$

The emission limit values were already adapted to the values of the 2002 TA Luft. Sulphur oxides exist only as traces in the exhaust gas.

The NO_x reduction amounts to 82 %. From that, a standardised raw gas concentration of 5278 mg/m³ NO_x is calculated. By means of the combustion calculation, the reduction amount of 195 kg NO_x/h can be derived. The stoichiometrically needed amount of ammonium hydroxide thus amounts to about 320 l/h.

Cost estimate (Writing-off time: 10 years / No depreciated value / interest rate: 6 %)	**Filter plant incl. accessories, blower, pipeline, …** **[€]**	**SCR incl. storage, proportioning...** **[€]**
Investment / replacement costs	2800 000.-	1500 000.-
Annual redemption	**372 400.-**	**199 500.-**
Operating costs:	**275 000.-**	**380 000.-**
Annual total costs	**1226 900.-**	

Allocated to the amount of glass produced, an amount of € 19.77/T_{glass} has to be invested accordingly for the emission control system including SCR.

The amount for the catalyst is € 9.34/t_{glass}.

The points 5.1.4.4 to 5.1.4.7 were not considered within the framework of the project since the reference system 12 represents only a hardly definable section of the entire factory.

5.3.6.8 Evaluation of reference plant 12:

Since 1989, the reference plant 12 is equipped with SCR. Information on the service life of the catalyst module is not available. From information of publications, four to five years of service life can be expected.

For the compliance of the required NO_x limit value of 1000 mg/m^3 (furnaces with nitrate use), the standardised concentrations predominating in the raw gas, of more than 5000 mg/m^3 have to be reduced by more than 80 % through the SCR plant.

Due to the small tonnage and the high specific heat requirement of the molten glasses, the expenditures for the emission control system are enormously high.

<u>Cost estimate: Conversion to oxy fuel technique</u>

From the viewpoint of ecology and economy, also here the question arises whether the conversion to oxy fuel technique is advantageous.

Following questions e.g. have to be considered:

Can the glass type and the necessary quality be achieved with oxy fuel?

- Can the glass type and the necessary quality be achieved with oxy fuel technique?
- Service life of the furnace?
- Refractory of the crown?
- Exhaust gas heat use?
- SNCR technique necessary in addition?

For the cost estimate assumptions are made since for the melted glass type no reference systems are available. Only melting energy costs incl. oxygen purchase and firing exclusively with natural gas are considered.

Assumptions:	Specific energy consumption oxy fuel melter: 9000 kJ/kg
	Rate of electric boost: 250 kW
	Natural gas price: € 0.025/kWh
	Electricity tariff: € 0.065/kWh
	Oxygen price: € 0.065/m^3
	No exhaust gas heat use

Following amounts result:

	Conventional furnace	**Oxy-fuel furnace**
Spec. energy consumption	16 440 kJ/kg_{Glas}	9000 kJ/kg_{Glas}
Electric boosting	250 kWh/h	250 kWh/h
Melting capacity	50 t/d	50 t/d
Gas consumption	928 m^3/h	497 m^3/h
Oxygen consumption	-	994 m^3/h
Fuel costs	111.21 €/t_{glass}	59.56 €/t_{glass}
Electricity	7.80 €/t_{glass}	7.80 €/t_{glass}
Oxygen costs	-	31.01 €/t_{glass}
Melting energy costs	**119.01 €/t_{glass}**	**98.37 €/t_{glass}**

Considering the assumed energy and supply prices, the estimated melting energy costs of the oxy fuel firing are on the level of the conventional firing from a specific energy consumption of 12 000 kJ/kg_{glass}.

Furthermore, for the oxy fuel melter compared to a regenerative sideport furnace the smaller capital expenditure and the potentially lower expenditure for secondary reduction measures have to be considered.

➔ Note again that the prices for energy and oxygen supply are different from site to site and can differ from the indicated values. It is to be emphasised that in particular the oxygen supply prices depend on the processing method, the system size, the needed amount and not least on the negotiation finesse of the plant operator.

5.3.7 Further information on the special glass industry

Reference plant 12 showed that the attainable degree of NO_x precipitation or the NO_x cleaned gas content of an SCR plant depends exclusively on the design or the catalyst volume. If one does not consider economical aspects, almost any small NO_x concentrations can be realised.

Bag filters are normally used in the special glass industry. The total dust contents are below 20 mg/m^3 then, in individual fields - according to toxicity of the emitted dusts also clearly less than 10 mg/m^3. Attention is to be paid especially to the dust content substances. In the special glass industry, however, there are also filter dusts with smaller toxic potential.

SO_x emissions play only a subordinate role in the special glass industry. The concentrations are mostly in the range of the uncertainties of the used measurement methods.

In special glass furnaces with NaCl as refining agent, very high HCl concentrations partly occur in the raw gas. Through suitable proportioning and selection of the sorption agent, the emissions assuredly fall below the limit value also at these plants. No remaining plants of the special glass industry have any problems with the HCl emission.

Normally the HF emission is unproblematic for the special glass industry - in particular because of the mainly used very pure raw materials. Certain sections require, however, the use of fluorinated raw materials. Here, suitable sorption agents have to be used under the set exhaust gas limiting conditions and filter technologies in order to keep the emission limit value.

In the special and fibre glass sectors, very often boron containing raw materials are added to the batch. The precipitation of gaseous boron compounds may be difficult with traditional emission control technology. The HVG is currently confronted with this subject within the framework of a research project.

Special glass tanks have recently been fired increasingly with oxygen as an oxidising medium. Using oxy fuel technology, emission limit values referred to a concentration and a standardisation to a purchase oxygen content are not significant since the remaining oxygen in the exhaust gas can not be assigned either to the oxidising medium nor to the inflowing ambient air. Here, specific product related emission limits for example in [kg/t_{glass}] have to be derived.

The conversion to oxy fuel firing could be comprehended by means of cost estimates. From the viewpoint of ecology as well as economy, there are many reasons for the operation of the oxy fuel melter in the special glass field, where with the conventional firing a very high specific consumption is necessary.

Nevertheless, every individual plant has to be considered separately.

5.4 Domestic glassware:

For the BVT consideration, two reference plants were selected. In this case a site was concerned where exclusively electric melters are operated and a further plant where the glass was melted in a regeneratively fired horseshoe tank with heavy fuel oil as fuel.

As to the electric melters, no information with regard to the questioning was received, the other plant was closed down from economical factors in the second half of the year 2006.

Therefore, only limited information on both plants is possible.

5.4.1 Plant 13

Horseshoe furnace (heavy-oil) with EP

	Plant 13
Type	Horseshoe furnace
Air preheating	Regenerative
Melting area	54 m^2
Fuel type	Heavy oil, H_u: 41 100 kJ/kg
Max. approved melting capacity	125 t/d
Last main repair	Year 2004
NO_x reduction measures	Sealing measures, lambda control

Operation data	Current value (2005)
Melting capacity	110 t/d
Cullet portion, referred to melting capacity	40 %
Batch humidity, referred to total batch	2 %
Oil consumption	1.330 kg/h
Max. crown temperature	1.512 °C
Spec. melting capacity	2.04 t/m^2d
Spec. energy consumption (incl. electric boosting)	4.970 kJ/kg_{Glas}

(Volume data are referred to standardised condition.)

Emission limits – Emission data (2005)

Component	Limit value [mg/m^3]	Measured value, standardised to 8 % O_2 [mg/m^3]	Measured value [kg/t_{glass}]
Total dust	50	16.5	0.034
NO_x	1000	827	1.71
SO_x	1800	944	2.02
HF	5	0.6	0.0013
HCl	30	11	0.0233
Heavy metals:			
Group II TA Luft 1986	1	0.3	$0.69 \cdot 10^{-3}$
Group III TA Luft 1986	5	0.06	$0.14 \cdot 10^{-3}$

NO_x concentrations below 800 mg/m^3 and dust concentrations of 2 mg/m^3 were already measured at the same plant within the framework of emission measurements.

Further data are not available.

5.4.2 Plant 14

Electrical furnaces

Three continuously operated full-electric heated furnaces are concerned whose forehearth and take out system are likewise electrically heated. The energy needed for the fusion and refining of the glass is added with the present type of plant immediately by electrodes utilizing the electric conductance of the batch. The electric energy is now transferred through so called top electrodes. These curved electrodes are dipped into the melt through the batch by means of relatively large apertures in the superstructure.

The batch is fed onto the molten glass from above and distributed uniformly. The batch layer on top of the melt is melted from below here and shields simultaneously the combustion space from the radiation of the molten glass (cold top plant). Thus, the vaporisation causing the dust emission in the first place is strongly restricted.

The melting rates are between 20 and 30 day tons. The specific energy consumption is between 1.0 and 1.3 kWh/kg_{glass}.

The exhaust gases of the electric melters are merged and released via the roof without emission control system.

