# Oxygen and natural gas preheating for oxy-float glass

Air Liquide and AGC Glass Europe have collaborated to develop a new technology based on oxy-combustion, combining a heat recovery equipment that provides a furnace with preheated oxygen and preheated natural gas by recovering energy from the flue gases, with a new generation of staged oxygen burner named Alglass Sun. Youssef Joumani*, Bertrand Leroux**, Antonella Contino***, Olivier Douxchamps**** and Johan Behen***** report for *Glass International*.

Heat recovery in air-firing conditions is a standard element of glass furnace design. Regenerators are complex devices with high investment costs related to whether they are common or multiple, from the choice of brick shapes to the height of the regenerator. Recuperators are the other main type of system used to recover heat from flue gases. The air temperature reaches from 700°C (recuperators) to 1250°C (regenerators), which amounts to up to one third of the power injected into the furnace.

Other methods investigated for increasing the efficiency of glass furnaces include oxygen combustion, batch preheating, submerged combustion, electricity production, boiler applications and syngas generation [1]. A well-known technique involves using full oxygen for combustion, thus avoiding the nitrogen responsible for $NO_x$ emissions.

Thus, combining heat recovery and full oxy-combustion is seen as the ideal solution for Air Liquide and AGC Glass Europe. This technique yields the benefit of oxy-combustion effectiveness, further increases energy efficiency, improves $CO_2$ and $NO_x$ reduction and has an attractive payback time.

## Fuel consumption gain

To understand the effects of oxygen temperature and natural gas temperature on burner efficiency, consider a burner providing 1MW by using 100 Nm³/h of natural gas with a low calorific value of 10kWh/Nm³. When oxygen is preheated to 550°C and natural gas to 450°C, extra energy is introduced into combustion. Replacing fossil fuel power directly with this energy reduces the combustible requirement by 6%, to94 Nm³/h.

However, this simplified fuel reduction calculation does not take into account the combustion mechanisms. Because oxygen is preheated, combustion starts earlier and flame efficiency is better. In addition, separated jet technology allows increased flame size and thus lower fume temperature than with cold reactants.

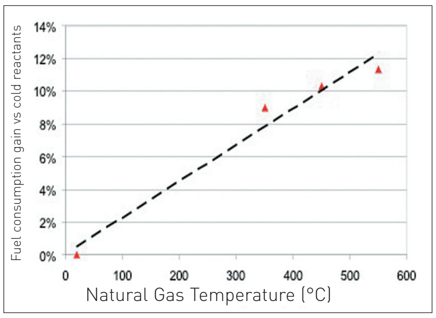


Fig 1. Measured fuel consumption gain vs natural gas temperature for oxygen at 550°C.

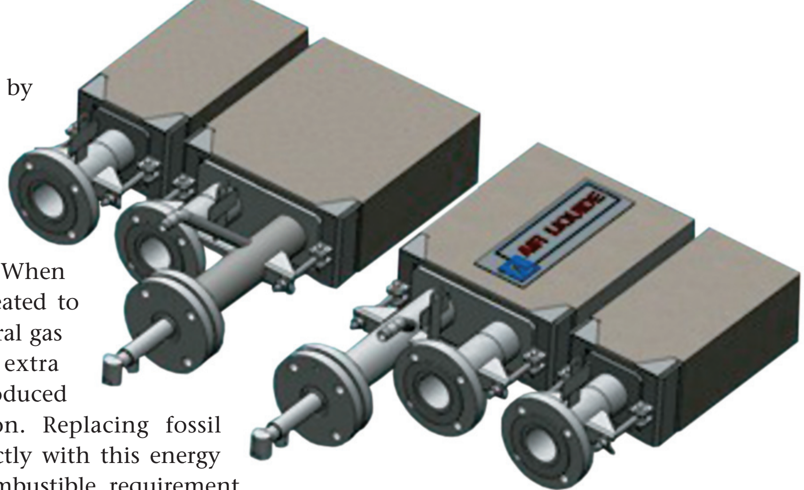


Fig 2. The Alglass Sun burner.

The difference in fume enthalpy is such that it induces a further decrease in fuel consumption, by 4%, thus leading to a fuel consumption gain of 10% as demonstrated by pilot trials when oxygen is at 550°C and natural gas at 450°C (***fig 1***).

