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Oxygen Technologies for Recovery & Boosting of Glass Furnaces

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ABSTRACT

Oxygen in the form of enrichment and lancing has been used for many years to recover lost production. Oxy-fuel boosting can provide up to 10% additional capacity. This paper will review these traditional technologies and, using referenced case studies of gas-oxy installations and at least one oil-oxy instillation, identify how production increases of up to 50% can be achieved by utilising BOC's patented Convective Glass Melting [CGM] crown mounted oxy-fuel burners. The CGM system offers glassmakers the opportunity to boost and also convert, on the fly, an air-fuel melter into a hybrid air-oxy-fuel melter, introducing up to 50% of the energy by oxy-fuel and the remainder by conventional air fuel.

Oxygen Combustion – The Fundamentals

Combustion Process

$CH_4 + 2\,O_2$ ------------> $CO_2 + 2\,H_2O$ (2643°C Natural Gas)
1mole + 2 moles ------> 1mole + 2 moles = <u>3 moles Total Exhaust</u>

Air = 20.9% O_2 + 79.1% N_2, 1 mole O_2 equivalent = 100/20.9 = 4.78 moles of air

CH_4 + 2 [Air] ------------> $CO_2 + 2\,H_2O + 2*(79.1/20.9)\,N_2$ (1941°C Natural Gas)
1mole + 9.57 moles --> 1mole + 2 moles + 7.57moles = <u>10.57 moles Total Exhaust</u>

Summary
Oxygen is significant lower volume than equivalent air
Oxygen produces a higher flame temperature than air

Oxygen Enrichment

Enrichment is the most basic form of using oxygen in glass melting applications. Enrichment is typically used in a furnace nearing the end of its campaign which is suffering from regenerator plugging or collapse. This regenerator damage will have resulted in a likely increase in furnace pressure, reduction in air pre-heat temperature necessitating more fuel and oxidant which in turn exacerbates the increase in furnace pressure. Ultimately the furnace pressure will be too great for the now required gas and air flow which will result in a reduction in glass pull rate. The application of oxygen by enrichment will result in a lower volume of exhaust gases. The most noticeable affect of introducing oxygen to replace air will be a reduction in furnace pressure allowing the regenerators to breathe again. The lower volume of exhaust will have an increased residence time in the regenerators and will increase the pre-heat temperature allowing a small reduction in fuel usage. The reduction in furnace pressure will enable additional fuel to be applied to the furnace to enable the melting of previously lost, “Recovered” tonnage.

The installation of an enrichment system is by the relatively simple method of injecting oxygen downstream of the combustion air fan prior to the reversal valve. The oxygen compatability of the materials of construction of the reversal valve is frequently the limitation of the maximum concentration of the enriched oxygen stream that can be used in the furnace. This is probably the most inefficient use of oxygen since the increased percentage oxygen goes to all burners and regenerator ports.

Enrichment is typically used on regenerative furnaces firing on either oil or gas and is applicable to all glass types. In the case of a recuperative furnace consideration should be given to injecting the oxygen downstream of the recuperator since this may be a source of leakage.

The recovered tonnage enables the furnace to operate above the minimum for profit but more importantly extends the furnace life which will provide the capital avoidance of delaying a repair.

Waste Oxygen [WOx] Enrichment

A type of enrichment that is almost unique to the Float Industry is the use of Waste Oxygen [WOx] from an on-site Nitrogen [N2] Generator dedicated to the Tin Bath. The oxygen concentration from an N2 Generator is typically less than 40% O2 by volume and is site specific. The balance of this gas is Nitrogen and Argon. Whilst the volume is not large the increased percentage of oxygen has been used on numerous occasions to improve the energy efficiency of the furnace. The modest costs associated with accessing the WOx entail a small blower to move the stream to the furnace area, the associated electrical power and ductwork between the nitrogen plant and point of use.. . This is a type of enrichment that is ideally addressed during the construction phase of the furnace since capital costs can be reduced through suitable plant layout design and are spread over the entire furnace campaign. The benefits obtained are dependent on both the nitrogen generator plant and the furnace operation however up to 2% energy savings can be achieved.