Available emission data (year 1998):

Component	Measured value [mg/m³]	Measured value [kg/t_{glass}]
Total dust	20.2	0.044
NO_x	499	1.49
SO_x	2.1	0.005

Current emission limit values are not known. The dust emissions are on a comparably low level. The concentration is not very significant since any concentrations can be adjusted with a variation of the sucking circumstances. The specific emissions are more interesting.

The NO_x emissions of the electric melters originate from the saltpetre disintegration. The reference furnace with energy consumption of 7000 kJ/kg_{glass} may emit 2.8 kgNO_x/t_{glass} with the use of nitrate containing batch composition. Accordingly, the required limit value of the 2002 TA Luft would be kept.

5.4.3 Further information on the domestic glassware industry

Greater numbers of domestic glassware are melted in continuously operated furnaces. To the knowledge of the HVG, all emission limit values, valid for the glass industry, in the field of domestic glassware.

With coming into effect of the emission limit values of the new TA Luft, the nitrogen oxides are the greatest challenge, in particular if nitrate containing batch compositions are present. From October 2010, new and old plants have to keep the limit value of 1000 mg/m^3. Only old plants with an exhaust gas volume flow of less than 5000 m^3/h may emit 1200 mg/m^3.

Domestic glassware is produced in smaller numbers also in pot furnaces. In pot furnaces, the emissions depend on the respective melting stage. The highest emissions occur during the feeding stages. In many cases the glass "is blown" on completion of the “melting up to batch free time”, i.e. with the immersion of a wet wood block or a potato into the batch, a powerful boiling up and homogenising of the melt occurs. In these stages also large concentration tops of the individual emission components can occur.

In Germany all pot furnaces are equipped with bag filter plants to the knowledge of the HVG. At these plants the required emission limit values can be kept with proper handling and possibly additional sorption agent use.

With the existence of gaseous heavy metal compounds, attention has to be paid especially to the exhaust gas temperature level before the filter plant. Gaseous arsenic compounds for example have, depending on the exhaust gas matrix, a vapour pressure so high that they can pass the filter plant in gaseous form also at temperatures below 100°C.

The wastewater and waste situation could not be discussed within the framework of the questioning. In the further processing, higher wastewater amounts accumulate compared to the hollow glass industry due to bevelling and polishing.

5.5 Glass fibre and mineral wool

In this branch of the glass industry, mainly natural gas fired furnaces with recuperative air preheating are operated in Germany. Due to the smaller air preheating temperatures compared to regenerative melters, they have less problems keeping the limit value of 800 mg/m^3 for nitrogen oxide emissions.

Electric and oxy fuel melters are also operated, however.

In the course of the project, a recuperative melter as well as a furnace operated with oxygen as an oxidising medium was selected concerning the insulation glass fibre production.

5.5.1 Plant 15

Oxy fuel fired furnace (C-glass) with EP

5.5.1.1 Melting plant

	Plant 15
Type	Oxy fuel furnace
Melting area	71.5 m^2
Fuel type	Natural gas, H_u: 35 903 kJ/m^3
Electric boosting (installed)	170 kVA
Type of glass	C-Glas
Max. approved melting capacity	206 t/d
Year of constructio	2006
Planned campaign	8 years
NO_x reduction measures	Near stoich. combustion, sealing measures, adjustable burners
Other measures	Sulphur poor raw materials and fuel
Waste gas heat recovery	None

Operating data	**Average value**
Melting capacity	199 t/d
Cullet fraction, referred to melting capacity	66 %
Batch humidity, referred to total batch	2.5 %
Gas consumption	820 m^3/h
Oxygen consumption	1750 m^3/h
Capacity of electric boosting	0 kW
Max. crown temperature	1500 °C
Spec. energy consumption (without oxygen production)	3551 kJ/kg_{glass}

(Volume data are referred to standardised condition.)

The oxygen is produced on the factory ground. A VSA plant is concerned supplying an oxidising agent with an O_2 portion of approx. 93 - 94 %.

Production wastes are added to the shredding products again in the discharge chute.

New recuperative reference melters have a specific energy consumption of about 5000 kJ/kg_{glass}.

A cost estimate of the melting energy costs (natural gas price: € 0.025/kWh; electricity tariff: € 0.065/kWh; oxygen price: € 0.065/m^3) results in the following:

Oxy fuel melter: € 24.56 (gas) + € 13.72 (O_2) = € 38.28/t_{glass}

Recuperative melter: € 34.72/t_{glass}

With the assumed prices and specific energy consumptions taken for granted, this means that one has to make a detailed cost account in order find the more economical melting aggregate considering the entire campaign.

5.5.1.2 Waste gas heat recovery: None

5.5.1.3 Waste gas treatment plant of the furnace:

For the reference plant 15, at present there are no official results of emission measurements available. The reference system was built up according to the model of an existing gas-fired furnace in a foreign country in Europe, also with oxy fuel firing and the same glass kind.

There emission measurements were carried out by the HVG within the framework of a research project.

The exhaust gases are annealed after leaving of the melter with ambient air and, like the exhaust gases of reference plant 15, cleaned by means of an electrostatic precipitator without additional sorption agent.

Emission limits – emission data

Component	Limit value [kg/h]	Measured value [kg/h]	Measured value [mg/m^3]	Measured value [kg/t_{glass}]
Total dust	0.37	0.021	3.4	0.0076
NO_x	9.17	2.30	371	0.83
SO_x	1.83	0.004	0.7	0.0014
HCl	0.092	0.004	0.7	0.0014
HF	0.018	0.003	0.5	0.0011

*) Emission limit values of the reference plant 15

**) Measured values of the foreign reference plant

The reference plant 15 is three times larger than the foreign plant. Thus, it also needs more melting energy from that, which has to be considered in the evaluation of the specific NO_x emission. Nevertheless, if one multiplies the NO_x mass flow of the reference plant by the factor 3, the emissions fall below the required value (mass flow).

All other measured values are on a very low level.

The produced filter dust (approx. 260 t/a) is remelted.

The reason for the small concentrations of acidic exhaust gas components is due on the one hand to the raw material selection, on the other hand to the high raw gas dust concentrations of 1750 mg/m^3 (with an O_2 content of the exhaust gases of 18.2 %) and the sorption qualities of the emitted dusts associated with that.

The cost estimate concerns the reference plant. The plant operator stated writing-off time of 8 years.

Cost estimate (Writing-off time: 8 years / No depreciated value / interest rate: 6 %)	**Filter plant incl. Accessoires** **[€]**
Investment / replacement costs	910 000.-
Annual redemption	**158 750.-**
Operating costs:	**60 000.-**
Annual total costs	**218 750.-**

Allocated to the average amount of produced glass, an amount of € 3.01/t_{glass} has to be invested accordingly by for the emission control system of the furnace.

5.5.1.4 Dust filters for batch handling:

In the batch house, no filter plants subject to obligatory check up exist. The expenditure for the dust deposit was estimated with **€** 0.16/t t_{glass}.

5.5.1.5 Forming / coating:

The largest expenditure in the field of the air purification has to be assigned to the processes of manufacture after the shredding.

Emission limits

Component	Limit Value [mg/m³]
Total dust	20 (Fall tower)
Total dust	10 (Production line)
NO_x	35
SO_x	50
Phenol + formaldehyde	15
Ammonia	65
Total carbon	15

Official results of measurement are not available.

For the production lines, discharge chutes and tempering furnaces following cost estimates were indicated:

Cost estimate (Writing-off time: 8 years / No depreciated value / interest rate: 6 %)	**Filter plants incl. accessoires** **[€]**
Investment / replacement costs	3140 000.-
Annual redemption	**498 475.-**
Operating costs:	**200 000.-**
Annual total costs	**698 475.-**

In this field, the costs amount to **€** 9.62/t_{glass}, and thus are more than three times higher than the cost of the emission control of the melting plant.

5.5.1.6 Wastewater:

In the wastewater field, there are only waters similar to household ones. All cooling, process and wastewaters from washing systems are recirculated and filtered.

A defined cost estimate is not available.

The required fresh water of 54 800 m^3/a which has to be supported with € 0.07/m^3 is covered by fountain water.

5.5.1.7 Wastes:

The waste situation could not be documented understandably. Reference system 15 concerns a new production site.

5.5.1.8 Evaluation of reference plant 15:

Due to missing official measurement results, the emissions of the reference system 15 had to be verified to by a reference system. The emissions of acidic exhaust gas components such as SO_x, HCl and HF are remarkably low. In addition, the nitrogen oxide emissions with the value of 500 mg/m^3 fall below the comparative value of a conventional melter.

The cost estimate with assumed amounts for energy and oxygen purchase showed that one has to carry out an exact cost account in order to prove advantages for a conventional or the oxy fuel technology on the decision-making with regard to the melting technology.

The costs for environmental control measures to the amount of € 12.79/t_{glass} (without considering waste and wastewater) are only to about 25 % caused by the emission control system of the exhaust gases of the glass furnaces. The exhaust gas processing of the product manufacturing requires by far the greater part.

