Melting and Modeling

EXPERIENCES WITH AN OXYGEN-FIRED CONTAINER GLASS FURNACE WITH SILICA CROWN - 14 YEARS A WORLD RECORD?

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ABSTRACT
Fourteen years ago the introduction of oxy-fuel combustion in glass melting technology in the Dutch glass industry was started. This paper refers to the first oxy-fuel furnace in The Netherlands, and the experiences with a silica crown. First an explanation about the environmental legislation in The Netherlands is given, which lead to the installation of this first oxy-fuel furnace. This is followed by a description of this first full scale oxy-fuel implementation and the experiences with emission reduction, energy consumption, refractory wear and glass composition in this furnace.

DUTCH ENVIRONMENTAL REGULATIONS:

At the end of the 1980's the government in the Netherlands made, compared to European standards, extensive plans to protect the environment and stimulating a more efficient use of our natural resources. The national environmental plans focused on the reduction of the emissions of components that cause acid rain like SO_x and NO_x, but also dust emissions and energy consumption should be decreased. Based on these plans the Netherlands Emission Regulations (NeR), with a special glass paragraph were developed in 1992-1993 and also the glass industry was invited to make a multiple year agreement to improve in a systematically and programmed way the energy efficiency of their processes.

In the early 90's the Dutch glass industry was already faced with large investments for end of pipe technologies in case NOx-emissions had to be reduced to levels which can not be reached by conventional primary measures only. At that same time, increasingly, oxy-fuel technology was developed and implemented in the United States. The Dutch glass industry, united in the VNG, decided to investigate, in cooperation with TNO-TPD in Eindhoven (Prof. Beerkens), the possibilities of introducing oxy-fuel technology in the Netherlands. A trip was made to the United States to visit several glass companies that already implemented oxy-fuel combustion technology.

The glass industry discovered in oxy-fuel a process integrated technology for the reduction of NOx, which could also improve the energy performance of the furnace and/or glass quality and melting loads could be increased by application of oxygen firing. This in contrast with the end of pipe technologies, like SCR and SNCR, which did not add to the performance and efficiency of the furnace and therefore could never be cost effective.

Because of the process-integrated character, the government was also interested in the oxy-fuel technology. They were willing to finance a demonstration project with a full-scale industrial oxy-fuel fired glass-melting furnace. The conditions of this financial support were that experiences with oxy-fuel should be shared with the other companies within the Dutch glass industry.

The glass industry was given the freedom, within the NeR, to choose between two different tracks to reduce the emission levels: First the reduction of NO_x-emission by implementing oxy-fuel (NO_x down to less than 1 kg/ton of molten glass), a technique that was developing in those days for most glass industries, followed by the reduction particulate emissions by the introduction of dust filters or electrostatic precipitators. The other track contains the same measures only in a different order. Mentioned in these regulations was, that instead of oxy-fuel firing improved lonox measures also could be implemented, if this would lead to similar emission values.

Both tracks should be completed in 2010, with an intermediate deadline in 2003 for either one of the measures. Negotiated was the fact that these extensive measurements could be implemented only at major cold repairs of the glass melting furnaces.

THE FIRST OXY-FUEL FURNACE:
In 1994 the L4 container glass furnace of O-I, at that time N.V. Vereenigde Glasfabrieken, was up for a rebuilt. The existing recuperative furnace was old and had a poor energy-efficiency. Also the building was not suitable to hold a regenerative furnace, either end or side-port, for the required production volume. For these reasons and the stricter emission limits it was decided to build an oxy-fuel furnace. For this ambitious project several partners were sought.

For the furnace design, Owens-Brockway was consulted, because of their long-term experience in developing new furnaces. They supplied the design of the furnace and the exhaust system. Owens-Brockway engineered the furnace steel and refractory and made the specifications of the flue gas system.

The flue system is designed to cool down the flue gases gradually to avoid early condensation of sulphates and protecting the stack, because there was no heat recovery system installed like regenerators. They also made a heat balance with their recently developed heat balance program for oxy-fuel furnaces.