Oxygen Lancing

Oxygen lancing is used in similar situations to enrichment however is typically associated with more severe or complex conditions. Lancing is the precise injection of oxygen to the point where it is most needed. Typically close to the furnace in an under-port or through-port location or even through a target wall. Whilst enrichment is indiscriminate in its injection and is less efficient, more total oxygen may be injected through lancing since it does not face the compatibility issues of the reversal valve and associated duct-work.

In the event of a partial regenerator collapse or increased pluggage at a specific port, lancing provides the ability to inject the oxygen at the port which is most effected. Through appropriate control systems there is additional flexibility to inject more oxygen on one side than the other depending on regenerator condition. The biggest limitation of a lancing system is the complexity and cost of the control system and field installation.

Lancing is typically used on regenerative furnaces firing on either oil or gas and is applicable to all glass types.

Oxygen Boosting

The difference between boosting and enrichment/lancing is that in addition to the injection of oxidant there is the addition of fuel as well in the case of boosting. Whilst boosting technologies can be used for Recovery and Furnace life extension their main goal is, in addition, to increase the furnace through-put and/or improve quality. The following technologies are examples of boosting.

Hot Spot Boosting

Hot spot boosting is typically limited to end-fired regenerative furnaces however can also be applied to unit melters or recuperative furnaces firing on either oil or gas and is applicable to all glass types. Typically, two conical oxy fuel burners are positioned at the furnace hotspot. By placing the burners at this position there is the opportunity to enhance the glass convection currents which improve glass residence time and increase quality. The addition of more fuel means that more glass can be melted in the same furnace. It should be noted that typically there will need to be a small reduction in the air fuel flows in order to allow the exhaust system to handle the additional volume from the oxy-fuel burners.

Hot spot is typically used on end fired regenerative furnaces firing on either oil or gas and is applicable to all glass types. It is possible to increase furnace through-put by up to 10% using hot spot boosting. Since the impact on the existing air fuel regenerator or recuperator is minimal there is the opportunity to switch off the oxy boosting when it is not required at lower tonnage. Alternatively, depending on relative energy costs, the oxy-boosting can be used to lower electric boost.

CONVENTIONAL ZERO PORT BOOST TECHNOLOGY

The use of oxy-fuel burners to boost glass furnaces is a proven technology, specifically in float furnaces that normally incorporate a 2-4 meter distance between the charge end wall and the first port jamb block. Figure 1 illustrates the application of this boosting technology.

The fifty furnaces worldwide that have implemented conventional zero port oxy-fuel technology over the last five years have provided the industry with significant understanding of oxy-fuel boosting's capabilities and limitations. The addition of 10-15% more energy into the furnace in the critical melting area can result in an increase in pull rate, quality and furnace life.

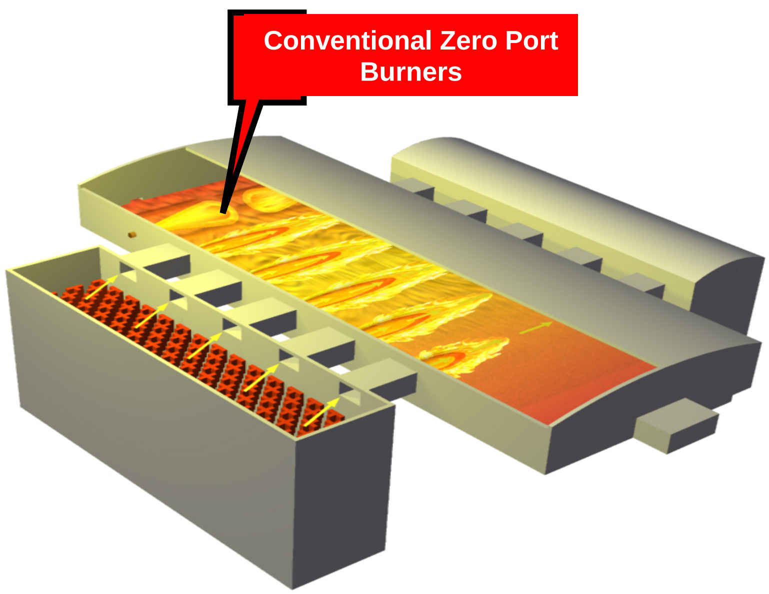


Figure 1

Glass Furnace utilizing
Conventional Oxy-Fuel Boost Technology

The results of oxy-fuel boosting have been mixed at times primarily due to a failure of the parties involved to establish a defined objective prior to installing the boost systems. The four most common reasons for installing oxy-fuel boost in glass furnaces are to:

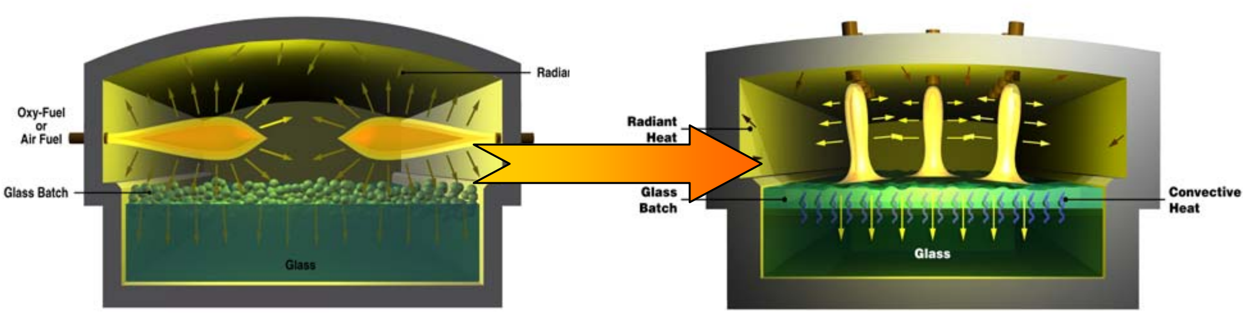
- Increase pull rate
- Improve product quality
- Extend furnace life due to regenerator checker failure
- Extend furnace life by preventing regenerator checker failure.

Each of these objectives requires a different approach for adapting oxy-fuel boosting to a regenerative furnace. For example: when increasing the pull rate of the furnace, the batch entering the charge end of the melter absorbs most of the additional energy supplied by the oxy-fuel burners and the air-fuel combustion system remains essentially unchanged. However, when extending the life of the furnace due to regenerator checker failure, the objective is to minimize the overall products of combustion within the system. To be most effective, the applied oxy-fuel energy must be removed on a total or overall basis from the air/fuel port energy, since there are very limited means of reducing the air flow on a given port. This may require a change in the furnace temperature operating schedule.

CONVECTIVE GLASS MELTING (CGM) TECHNOLOGY

The zero port breastwall area limits the amount of energy that can be introduced from conventional boost technology (Figure 2). If this limited production, quality, or life extension is sufficient to meet the glass manufacturer's objectives, then conventional (breast wall mounted) combustion is the preferred technology

BOC's Convective Glass Melting (CGM) technology (Figure 3) increases in the rate of heat transfer to the batch and thus increases the rate of melting. This benefit removes many of these limitations of conventional zero port boost and can provide increased performance improvements to many glass melters. (Refer to GPC 2001 CGM paper)



Conventional Oxy-Fuel Melter

Figure 2

CGM Oxy-Fuel Melter

Figure 3

BOC, in cooperation with Owens-Corning's composites fiberglass division, introduced the first successful, vertically oriented, crown mounted, oxy-fuel burners on a commercial size glass melting furnace in 1995. This three-month test concluded that CGM could substantially increase the rate of batch melting over a side-fired air-fuel or oxy-fuel furnace. Since these burners are located in the crown, the space limitations are overcome and the number of burners can be installed to meet the project objectives. In multiple cases, BOC has fired over 50% of the total energy of the furnace through the CGM burners, with less than 50% remaining on the air-fuel burners.

Since the first commercial installation of CGM in 1996, it has been installed in over 20 operating glass melters. They include