5.5.2 Plant 16

Recuperative heated furnace with EP

5.5.2.1 Melting plant

	Plant 16
Type	Sideport furnace
Air Preheating	Recuperative
Melting area	80 m^2
Fuel type	Natural gas, H_u = 36 119 kJ/m^3
Electric boosting (installed)	None
Max. approved melting capacity	300 t/d
Last main repair	Year 2002
Planned campaign	5 - 8 years
NO_x reduction measures	Near stoich. combustion, sealing measures, adjustable burners
Other measures	Sulphur poor fuels

Operating data	Average Value
Melting capacity	270 t/d
Cullet portion, referred to melting capacity	75 %
Batch humidity, referred to total batch	0.8 %
Oil consumption	1700 m^3/h
Max. crown temperature	1520 °C
Spec. melting capacity	3.75 t/m^2d
Spec. energy consumption	5458 kJ/kg_{gass}

(Volume data are referred to standardised condition.)

A so-called cyclone furnace in which the organic components are burned and passed on together with the exhaust gases of the melter is provided with the production waste with binding agent deposition. In total, about 3700 t/a of glass wool waste is melted down and recycled to the process.

5.5.2.2 Waste gas heat recovery: Not applicable

5.5.2.3 Waste gas treatment plant of the furnace

Filter type	EP with 2 fields
Temperature before filter	380 °C
Sorbent	None
Water injection	Yes
Amount of filter dust	400 t/a
Use of filter dust	100 % recycling (batch
Electric energy	194 kWh/h

Emission limits

Component	**Limit value [mg/m³]**
Total dust	30
NO_x	500
SO_x	100
HF	5
HCl	30

The emissions of all concentrations fall below the limit values.

5.5.2.4 Dust filters for batch handling

For the preparation, storage and the transport of batch and cullet, there are no emission control systems subject to obligatory check up. In total, 16 silo top piece filters are mounted.

5.5.2.5 Forming / coating

Emission limits

Component	**Emission [mg/m^3]**
Total dust	50
Phenol + formaldehyde	30
Ammonia	65
Total carbon	50

The required limit values are all kept.

On the lines of reference plant 15, very high expenditures for the product manufacturing incur also with this plant.

The investment / replacement costs for the emission control system amount to approx. € 10 mill.

5.5.2.6 Wastewater

Only industrial water such as in homes results. The discharge occurs via the municipal wastewater system. Rainwater is delivered after continuous monitoring into nearby waters. Process water is recirculated. The treatment takes place via filtration and/or rotation filter technology. The wastewater quantity is 15 000 m^3/a.

Cost data are not available.

5.5.2.7 Wastes

In the course of a main repair 780 t of refractory accumulate that are recycled by 100 %.

Otherwise, almost no wastes occur in the production process. Filter dusts from the exhaust gas control of the melting tanks, the batch house and the further processing are recycled.

5.5.2.8 Evaluation of reference plant 16:

The specific energy consumption of the recuperative furnace is 5458 kJ/kg_{glass} after a campaign of four years. In the new state, the value was about 5000 kJ/kg_{glass}.

The expense situation was already considered for reference plant 15.

All required emission limits of the furnace and the further processing are kept. The emissions of nitrogen oxides also fall below the limit value of 500 mg/m^3.

The costs of the exhaust air cleaning are higher in the field of the further processing of glass fibres than the costs of the emission control system of the furnaces.

Reference system 16 is equipped with an additional special melting technology, the so-called cyclone furnace. The cyclone furnace is connected to the melter and separately heated. The production wastes and associated organic components are melted and fed into the furnace. The organic components are burned free of residues. The waste gas of the cyclone furnace takes place together with the exhaust gases of the melter.

5.5.3 Further information on glass fibre and mineral wool

Besides the introduced reference systems, an oxy fuel and a recuperative melter, there are also glass furnaces with full-electric heating or so-called cupolas for the production of rock wool.

In the cupola, volcanic rock, lime, mineral loadings as well as rock wool recycling material through burning of coke are heated up to more than 1500 °C. The fluid rock fusion is then spun to fibres, added to an organic binding agent and hardened. Reliable information on the environmental control is not available.

In full-electric glass furnaces, traversing belt conveyors or other ingenious inserting techniques are employed in such a way that a closed batch blanket forms on top of the glass melt. Thus, the batch blanket takes over the function of a sorption stage. Together with a filtering precipitator, the emissions of electrically molten glasses (cold top furnaces) are clearly lower compared to conventionally molten glasses of the same type in flame heated furnaces.

Utilizing boron containing batch components, gaseous boron compounds are emitted, in particular if one melts down alkali-poor glasses. In the following section, some information is given on this problem gained within the framework of investigation activities of the HVG.

6 Current investigation results of the HVG in the field of air purification

For the last 30 years, the majority of the investigation activities of the HVG has been dedicated to the emissions in the glass industry and the primary and secondary reduction measures of individual emission components.

Particulate emissions - PM10 / PM2.5

In May 2004, a project concerning the particulate emissions of glass melters was finished.

In the sum, measurements were carried out on 18 furnaces from the different branches of the glass industry. It could be documented that the glass industry does not have any special problems with particulate emissions in comparison with other branches of industry.

The measurements were carried out with a cascade impactor of type Johnas II, with which the granule fractions > 10 µm, < 10 µm (PM 10) and < 2.5 µm (PM 2.5) can be captured and evaluated. All measurements were accompanied with time-parallel entire total dust measurements.

Thus, it could be found that the guideline supported detailed fine dust measurement technology in the exhaust gas of glass melters is afflicted with a problem. Within the cascade impactor, dust losses occur which in the first place are to be put down to the agglomeration of the dusts. On the first nozzle plate of the cascade impactor, one finds more or less strong dust deposits after the measurements. Adding up the single fractions in the cascade impactor and comparing them with the total dust content measured time-parallel, differently great losses of partly more than 30 % occur.

The weight losses in the cascade impactor affect the evaluation of the measurering results. Adding the loss portion to the coarse dust, PM 10 fractions of the total dust of 68 % and PM 2.5 fractions of 48 % were found for example in the exhaust gas of the ten examined container glass melters on the average. If one neglects the losses, PM 10 fractions of the total dust of 86 % and PM 2.5 fractions of 56 % result.

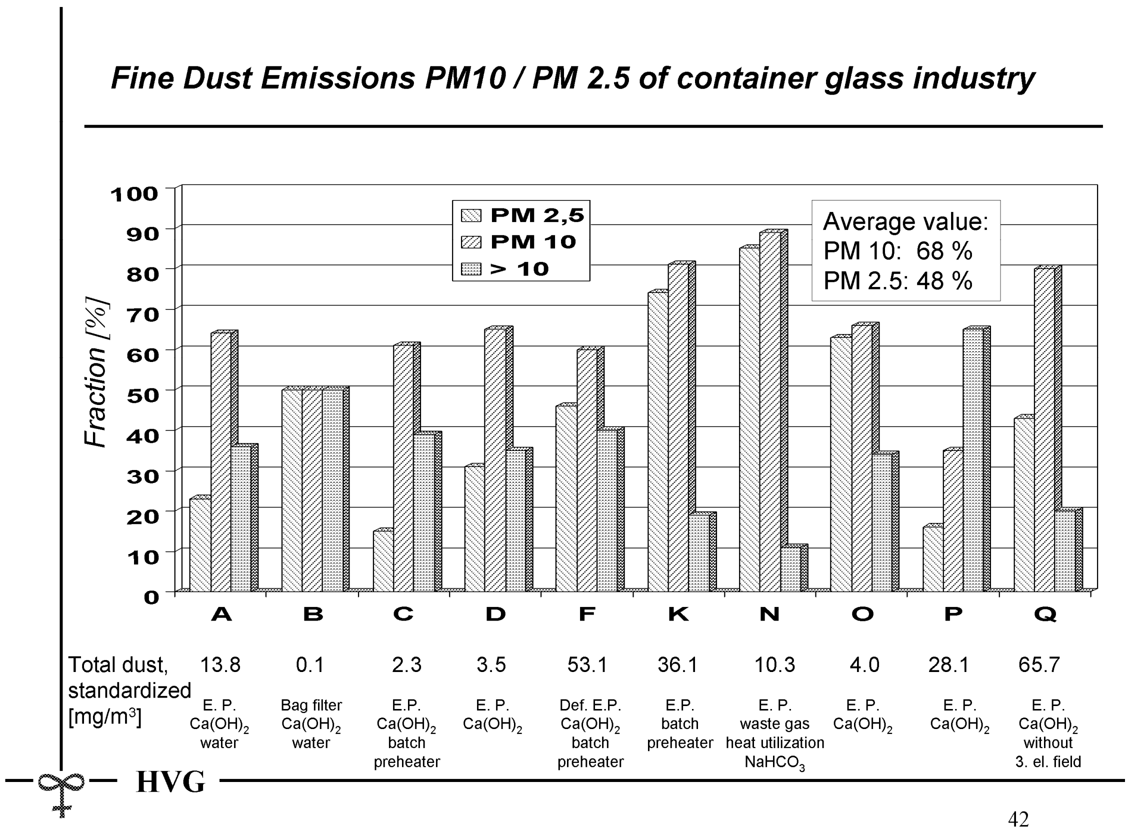
Similar fractions were also found in the sheet glass, special glass and optical fibre industries.