The expertise for the on site production of oxygen and the supply of the oxygen (valve trains, burners, etc.) was delivered by Air Liquide. They supplied a VSA-unit (Vacuum Swing Absorption-unit) with a capacity of 2100 nm^3/h oxygen (calculated to 100%) with a purity of 91 % ± 2%. Later this capacity was reduced to 1500 nm3/h, to use the installation more efficiently. To ensure uninterrupted oxygen supply a liquid oxygen tank with a capacity of 70.000 litres and evaporators was installed.

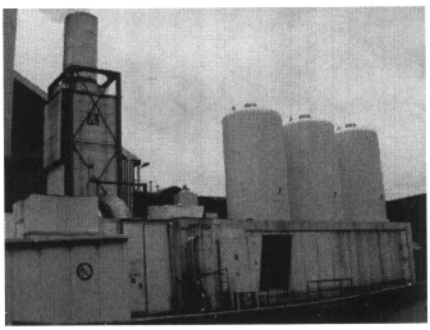

Figure 1: VSA-unit

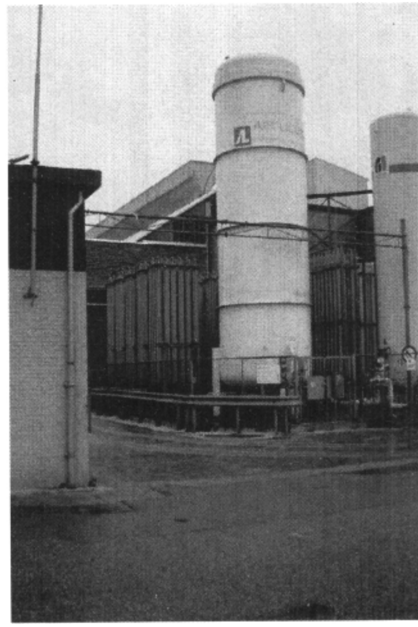

Figure 2: Back-up tank and evapora-

They also supplied the burners (1st generation pipe in pipe) and burner control system. In addition the oxygen supplier provided a model calculation of the combustion space with their ATHENA ® modelling tool. See figure 3 for an example of their modelling of the crown temperatures and the actual temperatures.

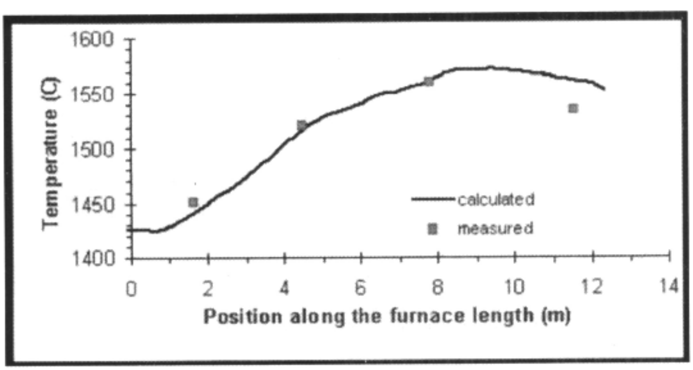

Figure 3: Calculation crown temperatures.

The furnace:
During the rebuilt of the L4 the melting area of the furnace was increased with 17% while the melting capacity increased with more than 25%. (see table 1)

Table 1: Furnace conversion data.

	Unit melter	Oxy-fuel
Melter Area	64 m^2	75 m^2
Length : Width ratio	1,9 :1	2 :1
Glass depth	0,9 m	0,9 m
Fuel	Natural gas	Natural gas
Boosting capacity	800 kW	800 kW
Burners	8 per side (opposite)	6 per side (staggered)
Burner capacity		6 of 1MW 6 of 0,5 MW
Melting capacity	136 ton/day	>200 ton/day
Glass colours	Amber, emerald green	Amber, emerald green
Products	Beer bottles, jars	Beer bottles, jars

The furnace was build in April 1994 and has been in production since. This makes it probably the longest running all oxy-fuel fired furnace, without a cold repair, in the world.

ENERGY EFFICIENCY:
The energy performance of the old L4 was poor (7200 MJ/ton), due to the low air preheat temperatures and poor insulation. The efficiency was improved with about 50%. To get a fair comparison, the specific energy demand was compared with 2 end-port furnaces (table 2). The end-ports used in the comparison belong to the most energy efficient furnaces in the world, which was shown by a benchmarking study in the Netherlands, done by TNO Eindhoven, which included over 100 furnaces world wide. The results are shown in figure 4.