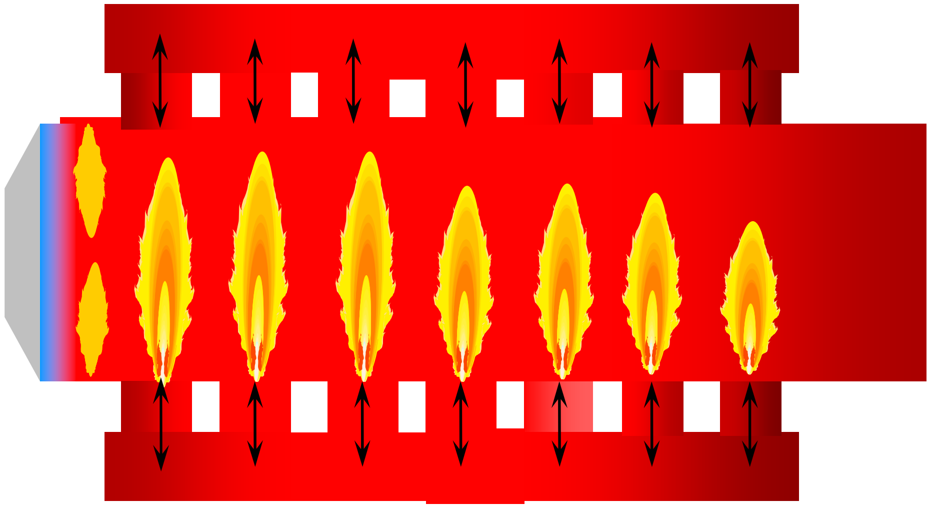
- The float, container, fiberglass, and tableware markets
- Oxy-gas and oxy-oil burners
- Air-fuel and oxy-fuel furnaces
- Asia, North America and Europe continents.

BOC filed patents to protect the CGM process as the technology continued to be developed. The first patent, US 6,237,369, was filed jointly with Owens Corning on February 10, 1997 and issued on May 29, 2001. The second patent US 6,422,041 was filed on August 16,1999 and issued on July 23, 2002. This patent discloses the use of CGM burners positioned over the raw batch materials in an air fired furnace. It details the use of the CGM burners to initially boost a three-port side-fired furnace by blocking off the first port and installing CGM burners. A CGM Hybrid configuration was then achieved by additionally blocking off the second port, installing CGM burners and continuing to fire the third port with air-fuel.

CASE STUDY: FLOAT FURNACE LIFE EXTENSION USING CGM

The float segment of the glass industry has continued to show global growth of about 2000 tpd of new product demand annually. As the major float glass suppliers install new furnaces, the number of furnace repairs per year also increases. This has placed a significant demand on capital to concurrently maintain growth and current business activity. Also, since many of the major float suppliers now have in excess of 25 furnaces, the scheduling of these repairs often conflict with human resources as well as capital. Therefore, if the life of a furnace can be extended, the capital allocated for that repair can be delayed, which helps provide a significant cash flow benefit. CGM has proven to be an effective way of providing continued operation of a float glass melter even when the checkers are significantly damaged.

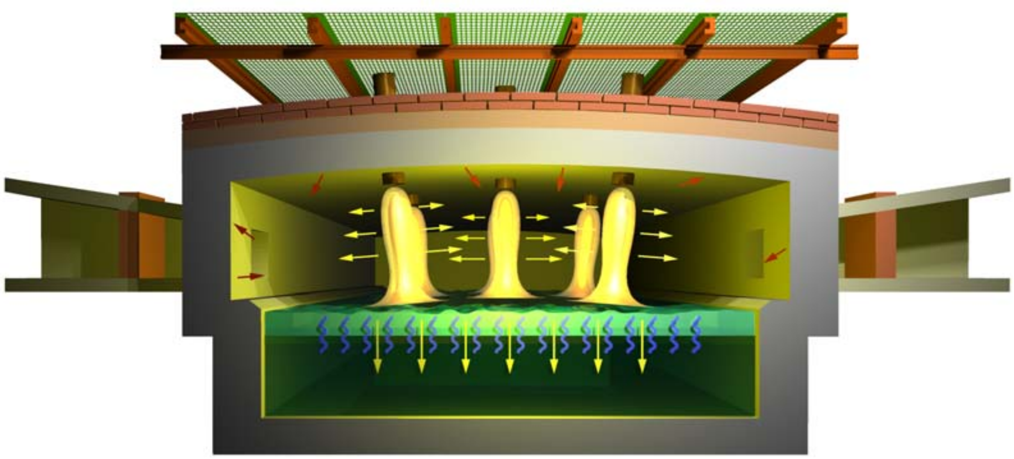
In 1999, Pilkington's Laurinburg float furnace was operating as a 7 port regenerative furnace with conventional oxy-fuel boost burners firing at 20 mmbtu/hr (Refer to Figure 4). The furnace was operating at 700 tpd with a need for increased product. In addition, after 13 years of operation, the furnace had serious regenerator checker damage, which was threatening an early



Pilkington's Laurinburg Float Furnace

Figure 4

repair. As a result of product demand and lack of materials in inventory for the repair, it was essential to maintain the furnace operation for a minimum of one year. After the review of several technologies, including port oxygen lancing and hot checker repair, CGM was chosen as the life extension technology.