Significant and understandable dependences of the particulate fractions of the total dust concentration, the employed absorption agents and the exhaust gas limiting conditions could not be found.

For the dimensioning of new systems, no additional aspects occurred. Small total dust contents of cleaned gas provide low particulate emissions.

With an estimated exhaust gas amount of 2500 000 m^3/h (7 mio. tons per year – 5000 kJ/kg_{glass}) of the entire glass industry in Germany, referred to dry exhaust gas in the standardised condition with 8 % of O_2, an entire dust emission of 35.7 kg/h results with a mean dust concentration of 14.3 mg/m^3 (mean value of all plants during the investigations). Taking as a basis the more unfavourable evaluation, a PM 10 mass flow of 31.8 kg/h is emitted, and respectively 24.3 kg/h if one adds the deposits and/or losses in the cascade impactor to the coarse dust.

The following diagram summarises the results in the container glass industry. In the evaluation, the deposits were added to the coarse dust.



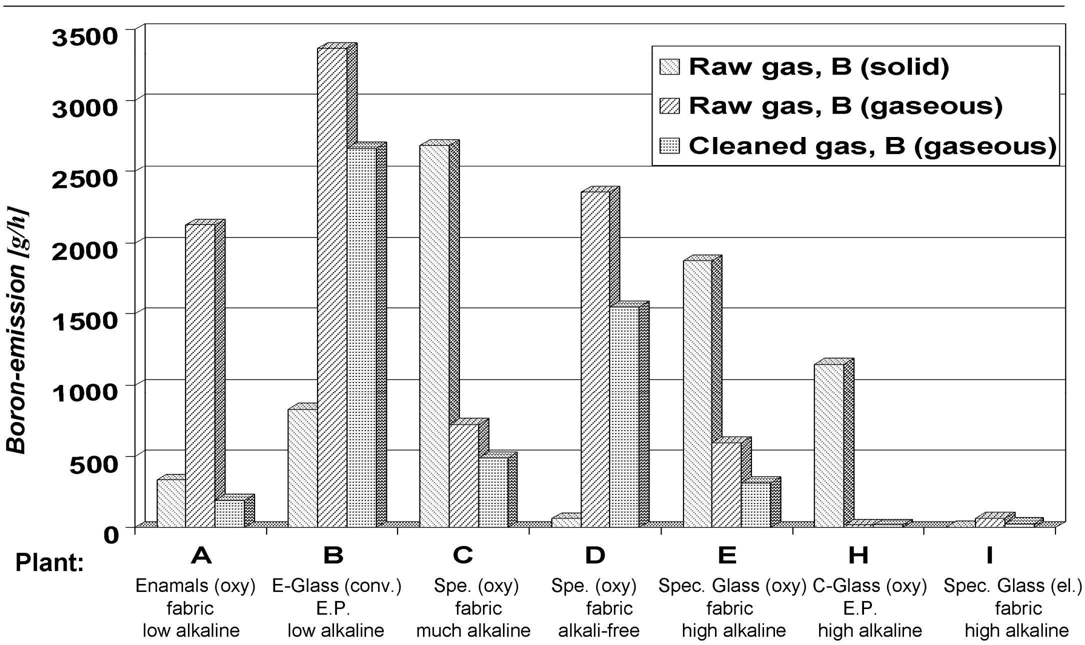
The particulate fractions are different from plant to plant.

Boron emissions

Within the framework of a research project finished in the year 2005 investigations into the emission of particulate and gaseous boron compounds were carried out on 18 glass furnaces with boron containing batch. The plants are different with regard to the molten glasses, furnace type, type of firing as well as downstream emission control technologies.

Some results are subsequently compiled.

Boron emissions of borosilicate glass melting furnaces



	A	B	C	D	E	H	I
B reduction:	92.2 %	36.4 %	85.7 %	35.9 %	87.3 %	98.7 %	64.3 %
B evaporation:	unknown	5.34 %	5.72 %	7.4 %	4.22 %	2.37 %	0.09 %

The indicated reduction represents the efficiency of the emission control system and refers to the sum of particulate and gaseous boron compounds.

Compared to the fossil fuel fired melters, the emissions of full-electric furnaces with "cold" superstructure - so-called cold top tanks (Plant I) - are on a clearly lower level.

For boron containing glasses, one must consider also a gaseous fraction in the exhaust gas besides the particulate boron compounds. The strength of the vaporisation of boron containing compounds and thus the boron emissions depends on the boron concentration in the melting batch and/or in the glass as well as on the ratio and the sum of boron and alkalis [4,5,6]. Due to the different composition of boron containing glasses as for example the glass fibres (E-glass, C-glass, glass wool) and the technical borosilicate glasses (Duran 50, Suprax, G20, Fiolax), one finds a large concentration bandwidth of boron containing compounds in the uncleaned exhaust gas of the melters concerned.

The part of particulate boron compounds in the raw gas is strongly dependent on the alkali content, possibly also on the alkaline earth content of the molten glasses. In alkali-rich glasses, one finds high total dust concentrations making available for example respective co-reactants for the sodium borate formation. In alkali-free glasses, the particulate boron compounds play only a subordinate role in the raw gas.

The precipitation of particulate boron compounds is unproblematic. It works very well both in E-filters and bag filter plants. On cold places of the filter plant and the exhaust gas system, the growing boron layers are causing trouble, however. The precipitation of gaseous boron compounds is clearly more difficult. They condense only at very low temperatures in the range of the water dew point, and thus pass the waste gas treatment plant and can lead to a visible plume even behind bag filters.

Further measures have to be taken in respect of the effective precipitation of gaseous boron compounds. In a current follow up project, especially the reduction potential of gaseous boron compounds is investigated through the installation of a high temperature sorption stage in addition to the inspection of the capability of available sorption stages with specific sorption agents, the influence of additional water injection and/or the injection of alkaline solutions. A mobile proportioning-plant was bought for this purpose enabling the injection of fine-ground glass raw materials (for example soda, limestone, dolomite, …) into the exhaust gas flow behind the superstructure at exhaust gas temperatures of 1400 °C.

First investigations in the exhaust gas of a recuperative E-glass melter were carried out successfully. Reduction rates of more than 80 % could be proved for gaseous boron compounds.

The activities are supported by thermo-chemical calculations in the run up and during the measurements.

Quartz particulate emissions

Due to its carcinogenic effect, fine dust particles of quartz will be subjected to an emission limit value e.g. of 1 mg/m^3 after Group III of the TA Luft possibly in forseeable time in Germany. The glass industry is regarded as a potential quartz fine dust emitter because of the high SiO_2 part in the product and the high quartz sand part in the batch. However, there are no emission data available up to now.

At the beginning of the project in February 2005, no tested measuring method existed for the definition of the quartz fine dust emissions in the form of crystalline quartz and cristobalite for the exhaust gas temperatures up to 400 °C occurring in the glass industry. The investigation activities focused first on a suitable sampling system and/or the checkout of a suitable filter medium.

In the course of the FE processing period, besides the development of the PM 4 stage for the cascade impactor Johnas II also the precipitation behaviour of a temperature-constant high-grade steel fibre filter medium was validated by the Institut für Energie-und Umwelttechnik e.V. (IUTA). Moreover, the validation of the analytics on quartz fine dust of the high-grade steel fibre filter was announced by the Institut für Gefahrstoffforschung (IGF) of the mining industry trade cooperative association at the Bochum Ruhr University. Accordingly, after the decomposition in aqua regia and the transfer of the test onto a silver filter, the analyses of used high-grade steel fibre filters (quartz DQ 12 A dust / cristobalite SF 6000) a straight-line calibrating function by means of XRD analysis.

Thus, an in situ measuring method simply to be operated is available.

In the cleaned gas of ten examined glass melters, all measurement results obtained both with high-grade steel fibre material and with other sampling versions were partly below the analytical detection limit and/or clearly below the above stated concentration for quartz fine dust.

The analysis results of comparative investigations in the lab of the HVG with high-grade steel fibre filters and nitrocellulose filters, the use of which is standard in the field of the industrial safety, were different for both the quartz analysis (factor 2) and the cristobalite. Particulate dusts of a sand drying plant were used as test dust. In addition, the high-grade steel fibre filters without dust impact show a clear increase in weight together with a colour modification of the filter medium in the hot exhaust gas of glass melters.

In future, open questions as to the analytics have to be clarified, i.e. further investigations are required.