## Separated jet burners

The Air Liquide separated jet burner called Alglass Sun (***fig 2***), which has been tested in several oxy furnaces [2], has been adapted to work with high-temperature reactants. Because of the high temperatures to which the natural gas and oxygen are preheated, they cannot be premixed: $CH_4$ self-ignites at 550°C in pure oxygen, while species like $C_2H_6$ and $C_3H_8$ burn at 470°C in as a little as 2.3% oxygen. Front flame speed

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does not play an important role, as traditional velocities of reactants are approximately 20 - 70m/s. The burner has the following main characteristics:

- Two fuel lances, allowing an easy switch from natural gas and fuel oil depending on the costs of the combustibles. Such switching is very common in glass factories.
- High oxygen staging for better heat transfer and adjustability of flame shapes and $NO_x$ level. The typical level of $NO_x$ measured in our pilot furnace is 100ppm when oxygen is equally distributed between the four oxygen injectors. It goes down to 60ppm when 75% oxygen is distributed to the two extreme injectors. There is obviously a limit because when $NO_x$ decreases, the CO levels in the fumes increase. At 75%, the CO generated in the rich zones of the flame is burnt by the oxygen in the lean zones. At higher staging than 75%, CO increases dramatically and may reach 500 - 1000ppm because of an inadequate distribution of $O_2$ in the fuel-rich zones.
- The burner is made in four blocks but can be manufactured in one or two blocks. The multi-block concept allows adaptation of the burner position as a function of furnace constraints.

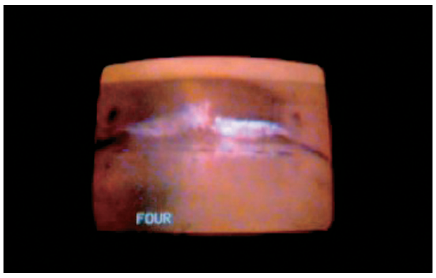


Fig 3. Alglass Sun flame in the AGC furnace.

## Oxygen preheating technology

At standard temperature, most standard metallic materials combust very easily in an oxygen-enriched atmosphere. To avoid this, EIGA has set rules on oxygen use [3]: For example, the maximum velocity allowed in pipeline at pressure below 10 bars is 60m/s to minimise the energy available for ignition in case of local overheating by viscous heating or particle impact.

However, ASME and EIGA expertise mostly focuses on temperatures below 200°C. To analyse oxygen hazards, AGC Glass Europe and Air Liquide have carried out several studies with top institutes and experts to obtain optimum know-how.

Fig 4. Alglass Sun burner installation.

## Collaborative studies

Firstly, a set of 10 assorted metallic and non-metallic materials was exposed to cyclic oxygen flow in order to accelerate oxidation and corrosion. Each sample was subjected to 1000 one-hour cycles.

Through these experiments, we identified a range of five to eight materials that underwent ignition tests in a hot oxygen chamber to shed light on ignition conditions at 2 bars. The protocol of these lab-scale experiments was the one defined in ASME guidelines for measuring the exemption pressure of a material in contact with a pure oxygen flow. Some materials were excluded because their flammability properties against preheated oxygen were too low with threshold pressure close to 3 bars.

The materials that properly withstood cyclic oxidation and promoted combustion were exposed to a flow of hot oxygen for more than one year. From this sequence of tests, monitored by an independent expert, the conditions for heat exchanger design and safe use of hot oxygen were clearly defined.

## Air/$O_2$ exchangers

Once suitable materials were chosen, a lab-scale pilot exchanger was designed and tested at an Air Liquide research centre over several months. In the absence of fumes, an electric preheater was used to heat 66 $Nm^3/h$ of air to 700°C. Calibrated orifices were installed inside the pilot exchanger to test the effect of oxygen velocity on oxidation and corrosion.

Several step changes were carried out on oxygen flow, air flow and air temperature to examine how oxygen temperature varied as a function of these parameters. For example, it was shown that reducing air flow by 25% might decrease oxygen temperature by only 15°C. At 50% of the nominal oxygen flow, oxygen temperature varied by about 60°C for a given air flow.

These tests enabled us to determine how to adapt air flow for a given $O_2$ flow. Particular focus was given to insulation, i.e. type, thickness and mounting procedure.

## Natural gas preheating

The use of hot natural gas is known in the chemical industry. Natural gas is heated up to 400°C in an exchanger, using process exhaust gas or by direct exchange with flue gases. However, there is large difference between this and the characteristics of our technology: The natural gas is at several bars instead of 2 bars, and the natural gas is heated by flue gases at around 1200°C rather than by air.

A dedicated air/NG exchanger was designed using materials compatible with preheated methane. Metal dusting and the compatibility of materials in a hot reduced atmosphere (carbon atoms are high reducing agents) were taken into account in the choice of materials.

Before finalisation of the design, risk analysis concerning the use of preheated natural gas was conducted and a number of recommendations were acted on.