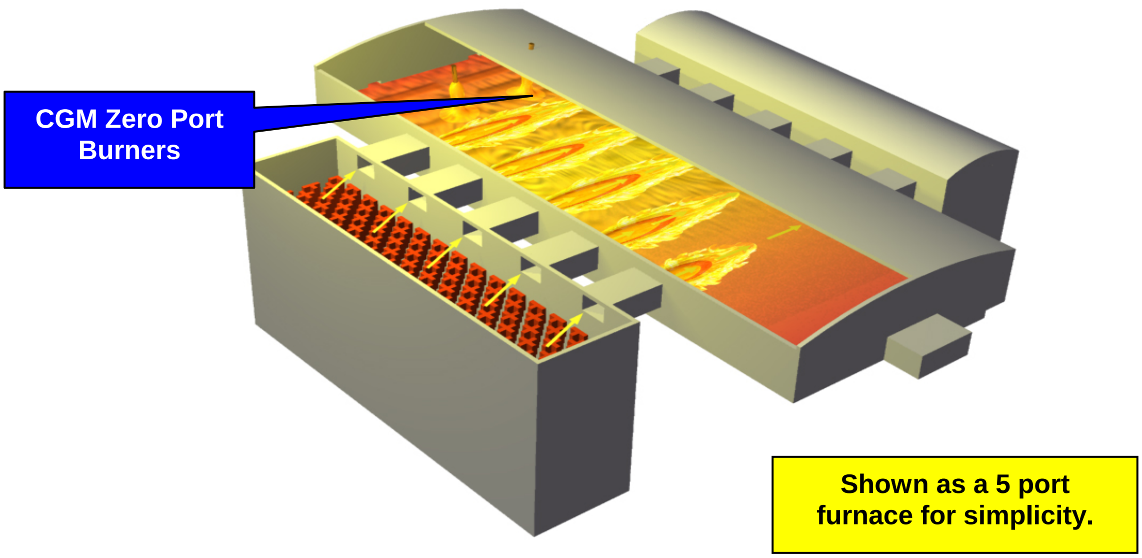
Typical CGM Furnace Installation

Figure 5

The installation of the CGM on a glass furnace typically consists of the following steps: (Refer to Figure 5)

- A seal coating of silica castable was installed over the silica crown (1)
- A crown access platform was installed over the section of the crown where the CGM burners were to be installed
- Six holes in the silica crown were drilled while the furnace was in production
- The combustion piping system was installed, including a multi-zone flow control skid
- Damper gates to isolate the first port were purchased and installed.

The only negative effect on production during this time was an incremental increase in stones resulting from the drilling process.