7 Oxy fuel firing - Profitability studies and ecological aspects

The adaptation of the melting technique of conventional fired glass melting furnaces to exclusively oxy fuel firing was realised on many plants in the special glass sector. According to the knowledge of HVG, furthermore there are two container glass melters, a cast glass melter as well as some melting furnaces in the optical fibre sector in Germany using pure oxygen as an oxidising agent at the combustion of the fossil fuels.

Oxygen generation

For small plants, the oxygen is delivered normally in the form of fluid oxygen by lorries and stored.

For larger plants, the oxygen is produced mostly as cryogenic oxygen of an air separation unit on the factory ground. Cryogenic air separation is a method that compresses and cools down atmospheric air, and then - dependent on the different boiling points - disassembles the so obtained liquid into his components in a distillation column.

The oxygen generation can be carried out also with a so-called VSA plant. These plants use the method of the gas separation through adsorption. In this method, air flows through a molecular sieve in which the nitrogen and carbon dioxide are bound due to its physical qualities. However, oxygen and argon flow through the molecular sieve. When the sieve is aerated, regeneration occurs through pressure drawdown under atmospheric pressure so that nitrogen and carbon dioxide become desorpted.

A further possibility of the oxygen generation is a VPSA plant. This vacuum pressure swing adsorption method is a noncryogenic technology that produces oxygen from the air using an adsorbent in a pressure swing method in order to remove nitrogen.

The melting rate and the necessary energy demand of the molten glass and so the amount of the needed oxygen determine the size and presumably the type of the oxygen manufacturing plant. However, this decision criterion is not supposed to be subject of this consideration.

Fluid oxygen and cryogenic oxygen offer the advantage that the O_2 content of the oxidising agent is almost 100 %. In the two other processing methods, the O_2 content is between 92 and 95 %, so that about 5 % of argon and 2 to 3 % of nitrogen are present as ballast.

Causes of the NO_x formation

The NO_x emission of glass furnaces are basically caused through the thermal NO_x formation in the flame (nitrogen oxide formation according to Zeldovic). This is in turn mainly conditioned through the flame temperature, the oxygen content in the reaction zone and the retention time at high temperature.

With advancing retention time at high temperature and increasing oxygen partial pressure, the nitrogen oxide formation increases. In practice, these actuating variables interact with operating parameters such as the air excess, temperature of the combustion air, flame type, fuel type, mixture of fuel and combustion air, different burner parameters, etc...

In glass furnaces on which for product quality reasons saltpetre has to be utilised, the saltpetre disintegration is a further cause of the NO_X formation.

The combustion space temperature of glass furnaces are in general between 1500 °C and 1700 °C. The combustion air is preheated to up to 800 °C for recuperative and up to 1350 °C for regenerative glass melters. With that, correspondingly high flame temperatures are reached with the result of a strong thermal NO_X formation.

With regard to the pollution control, oxy fuel melters have the great advantage that the emissions of nitrogen oxides are on a level that can be achieved only by secondary measures (SNCR and/or SCR) with conventional furnaces.

<u>Consideration of emission limit value</u>

While for natural gas fired glass furnaces in the special glass field NO_X concentration values up to 5000 mg/m^3 were found, in the last years the NO_X emissions were clearly lowered in glass furnaces through the utilisation of a series of primary reduction measures.

In the new TA Luft of 01.10.2002, an <u>emission target value</u> of <u>500 mg/m^3</u> was defined for the component NO_X for glass melters (from the year 2010). For horseshoe and sideport melters with an exhaust gas volume flow of less than 50 000 m^3/h, an NO_X mass concentration of <u>800 mg/m^3 (emission limit value)</u> must not be exceeded. This limit value is valid also for old plants with an exhaust gas volume flow of more than 50 000 m^3/h. As far as for reasons of the product quality a nitrate utilisation is necessary, the NO_X concentration must not exceed 1000 mg/m^3. For old plants with an exhaust gas volume flow below 5000 m^3/h, 1.2 g/m^3 must not be exceeded.

Due to the extensive absence of the nitrogen ballast, completely different conditions arise for NO_X formation in the flame, exhaust gas volume flow, exhaust gas humidity and NO_X concentration with oxy fuel compared to conventional technique.

No NO_X would arise with the use of pure oxygen as oxidising agent and a nitrogen-free fuel if the combustion space could sealed against the ambient air simultaneously. It must be taken into account, however, that in spite of seal measures ambient air flows in into the plant and with that nitrogen reaches the combustion zone. In addition, more or less chemically bonded nitrogen from the fuel and from the nitrogen as accompanying substance of the oxidising agent is available.

The indicated reference plants show, however, that low emission values can be reached independently of the type of the fuel and the production method of the oxygen.

In oxy fuel melters, but also in full-electric melters, completely different conditions arise in exhaust gases with regard to exhaust gas volume flow, emissions and pollutant concentration than in conventional fuel air fired glass furnaces. Until the 2002 TA-Luft, there were no regulations that considered the special features of those melters. In the currently valid TA-Luft of 1.10.2002, following stipulation, however, was inserted under the digit 5.4.2.8:

"Special regulations are to be found for oxy fuel and for electric melters. The particular energy consumption of comparable modern fuel air fired furnaces and the capability of emission control plants are to be considered. The VDI guideline 2578 (edition November 1999) is pointed out."

Accordingly, product related emissions equivalent to the NO_x emission value of the reference melter has to be derived for glass furnaces with oxy fuel firing and electric furnaces, dependent on the particular energy consumption of modern fuel air fired furnaces. Thus, it should be guaranteed that an oxy fuel tank is not judged less favourable than a conventional fossil fuel fired melter with regard to the NO_x emissions.

The derivation of product-related emission limits has proved of value, for example in [$kg_{pollutant}/t_{glass}$]. With the determination of particular product-related emission limit values, the fact is taken into account that the conversion of measured NO_x emission values to a definite reference oxygen content is not possible.

Economical aspects

In deciding whether an existing or new furnace is to be designed with conventional firing and heat recovery technology or with oxy fuel firing, various reasons and questions play a role. To answer these, from the ecological and economic viewpoint issues have to be considered such as for example glass quality - capital expenditure - oxygen costs and operating costs - NO_x emissions - CO_2 emissions - space requirements - service life of the melter - refractory – waste gas heat recovery - and so forth.

The most important of these points is certainly the aspect of cost effectiveness.

The apprehension that the operation of an oxy fuel melter involves a shorter campaign could be attenuated in particular by the construction of the furnace superstructure and the kind of the feeding.

In the special glass industry, where high specific energy consumption is necessary with conventional melting technology due to the system size and the type of molten glass, the adaptation to oxy fuel firing could be comprehended by means of cost estimates. In the special glass industry, the estimated melting energy costs incl. oxygen generation for an oxy fuel melter were lower in many cases due to the clearly lower energy demand.

In the cost estimate in the glass and mineral fibre industries, attention must be put increasingly to the capital expenditure and the capital investment in stock connected with that. This is valid also for the produced mass glasses of the container and flat glass industries.

The prices for energy and oxygen supply are different depending on the production site and the necessary amounts. It should be emphasised that in particular the oxygen delivery costs depend on the kind of the processing method, the system size, the oxygen consumption and not least on the negotiation finesse of the plant operator, or also on the issue of additional air components (nitrogen / argon) are marketed.

Comprehensive reliable numbers are not available for any of the mentioned reference plants. For this reason assumptions were made for the cost estimate that have crystallized as the current average from conversations with suppliers of air separation units and employees of the glass industry. Following values are taken as a basis for the estimates:

Natural gas price: € 0.025/kWh

Electricity tariff: € 0.065/kWh

Fluid oxygen price (delivered): € 0.11/m^3

Cryogenic or VSA/VPSA oxygen price: € 0.065/m^3

In the special glass sector one has to consider melting energy costs of up to € 120/t_{glass} and more depending on the system size and the type of glass. On the other hand, for a highly loaded oxy fuel melter in the container glass field (without electric boosting) about € 33/t_{glass} can be estimated including the costs for the energy generation and a spec. energy consumption of 3200 kJ/kg_{glass} at the beginning of the campaign. Large regenerative furnaces can reach about 3200 kJ/kg_{glass} in the new state. Thus, the estimated melting energy costs amount to € 22/t_{glass}.

The difference must be get together through the smaller capital expenditure (incl. financing/writing-off) for the oxy fuel compared to the conventional furnace.

Comparing the costs of a float glass furnace with 800 day tons is clearly more difficult since no reliable information on the specific energy consumption or the service life of an oxy fuel furnace of this size is available. Moreover, the advantages of the capital expenditure of the furnace are on the side of the oxy fuel technique, in particular through the absence of the regenerators of sideport furnace. However, the operating costs including the oxygen generation might exceed those of the conventional firing. Therefore, the efficiency largely depends on the difference in the specific energy consumption between the two types of plants, the amount of the costs of oxygen production and on the expenditure necessary for primary or secondary NO_x abatement measures with conventional combustion.