## Pilot tests

After validation of the Alglass Sun burner at Air Liquide's Claude Delorme Research Centre, the first validation

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Fig 5. Air/fumes recuperators.

campaign at industrial scale was carried out. Port #1 of an AGC Glass Europe furnace was converted to oxygen by installing two Alglass Sun 4MW burners face-to-face (***fig 3***). Air flow was stopped and oxygen controlled by an extra skid.

This demonstration, using preheated natural gas, was a success. The temperature increase of the furnace walls due to oxy-combustion was less than 30°C.

A second validation campaign was organized for the air/$O_2$ exchanger and the Alglass Sun burners with preheated oxygen. Several parameters of the burners were tracked: Effect of oxygen distribution (50% or 75%); fuel type (natural gas or heavy fuel oil); and nozzle tip (single injection or multiple injections).

During this campaign, the two natural gas lines were preheated electrically. A fuel consumption gain of approximately 10% was measured when using preheated reactants (***fig 4***). The typical flame size was 4 x 2 metres. Staging the oxygen to 75% induced a two-metre increase in flame length. The coverage of the batch was fully controlled by this means.

The operators were able to use fire adjustment to manage foam, glass quality and batch line perfectly. Special attention was paid to soot formation to check whether natural gas cracking occurred in the pipes. After three weeks of operation, no soot was observed at the gas lance tips.

## Industrial results

In 2008, a newly rebuilt AGC Glass Europe furnace was equipped with Air Liquide Alglass Sun burners and with the complete package of heat recovery equipment (***fig 5***). Oxygen and fuel skids (***fig 6***) were commissioned from Air Liquide's ALTEC technical centre in Krefeld, Germany.

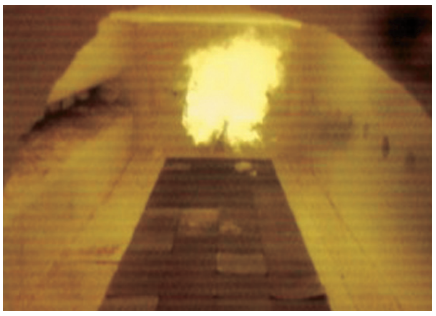
After the furnace was heated up, the burners were successfully started one by one. A short period was dedicated to cold $O_2$ operations, with particular attention to the behaviour of the furnace and the interaction between oxy-combustion and glass bath. Operators used to working with air firing learned to operate their furnace in oxy-firing conditions. To completely master the process they had to understand oxy-flames and make the links between burner power, flues gas temperatures and $O_2$ concentration in fumes. Thanks to good preparation, the transition was efficient.

▲ Fig 6. Air Liquide oxygen skid.

During this time, the flames were observed continuously. Although the burner was designed for hot reactants, it was shown that the flames remained stable and straight enough in cold reactant configuration (as illustrated by ***fig 7***). After this short period, the air/$O_2$ heat exchangers were started. With preheated reactants, the flames were straight and luminous, covered the batch well and did not overheat the crown. Flame lengths were as predicted: Four to six metres long, depending on the burner's location and power and the nature of the fuel.

As Alglass Sun burners provide wide flames, no CO was observed in the flue gases. With good management of the furnace settings, it was possible to switch from cold $O_2$ to hot $O_2$ without changing the operating mode. Furnace operators were able to deal perfectly with potential extra foam, batch line change and crown overheating.

After this step, natural gas was successfully preheated to 400 - 450°C. $NO_x$ emissions have been measured several times by the relevant government agencies and a minimum of 75% reduction was observed in comparison with air conditions. The decrease in $CO_2$ emissions, even taking into account $CO_2$ emitted by $O_2$ production, is near the target of 15% compared with air. The fuel consumption target using preheated oxygen and natural gas is a 25% gain over air. The results are already close to this value and the objective is to reach it this year.



▲ Fig 7. Cold oxygen and natural gas.

## Conclusion

This article has presented the results of the industrial full-oxy conversion of a float glass furnace belonging to the AGC Glass Europe group. It has described the technology of oxygen and natural gas preheating and staged oxy-combustion.

The joint project succeeded in solving all the technical challenges posed. Alglass Sun burners were installed and started successfully, operating today with preheated natural gas and preheated oxygen. The team is close to reaching the target fuel consumption gain (vs air firing) of 25%. Achievement of such a gain would make it feasible to envisage converting float glass furnaces worldwide to full oxy.

In addition, thanks to oxygen staging of the Alglass Sun burners, low levels of $NO_x$ have been reached, with a 75% reduction in $NO_x$ emissions observed (vs air). ■

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**[2]** B. Leroux, J-F. Simon, A. Poirier, G. Constantin, Y. Joumani, R. Tsiava, First industrial results of ALGLASS SUN operations, XX Glass Problems Conference, 2006.

**[3]** EIGA, Oxygen pipeline Systems, IGC Doc 13/02/E.