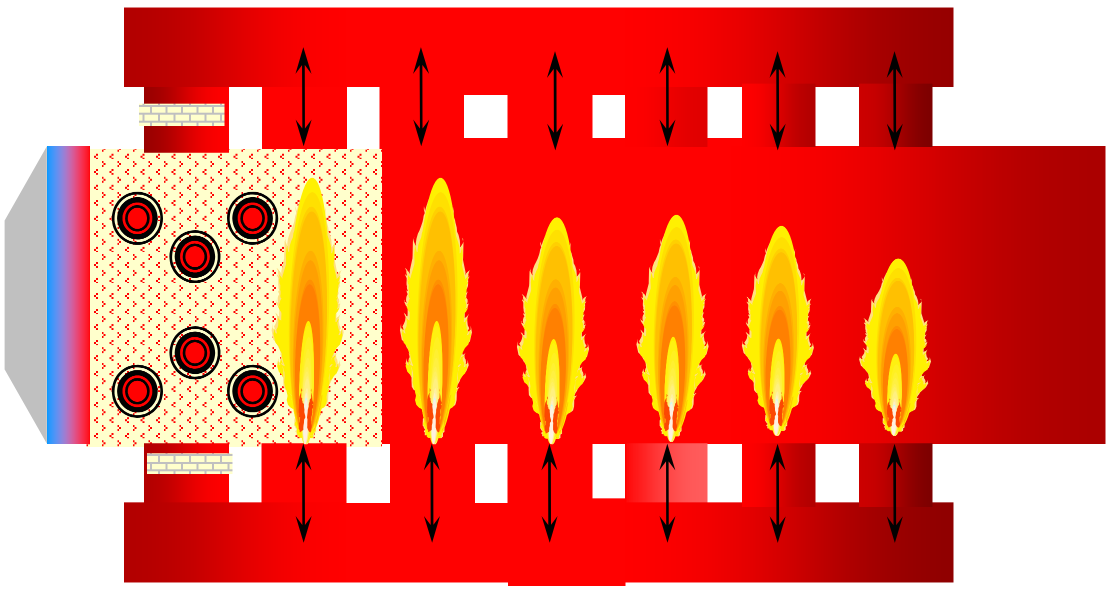


Pilkington's Laurinburg Float Furnace
With CGM Zero Port operation
Figure 6

(1) The silica castable seal coat is important in crowns to protect it against the problems associated with the higher alkali concentrations, which exists in oxy-fuel furnaces. Crown wear around existing ratholes will accelerate without this seal coat. It is recognized that this wear is the general result of the oxy-fuel atmosphere and not the CGM.

On November 1, 1999, two CGM burners were placed in the zero port area of the crown and fired at the same total rate of 20 mmbtu/hr as the side wall burners, which were simultaneously removed (Refer to Figure 6). This action was to give plant operations time to observe the CGM operation prior to expanding CGM to the hybrid configuration. The conversion from sidewall to CGM operation was accomplished while in normal production with no adverse effects on production. The primary observations were a noticeable increase in glazing of the batch as it exited the doghouse into the melter and the receding of the batch line by approximately 1/3 of the width of a port.

In December 1999, No. 1 port was blocked off and four additional CGM burners were installed in the approximate positions shown in Figure 7. This conversion was conducted with the furnace in operation with little observable effect on the production capacity or select rate. The CGM burners were initially adjusted to fire at 77% of the air-fuel firing level of Port No. 1. This maintained the furnace in approximately the same operation including batch line, pull rate, and quality as it had been prior to the installation of the additional four CGM burners.



Port Fuel Distribution **30% 13% 15% 10% 10% 16% 6%**

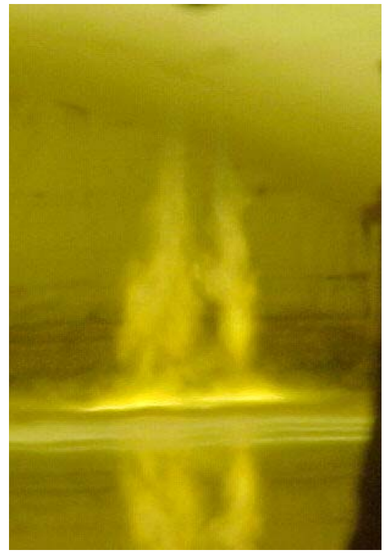
<u>Pilkington's Laurinburg Float Furnace – Fuel Distribution with CGM</u>

Figure 7

While the initial objective on installing CGM was to increase the pull rate above that prior to its installation, the continued deterioration of the furnace regenerators placed an increased demand on CGM to simply maintain the existing production. The CGM firing rate was increased to a maximum of 65,400 scfh or approximately 30% of the furnace firing capacity. Initial consideration was given to extending the CGM to Port No. 2, but the availability of oxygen supply in the local region prohibited this action. Figure 8 is a photograph of two of the CGM burners in operation filmed during a reversal of the air-fuel combustion system.

Pilkington Laurinburg Furnace
CGM Flames in Operation

Figure 8



The furnace operated in this configuration until its repair through December 2000 or a total of 14 months. Due to the continual deterioration of the regenerators, it was difficult to assess the absolute value of CGM from daily observations. Therefore, Pilkington engaged in a thorough analysis based on established operational practices and CFD Modeling.

Figure 9 illustrates the benefits of implementing CGM on this furnace as a function of recovered tons melted. The primary conclusions of this study were:

- CGM provided 51,000 tonnes more product than could have been achieved otherwise, which is approximately a 25% increase in melting capability.
- The furnace melting capacity without CGM may not have been sufficient to maintain the ribbon and hence production would have halted prior to the scheduled repair date.