Well-known furnace builders provided the HVG with differentiated unofficial comparative analyses carried out in the container glass field with regard to the efficiency. The calculations were all done without downstream heat exchanger considering foreseeable data of investments, operation and maintenance including the CO_2 emission market.

For a furnace with a tonnage of 300 t/d, a cullet fraction of 85 % and a mean specific energy demand of 4050 kJ/kg (conventional sideport furnace) and 3620 kJ/kg (oxy fuel technique and silica crown), respectively, for a 10 year service life (10 year writing-off time without depreciated value (6 % of interests)), the following values can be estimated taking the energy and oxygen prices of the preceding page into account:

Annual total cost estimate:

Regenerative fired sideport furnace:	4.82 Mio. €
Oxy fuel furnace:	5.14 Mio. €

The investment for the oxy fuel furnace is several million euros lower than the investment of a regenerative heated sideport furnace. That is a great advantage for the annual redemption. This advantage is imbalanced by the oxygen costs (approx. 1.35 mill. € annually).

According to the furnace builders, the reasons for the small capital investment for the oxy fuel furnace are the lower expenditures for refractory, exhaust system and adjustment mechanisms. In addition planning and assembly costs are lower, the space requirement of the oxy fuel furnace is smaller compared to the regenerative heated sideport furnace. Moreover, the electric power need for compressed, cooling and combustion air (without oxygen production) and the maintenance cost of the oxy fuel furnace are lower than that of the conventionally heated plant.

Adding the expenditure for the operation of an SCR plant or extensive primary measures for the NO_x abatement necessary with the conventional plant, both concepts are equal with respect to the costs in the case considered.

The estimated capital investment for an oxy fuel melter with ZAC superstructure is for instance 1.4 mill. € higher than the amount for a furnace with silica crown.

Ecological aspects

Considering the oxy fuel technique from the viewpoint of ecology, the low NO_x emissions should be mentioned first. For soda lime silica glasses they are between 0.2 and 0.8 kg/t_{glass} for the chosen reference systems. This value can currently be reached only by means of secondary reduction measures on conventional furnaces with regenerative air preheating.

Secondary reduction measures on conventional melters also require the use of urea or ammonia besides the materials usage for catalysts (SCR), stock tanks, pipelines or steel constructions. Ammonia is very energy and raw material-intense to be produced and furthermore is partly emitted in the form of ammonia slip.

Ammonia is nowadays almost exclusively made by the Haber-Bosch process. The majority of the plants currently operate after the steam reforming process with natural gas as a hydrogen supplier. The first step is the production of synthesis gas: sulphur less natural gas is converted into hydrogen and carbon dioxide in three steps with vapour and oxygen from the air. The carbon dioxide is elutriated then. After that, the hydrogen reacts to ammonia with the nitrogen from the air at iron catalysts under release of heat. All procedural steps require high temperatures and high pressure. The energy demand of the best processes is 30 GJ/t_{NH_3}. For ammonium hydroxide (25 % - ρ =0.226kg $_{NH_3}$/l) this corresponds to an energy demand of 1.88 kWh/l, without consideration of mixing, transport, and/or storage expenditure.

On the other hand, also for the oxygen generation a great amount of technical equipment and supply of electric energy are necessary. In the literature, the values vary between 0.2 and 1 kWh/m^3 according to system size and type of oxygen used. For the field of the glass industry, figures of 0.4 to 1 kWh/m^3 are stated.

For a realised oxygen generation plant designed for an amount of 2000 m^3/h of oxygen, an energy demand of 0.86 kWh/m^3 was stated for example.

Considering large furnaces of the container glass industry without waste gas use and electric boosting, approx. 3200 kJ/kg_{glass} (0.89 kWh/kg_{glass}) and approx. 3400 kJ/kg_{glass} (0.94 kWh/kg_{glass}) can be achieved for effective oxy fuel furnaces in the new state and for horseshoe furnaces, respectively. Taking into account the power station efficacy of 33 % for the generation of the electric energy and estimates the oxygen consumption of a very efficient furnace in the new state with 0.17 m^3/kg_{glass}, then 1.33 kWh/kg_{glass} of melting energy are to be spent for the oxy fuel firing.

According to this calculation, the CO_2 balance turns out to be favourable for the conventional furnace engineering if one assumes that the electric energy is gained of fossil fuels. Utilizing exhaust gas heat (see reference plant 1) the disadvantage can be balanced again.

In other fields of the glass industry involving higher specific energy consumption the advantages of the balancing are with the oxy fuel technique.

Data for estimating the CO_2 emissions (without batch reactions):

- Specific CO_2 emissions of natural gas: approx. 0.2 kg/kWh
- Specific CO_2 emissions of fuel oil: approx. 0.28 kg/kWh
- CO_2 emissions of the oxygen generation: approx. 0.5 kg/kWh

➔ In the sum it can be stated that with regard to the economic and ecological effects, every individual plant has to be considered separately under inclusion of all parameters.

8 Cross media issues

Filter dust recycling

In Germany all glass melters are equipped with emission control plants, largely corresponding to the state of the art. Normally this is a matter of electrostatic precipitators or bag filter plants with dry sorption stages and calcium hydroxide, sometimes also soda or sodium bicarbonate as sorption agents. In some cases, sorption agents are not necessary. In the special glass field, there are occasionally also granulated limestone filters or wet scrubbers for the emission control system.

In mass glass manufacturing in the container, fibre and flat glass field, the precipitated filter dusts are almost completely added to the batch and remelted. They relieve the waste situation of the site considerably with that.

Sulphur-containing raw materials are nowadays used almost exclusively for the refining of industrial container, flat and fibre glasses. A comprehensive representation of the sulphate refining is not simple because sulphur and its compounds become effective in a different way at different points of the glass melting process [7].

Usually Na_2SO_4 is used as a batch raw material for the sulphate refining. Using $Ca(OH)_2$ as sorption agent, $CaSO_4$ mainly comes into the process with the complete filter dust recycling whose purifying effect in glass melting follows other reaction mechanisms. For this reason, Na_2SO_4 is added to the batch in many cases also when heavy fuel oil is used considerable sulphur amounts recycled due to the emission control system.

Considering the SO_2 concentration of 1225 mg/m^3 present at the combustion of heavy fuel oil with a sulphur content of 1 % and an oxygen content of 8 % in the dry exhaust gas, then only small space remains for sulphur-containing exhaust gases from the refining of the glass in order to keep to the limit values of the TA Luft.

After the TA-Luft, heavy fuel oil fired container und flat glass furnaces may emit 1.5 g/m^3 (0.80 g/m^3 with gas heating) sulphur oxides from the year 2007. Conditions are linked to the limit value, such as in the case of the container glass industry near-stoichiometric combustion, complete filter dust recycling, sulphate refining and a cullet proportion of more than 40 %. If the conditions are not fulfilled, the limit value is 0.80 g/m^3 for fuel oil usage and 0.40 g/m^3 for gas burning.

One recognises quickly that there are limits to the use of heavy fuel oil with arbitrary sulphur content and complete filter dust recycling.

A high cullet fraction requiring a certain play with the mixture prescription due to the impurities carried along represents a further obstacle for the filter dust recycling. This is a further limit to the filter dust amounts.

Usually $Ca(OH)_2$ is used as dry sorption agent and under favourable conditions an SO_x reduction of 50 - 60 % is achieved. Using $NaHCO_3$ and ideal conditions with regard to mixing, grain size or exhaust gas temperature also reduction rates of more than 80 % were achieved.

The capacity of an emission control plant cannot always be fully used with complete filter dust recycling and heavy fuel oil as fuel for the glass melter. The sulphur solubility in the glass is restricted, in the last 20 years even regressive. With the complete filter dust recycling, the SO_x concentrations in the raw gas will increase and already soon, a date will be reached at which the required emission limit value cannot be kept anymore, also with a very good rate of SO_x reduction.

The decrease in the sulphur bound in the glass matrix of soda lime silica glasses does not allow unambiguous allocation. The near-stoichiometric combustion as a measure for the NO_x reduction and the associated partly reducing conditions in the atmosphere of the superstructure presumably play a role to be paid attention to.

Some glass manufacturers also use the filter dust recycling in order also to influence the selenium flows. In the production of white container glass, selenium is used for physically decolouring - according to the principle of the complementary colours - the impurities in colour that in the first place occur in the process due to recycled cullet. Usually the batch is provided with selenium in the form of sodium selenite or metallic selenium.

While melting down selenium containing compounds the greatest part vaporises, however, and in gaseous state is released from the process with the exhaust gas. In the waste gas treatment plant, in part more than 90 % of the gaseous selenium compounds are precipitated, bound for example as calcium selenite and remelted. In dependence on the required glass quality, in some cases no additional entry of selenium combinations into the batch was necessary due to this measure. With concurrent measurements of the selenium content in the filter dust and calorimetry of the produced glass, for some weeks the production of white container glass was achieved exclusively by means of the filter dust as selenium carrier.