Table 2: Furnace comparison data.

	Oxy fuel	End-port	End-port
E-Boost	YES	YES	NO
Glass colour	amber	green	amber/green
% cullet	77 %	79 %	74%
Pull (T/m2/day)	2,9	2,9	2,6

Compared to a modern end-port furnace, you can see that although energy is needed for the production of oxygen, the efficiency of an oxy-fuel furnace is comparable to a conventional end-port furnace. In this case the electrical power is not is not recalculated to primary energy.

However, since the costs of electrical power in The Netherlands are higher than those for Natural gas you can see in the same graph that the oxy-fuel is less cost efficient.

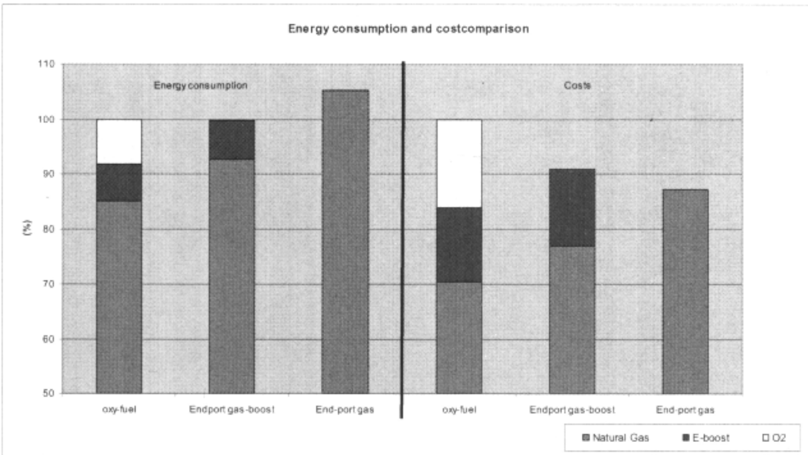

Figure 4: Energy consumption and energy cost

Over the years several comparisons were made to investigate the advantages and disadvantages of oxy-fuel firing. The ageing of the furnace was compared to the end-port furnaces, which were used for the energy comparison. As one can see in the graph below the ageing of an oxy-fuel furnace is less than that of a conventional furnace. As conventional end-port show an energy consumption increase of about 1 to 1,5% per year, the oxy-fuel furnace showed no ageing. The main reason is the lack of regenerators which loose efficiency because of fouling.

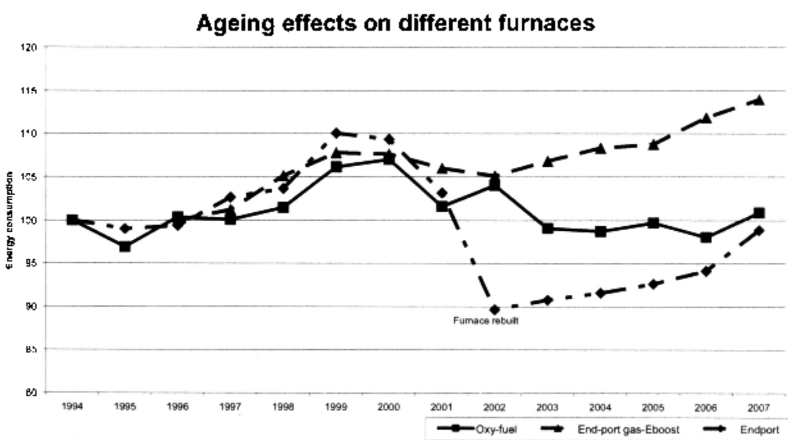

Figure 5: Ageing comparison between an oxy-fuel furnace and 2 end-

ENVIRONMENTAL ISSUES:
Comparing the emission data (see table 3), you can see much lower NO_x-emission levels for the oxy-fuel furnace compared to the "air" fired furnace. The higher SO_x-emission and dust emission is mainly caused by the colour of glass produced in the oxy-fuel furnace with higher surface temperatures and high sulphate in the batch. Also the higher flame temperature and water content in the flue gases cause increased evaporation rates and concentrations of glass components in the flue gases are higher. The figures in this table are given in kg/ton of molten glass, because of the lower flue gas volume. Because of the much smaller volumes of flue gas (hardly any nitrogen from air) per ton molten glass, the concentrations of the emitted components are higher than the flue gas concentrations in air-fuel fired furnaces. Typically the amount of flue gas per ton molten glass decreases by a factor 3-4.