Near-Stoichiometric Combustion

The advantages of the near-stoichiometric combustion for the energy consumption or the NO_x emissions of a glass melter are obvious. Nevertheless, this measure cannot be fully used for many glasses and the respective glass quality required.

The realisation of near-stoichiometric operating parameters often represents a tightrope walk and they can effectively kept only through exact measuring and control techniques of fuel and oxidising media as well as an extensive burn-out control through O_2 or CO measurements.

In individual cases, CO concentrations occur in the exhaust gas because of the near-stoichiometric combustion. The experiences of the HVG in the field of the emission measurement technology showed that CO concentrations of 500 mg/m^3 and more in part in the chamber head of a regenerative glass melter are oxidised on their way through the regenerators again and are no more provable in the cleaned gas.

8 Summery of the project

On behalf of the Federal Office for Environment Protection, the Research Association of the German Glass Industry (HVG) elaborated a German contribution to the revision of the BAT guideline for the glass industry beginning in 2007. The major objective of the project was to investigate and document by means of reference plants the best available techniques of the glass industry in the field of the environmental control. As a basis for the project management, a questionnaire was prepared that allowed the recording of all emission relevant data, showed detailed investment and operating costs of the used environmental control measures and considered the fields of wastes and wastewater.

In total, 16 glass melting plants from the fields of container glass, flat glass, special glass, domestic glass and glass fibres were examined. As to the knowledge of the HVG these plants reflect the currently best available techniques in Germany. Many plants were visited together with representatives of the Federal Office for Environment Protection (UBA) and investigated under technical as well as economic aspects.

Due to the economically strained situation in the years since appearance of the IPPC guideline in 2000 and the substitution of plastic for glass bottles, production closures and factory closings occurred in the container glass industry sacrificing BAT plants (oxy fuel melter with raw material preheater - sideport melter with raw material preheater - LowNO_X melter). At this time the functional efficiency of the existing plants was kept normally only with scanty repairs and redesigns were not realised. In addition, the TV glass market collapsed. This resulted in the consequence, that in total five large TV screen and funnel tanks in Germany were deactivated. These plants were all equipped with SCR catalysts.

Special interest was dedicated in this project to the oxy fuel firing in order to examine new developments concerning the technical progress, the reliability, the actual reduction potential as well as the costs incurred. In the special glass field an almost complete adaptation of conventional heating to oxy fuel firing took place. Oxygen fired melters also exist in the fibre, container and cast glass sectors.

In addition, information is provided from the experiences of the HVG in order to pass on findings in anonymous form or to present current results of research projects.

The environmental problems mainly focus on the air purification. In the special glass field waste and wastewater play a bigger role than in mass glass production or in the fibre glass field. Detailed waste balances or information on the wastewater situation could be given for some reference systems in the container and flat glass sectors.

In Germany all glass furnaces are equipped with emission control plants, that largely correspond to the state of the art. Normally, electrostatic precipitators or bag filter plants with in series connected dry sorption stage and calcium hydroxide, sometimes also soda or sodium bicarbonate as sorption agents. In some cases sorption agents can be omitted. In the special glass field, there are occasionally also granulated limestone filters or wet methods for the emission control.

The dusts in the batch house and/or at the conveyance and storage of the cargoes in bulk are precipitated by central filter plants and recycled to the process in many cases. Silos are dusted during the pneumatic loading by means of so-called silo filters. Problems with keeping limit values do not occur with intact filter plants.

In mass glass manufacturing in the hollow, fibre and sheet glass field the precipitated filter dusts are almost completely added to the mixture and remelted. They relieve the waste situation of the site considerably with that. In the special glass field the filter dust recycling is practised rarely and the accumulated filter dust is used e.g. as stowage or deposited according to load with dust content.

Container glass industry

Almost 60 % of the molten glass amount in Germany is allotted to the container glass industry. Container glasses are mainly melted in regenerative horseshoe furnaces with regenerative air preheating and natural gas and/or heavy fuel oil as fuel. In addition, there exist regenerative sideport furnaces, two oxy fuel and two $LowNO_X$ melters. At one production site, the exhaust gases of the connected melting tanks are treated with an SCR plant.

The SNCR technology utilized e.g. on recuperative furnaces or on furnaces with multistage chamber system is not used.

Within the framework of the project, four reference plants of the container glass industry were investigated and the available data of deactivated plants presented.

Besides the glass colour, the furnace design or the portion of electric boosting, the specific energy demand is, as for all glass melters, strongly dependent on the age of the melting aggregates since the last main repair. In the new state, large conventional regenerative furnaces can reach values of about 3400 kJ/kg_{glass}, and for oxy fuel tanks about 3200 kJ/kg_{glass} are estimated. Smaller or medium sized tanks feature partly clearly higher specific energy consumption so that values of 6000 kJ/kg_{glass} or more can occur. The average rise of the energy consumption through furnace ageing was about 2.5 % at the reference plants.

In the field of the air purification, the required emission limit values of the TA-Luft are all kept. A sufficient amount of sorption agent is necessary for the gaseous selenium compounds representing an important emission component in the production of white glass. The NO_x emission is the most important emission component. The NO_x emissions of oxy fuel melters are on a level of partly less than 0.3 kg/t_{glass}, i.e. a specific emission corresponding to a standardised concentration of about 200 mg/m^3 in the exhaust gas of a conventional reference melter. Such low emissions can be almost achieved with LowNO_x melters or plants with secondary reduction technology.

The NO_x concentrations in the container glass industry are below 900 mg/m^3 on the arithmetic average over the last five years. Many plants already today fall below the TA-Luft limit value of 800 mg/m^3 valid from 2010; however, for some plants the values are still clearly higher. The NO_x concentrations of the reference plant 3 show that large horseshoe furnaces with regenerative air preheating and the correspondingly necessary expenditure for primary reduction technology almost achieve the NO_x target value of 500 mg/m^3.

The costs of environmental control measures for the air purification are not to be neglected with products with relatively small added value with regard to the competitive capacity. For the emission control system of large plants, up to € 4/t_{glass} have to be invested. The operation of an SCR plant can be estimated with € 2/t_{glass}. With decreasing system size and/or the tonnage of a furnace, the costs of the air purification allocated to the melting rate go up considerably.

Through the installation of heat exchangers or raw material preheaters in the exhaust gas of the furnaces considerable amounts of heat can be recovered. Heat exchanger systems and downstream plants, e.g. for the power generation, are maintenance intense and may need a precise cost benefit calculation.

The economic point of view is also the most important aspect when the use of future melting technologies are discussed, i.e. the adaptation of conventional to oxy fuel firing. The higher operating costs due to the oxygen generation or purchase costs of the regenerative melter face the smaller capital expenditure of the oxy fuel furnace.

Flat glass industry

At present, eleven float glass lines as well as two cast glass tanks are operated in Germany. While all the mentioned tanks are being fired conventionally, there is a further cast glass tank with oxy fuel firing and heavy fuel oil as fuel.

All float aggregates use sideport furnaces with regenerative air preheating and are equipped with electrostatic precipitators and dry sorption stage (calcium hydroxide).

Since the end of 2006, a plant with SCR technique has been operated.

The maximum tonnages vary between 550 and over 800 t/d according to the melter and molten glass.

The specific energy consumption of a float furnace is clearly higher than that of a highly loaded large container glass furnace. The modification in the specific energy consumption is also subjected to the negative influence of the furnace ageing.

The filter dust recycling is practised on all float lines.

The compliance of the required emission limit values of dust, SO_2, HCl and HF is unproblematic. In the production of selenium coloured glasses, attention has to be paid to the use of a sufficient amount of sorption agent, as with the container glass industry. If sodium bicarbonate is used as sorption agent, raw gas concentrations must already be present that touch the emission limit value due to the bad reaction with the inorganic fluorine combinations.

The quality requirements for the molten glass are clearly higher compared to the container glass industry. Obviously, all operators use the known possibilities of the primary measures for the NO_x reduction under observation of the quality requirements. Nevertheless, the primary methods used for the reduction of the nitrogen oxide emissions are different. It is known that effective measures for the reduction of the NO_x emissions are supported by extensive furnace designs with divided chambers. With that exact fuel/air conditions can be adjusted at the individual burner ports and monitored and controlled through zirconia dioxide probes for the O_2 measurement in the corresponding chamber heads. At the reference systems operated with fuel oil and/or a mixture of fuel oil and natural gas, the value of 800 mg/m^3 can be firmly kept.

With the Pilkington 3R process, secondary fuel is injected at the leaving exhaust gas side at the entry of the burned out exhaust gases into the regenerator in addition to the near-stoichiometric operation. Results of the measurement are not available at the HVG.

Both methods are associated with costs. The capital expenditure is presumably higher in the first case, whereas the operating costs in comparison to the 3R process are lower. The annual financial expenditure should be greater for the 3R process. However, one has to consider that a part of the added additional amount of heat can be recovered in a downstream heat exchanger and the attainable NO_x reduction rates are higher.

Whether the NO_x limit value of 800 mg/m^3 of the TA Luft can be reached for the old plants in 2010 with natural gas fired flat glass furnaces (without 3R) is currently still open. In particular, with open chamber system and standard burner and adjustment systems the installation of secondary reduction measures may become necessary. Furnace designs with open chamber system restrict the opportunity for effective primary measures for the nitrogen oxide reduction. The air distribution to the individual burner ports is defined by the design, the fuel must be adapted according to the air amount. Control mechanisms for the air distribution are difficult but to a small extent can be realised for example through so-called blocking air lances in the chamber foot.

Oxy fuel melters are not used in the float glass industry in Germany. Moreover, safeguarded information on the particular energy consumption or the service life of an oxy fuel furnace of this size is not available. The advantages in respect of the capital expenditure of the furnace are on the side of the oxy fuel technique in particular due to the missing regenerators of the sideport furnace. The operating costs including the oxygen generation on the other hand should be higher than those of the conventional firing. Thus, the efficiency significantly depends on the difference in the amount of the specific energy consumption between the two plant types, the costs of oxygen generation and the expenditure for primary and secondary NO_x reduction measures with conventional firing

Considering the oxy fuel technique from the viewpoint of ecology, the low NO_x emissions should be mentioned first. For the introduced reference systems, they are between 0.2 and 0.8 kg/t_{glass}, and at present only by means of secondary reduction measures on conventional furnaces with regenerative air preheating. The CO_2 balance should turn out for the benefit of the conventional furnace engineering if one assumes that the electric energy for the oxygen generation is gained not from nuclear power but of fossil fuels.

<u>Special glass industry</u>

In the special glass industry, the extensive adaptation of conventional furnace engineering to oxy fuel firing could be documented. The savings in the specific heat consumption of many special glass tanks are partly so great that the saving potentials for the capital expenditure may remain unconsidered. Including the oxygen costs the melting energy of the oxy fuel tank are often clearly lower than those of the conventional reference furnace for which the capital expenditure is normally higher.

With the adaptation to oxy fuel firing the NO_x emissions could be lowered drastically. In addition, operating the installed SNCR plants without ammonia injection in order to keep to the required emission limits could be achieved through continuous optimisation processes.

In the special glass field, the exhaust gases of conventionally fired furnaces have been treated by a SCR plant since 1989. In order to keep the required NO_x limit value of 1000 mg/m^3 (furnaces with nitrate usage) the catalyst with a reduction rate of 80 % has to be employed.

Often filtering precipitators (bag filters) are used for the emission control system whose particulate emission components are frequently in the range of the limit of measuring detection. In many cases, also the use of sorption agents is not needed. With the use of arsenic as batch material, special attention has to be put to the temperature regime of the filter plant so that gaseous compounds do not pass this plant and can be precipitated as particulate matter.

SO_x emissions play only a subordinate role in the special glass industry. The concentrations are mostly in the range of the uncertainties of measurement of the measuring methods employed.

Very high HCl contents partly occur in the raw gas of special glass furnaces with NaCl as refining agent. Also at these plants, the emissions fall below the limit value with proper proportioning and selection of the sorption agent. No remaining plants of the special glass sector have any problems with the HCl emissions.

Normally the HF emission is unproblematic for the special glass industry - in particular because of the very pure raw materials mainly used. Certain sections require, however, the use of fluorinated raw materials. Then appropriate sorption agents have to be used under the set exhaust gas limiting conditions and filter technologies in order to keep the emission limit value.

In the special and fibre glass sectors, very often boron containing raw materials are added to the batch. The precipitation of gaseous boron compounds may prove difficult with traditional emission control technology. The HVG is currently treating this subject within the framework of a research project for which very good reduction rates could be achieved up to now.

The waste and wastewater situation could not be sufficiently investigated within the framework of the project. According to glass type and product considerable efforts and expenditures have partly to be made in this field.

Domestic glass

Greater numbers of domestic glass are melted in continuously operated furnaces. All emission limit values, valid for the glass industry, are kept as to the knowledge of the HVG in this sector.

With the coming into effect of the emission limit values of the new TA Luft, the nitrogen oxides present the greatest challenge in particular for nitrate containing batch compositions. From October 2010 new and old plants have to keep a value of 1000 mg/m^3. Only old plants with an exhaust gas volume flow of less than 5000 m^3/h may emit 1200 mg/m^3.

Domestic glasses are produced in smaller numbers also in pot furnaces.

In pot furnaces the emission situation depends on the respective melting stage. The highest emissions occur during the feeding stages. In many cases the glass "is blown" on completion of ‘melting up to batch free time’, i.e. with the immersion of a wet wood block or a potato into the batch a powerful priming and homogenising of the melting occurs. In these stages also large concentration peaks of the individual emission components may be observed.

In Germany, all pot furnaces are equipped with bag filter plants to the knowledge the HVG. The required emission limit values can be met at these plants with proper handling and possibly additional sorption agent usage.

With the existence of gaseous heavy metal compounds attention has to be paid especially to the exhaust gas temperature level before the filter plant.

Glass fibre and mineral wool

In this branch of industry, mainly natural gas fired furnaces with recuperative air preheating are in operation in Germany. However, there are also electric and oxy fuel furnaces. In addition, cupolas are used for the melting of rock wool.

In the cupola volcanic rock, lime, additions of minerals as well as rock wool recycling material are heated up to more than 1500 °C through burning of coke. The fluid rock melt is then spun to fibre, spiked with an organic binding agent and hardened. Reliable information on the environmental control is not available.

The emissions of the two reference plants, an oxy fuel and a recuperative furnace, are below the limit values also without usage of additional sorption agents.

The NO_x emissions are remarkably low in both cases.

Additional measures for exhaust gas cleaning have to be taken in applying the organic binding agents (finishing) and for the subsequent further processing. The system size and the exhaust gas volume flows to be treated exceed those of the exhaust gases of the furnaces by a multiple. Here emission values for organic compounds have to be met which otherwise do not occur in the glass industry (phenol / formaldehyde / ammonia / entire C). The expenditures for the air purification are enormously high in the further processing.

Special waste or wastewater problems do not occur. The production wastes are either melted down or added to the product again.

In full-electrical heated glass furnaces, fossil fuel has to be used only for the initiation. During the operation the batch layer on the glass melt is melting from below and thus functions as a sorption stage. In the connection with a precipitating filter, the emissions of electrically molten glasses ("cold top furnaces") are normally on a lower level in comparison with conventionally molten glasses of same type.

Further fields of the glass industry

Besides the container and flat glass, the domestic and special glass and the glass and mineral fibre sectors, there are further fields of the glass industry.

Water glass is melted in regenerative furnaces. Often heavy fuel oil is used as fuel. The batch composition for water glass consists only of sand and soda (and/or potassium carbonate). The precipitated filter dust of the emission control plant is remelted. Soda is normally used as a sorption agent. The emissions from water glass melts contain exclusively components originating from the fuel. There are no special emission problems. For the reduction of nitrogen oxide emissions, primary and secondary (SCNR) reduction measures are utilised.

In the production of glass frit or enamel glasses, partly plants are operated where pure oxygen is used as oxidation agent. The emissions of the furnaces are on a very high level due to the substances used and the colouring components, so that for example raw gas sided emissions of HF compounds of more than 1000 mg/m^3 can occur. For this reason, very high costs are incurred for the emission control system of fossil fuel plants. In a concrete case, this means that three bag filters with sorption stages connected in series have to be employed for the emissions to fall below the required limit values. The filter dust is circulated until the enrichment with calcium fluoride reaches a measure which allows it to be processed as an aggregate in the cement industry.

Quartz glass belongs to the special glass sector. Quartz glass is electrically melted. Emissions occur exclusively as particulate vaporisation products with the entry of the fluid quartz glass into the atmosphere. The particulate compounds can be sucked off and treated.

In conclusion, it remains to be said that the various sectors of the glass industry are partly drastically different, both with regard to the molten glasses, the used melting technologies, the production techniques as well as the expenditure for emission control and/or for the waste and wastewater treating.

Also within the individual sectors there are great differences. Therefore, sector specific data such as for instance the specific emission values in kg/t_{glass} can only be estimated. The specific energy consumption of a melting aggregate significantly depends on the glass type and the quality requirements for the glass. It is decisively determined by the size and load of a melting furnace so that comparable glasses frequently require an energy demand distinguished from each other by around the factor 2.

For this reason, for the evaluation of a glass melting plant with regard to environment-relevant aspects individual consideration is necessary. Reference plants can only be referred to if balance boundaries are set which allow a realistic juxtaposition.

Offenbach, March 2007

Project manager

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