Table 3: Environmental data

Component	Oxy-fuel	End-port
NO_x	< 0,90	< 1,80
SO_x	< 1,10*	< 0,60
Dust	< 0,20	< 0,10 (without filter)
F	< 0,004	< 0,001
CL	< 0,05	< 0,013
Lead	< 0,01	< 0,01

* Due to higher input of sulphate required to obtain the desired glass colour

The NO_x-emissions were influenced over the years by increased infiltration of cold air, either coming from the cooling wind or the furnace camera. Proper sealing of the joint between the sidewalls and the tuck stones and conscious use of camera purging air reduced the influences of these factors.

Because Dutch (low calorific) natural gas contains 12-14 % of nitrogen, lower values than the furnace emitted were at that moment difficult to reach. With high calorific gas (no N_2) and 100 % oxygen it is possible to reach NOx-emission values lower than 0,6 kg/ton of glass.

Recent developments in the conventional furnaces (lonox burners, port design) make it possible to reach similar emission levels for NO_x as oxy-fuel firing as well as similar energy consumption.

REFRACTORY WEAR:
A short time after start-up the first problems with superstructure refractory wear occurred. Dripping of refractory corrosion products was observed in front of the burners and peepholes. Also grooves originating from the silica crown became visible. After a few months wear on joints in the silica became visible.

All this resulted in a stoning problem in the finished product. Due to the chemical composition of the stones, they were called "Zacoline." Investigations were started and the flue gas composition was checked. Due to the lower flue gas volume, the concentration of volatile components in the flue gas was found to be3-5 times higher compared to a conventional furnace, especially sodium hydroxide. Also the water content of the flue gasses was higher, 50% compared to 18% for a conventional furnace, because of the absence of large quantities of nitrogen in the combustion process.

Also the required crown temperatures for good melting appeared to be very low (<1400 °C) at that time, because the heat transfer to the glass bath was excellent. All this resulted in a deep penetration and reaction of sodium hydroxide with the silica from the silica crown, forming low temperature melting sodium silicates. The reaction between sodium hydroxide vapours originating from the melt and silica takes place below a certain critical temperature, depending on the sodium hydroxide concentration. In oxygen-fired furnaces the NaOH concentration is very high and this limits the temperature window for the crown: the temperature has to be controlled between 1460 and 1600 °C. In an air fired furnace the window is wider, typically: 1380-1600 °C.

In the colder areas of the silica crown the silica is attacked by NaOH vapours forming rat holes and relatively cold open joints, this will enhance the reaction process. The reaction products can melt during temperature changes.

During pull changes the temperature of the crown changed and silica melted of the crown and was running over the AZS material of the superstructure. This resulted in the grooves in the AZS and stones containing Al_2O_3, SiO_2 and ZrO_2.

After these observations and experiences the crown temperature was kept constant above 1470 °C. Also the temperatures were kept stable during pull changes.
This resulted in a decrease of silica wear, but it never stopped completely, which resulted in extensive maintenance over the years. Since 1997, every year, some hot repair work has been done on the crown, mainly ceramic welding and a complete overcoat of the crown with a concrete layer. (figures 6 and 7)

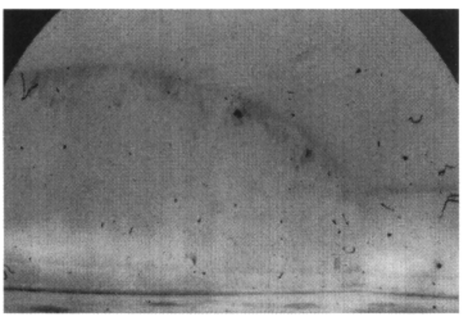

Figure 6: Condition crown and bridgewall in 2002.

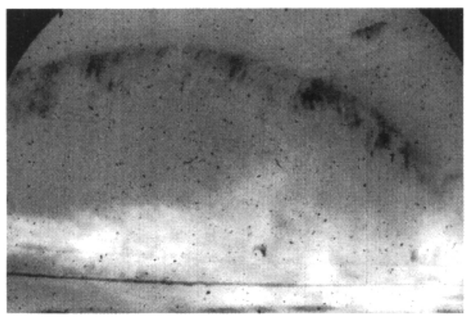

Figure 6: Condition crown and bridgewall in 2002.

OPERATING THE FURNACE:
Because oxy-fuel firing provided a very new technology to the glass industry in the Netherlands, people in the plant had to learn a new set of safety rules, coming from working with oxygen. Extra attention was needed, to work with clean tools and clothing, to make sure no dust or oil residue would come into contact with the oxygen.

The furnace was also equipped with extra safety features to make sure that firing the furnace with oxygen was safe. These safety features included extra control of refractory temperature (extra thermocouples in breast walls and flue gas channel) and furnace pressure. Alarms would trigger the combustion system to run in so called "idle" mode (reduced firing with less burners) or to a complete shutdown.

Because external safety is a major concern of all companies, extra safety measures had to be taken for the storage of the liquid oxygen. All oxygen installation are checked on a yearly basis by an outside company specialized in this kind of inspections. Thanks to all the measures taken and responsible behaviour, no issues with safety have been report in the last 14 years.

Looking at the costs, it is obvious that making oxygen compared to the use of air as an oxidant has its price. Calculations for this furnace were made to investigate the economic feasibility of an oxy-fuel furnace compared to a conventional furnace. The oxy-fuel option was, in this case, compared to a conventional end-port furnace, taking into account the reduced investment (no regenerators, no construction changes in the building), reduced construction time and the energy savings, but also the variable costs for the oxygen production. At that time with the funding of the government, the project was feasible.

At this moment we can see, from our practice that by proper maintenance, good control and early repairs of open joints or holes, it is possible to have a similar lifetime like conventional furnaces of over12 years.

GLASS PROPERTIES

Beside the stoning problems, which were mentioned before, there were some glass property related issues. The water content in the glass changed to a higher level after the conversion of the recuperative furnace to an oxygen fired one. This was caused by the higher water vapour pressure above the melt. The higher water content in the melt had some influence on the workability of the glass. The viscosity of the glass was not the same and changes in the batch composition were necessary to correct this. Some batch modifications appeared also to be necessary in order to stabilize the glass colour in the oxygen fired furnace. Due to different redox conditions in the glass and combustion space, salt cake and carbon amounts and ratios had to be changed.

OTHER OXY-FUEL EXPERIENCES AT O-I IN THE NETHERLANDS:

In 1997, O-I build a second oxy-fuel furnace in its Schiedam plant, similar to the 1st oxy-fuel furnace, with some improvements in the refractory design and choice of materials, except for the crown material. Burners, controls and oxygen supply are the same as in the first oxy-fuel furnace.

Experiences in the second oxy-fuel furnace of O-I show that design changes and a different material choice as well as steady control (from the start) of the furnace temperatures can reduce the refractory wear. Still small joints can cause refractory problems and holes should be repaired as quickly as possible.
After 11 years the first extensive crown repair has been done. Damage to the crown was caused by fluctuating conditions as a result of a plant fire and power failure.

CONCLUSIONS:

Looking at the experiences in the past 14 years, oxy-fuel could be considered as a possible alternative for the reduction of NO_x-emissions for the future when the economical issues are resolved.

Although not all the refractory problems are completely solved we can conclude that oxy-fuel is an acceptable alternative to reduce NO_x-emissions below 1 kg/ton of molten glass in the container glass sector. Even with a silica crown acceptable life times can be reached when process conditions are kept stable and the furnace is maintained timely and properly.

The refractory problems are limited mainly to the combustion space and this can be reduced by improved design, steady conditions and proper maintenance.

An oxy-fuel furnace can be run for a longer period of time, even with a silica crown.

A combination of the right design and handling of the furnace can lead to lifetimes longer than conventional furnaces, because of the steady conditions wear on other parts like sidewalls can also be reduced.

Observations in the L4 showed that glass problems can be solved by adaptations of the batch and steady conditions in the furnace.

Still one issue keeps unresolved to make oxy-fuel furnaces the successful solution for the future. These are the costs for the production of oxygen. For this, a full conversion to oxy-fuel should be checked on economic feasibility in each individual case.