General furnace conditions after 14 months of firing CGM were no worse than expected of a furnace of its age. The silica crown did deteriorate slightly as expected under oxy-fuel combustion and there was some incremental wear directly around the burner blocks. This increased wear is believed to be attributed to alkali condensation around the burner tube, which is cooled by the oxygen gas flow through the tube.

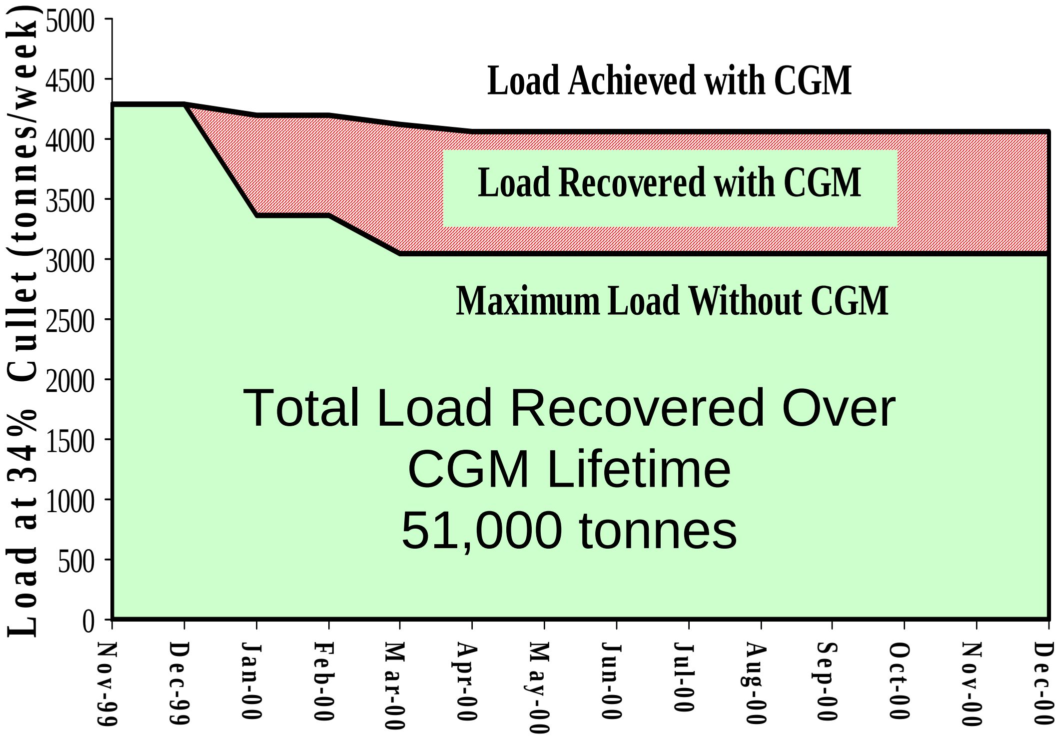


Figure 9

While this application was for life extension, it was in reality a cross between an oxy-fuel and air-fuel furnace, or a hybrid configuration. The concept of melting with oxy-fuel CGM and refining with conventional air-fuel combustion is worthy of consideration in future furnace designs. This hybrid configuration has the following advantages:

- Lower conversion capital cost due to considerably less fused cast alumina.
- Lower operating cost due to reduction in oxygen consumption.
- Lower NOx formation due to reduced air-fuel combustion.
- Better foam control using conventional technologies.
- Heat recovery of the oxygen products of combustion by preheating of the combustion air.

CGM Propane

Many furnaces which fire natural gas use propane as a back up fuel source for periods of interruption in gas supply. Utilising test furnace heat transfer data has shown that propane can be used in a natural gas CGM burner to produce equivalent melting. For long term propane operation, it is recommended that dedicated CGM propane burners are utilised to provide optimum heat transfer. CGM propane burners have been operated continuously for periods in excess of 12 months.

CGM Oil
With more than 20 CGM gas applications installed, BOC was approached by glass manufacturers in Asia to develop an oil version of the CGM.

The first oil prototype was installed in a 100% oxy-fuel furnace melting TV panel glass as shown in Figure 10. By removing two existing horizontal oxy oil burners and replacing with a single oxy oil CGM burner, it was possible to melt the same amount of glass with one burner with slight energy savings. By increasing the oil firing on the CGM oil burner, it was possible, through incremental steps, to increase the furnace throughput by 50%.

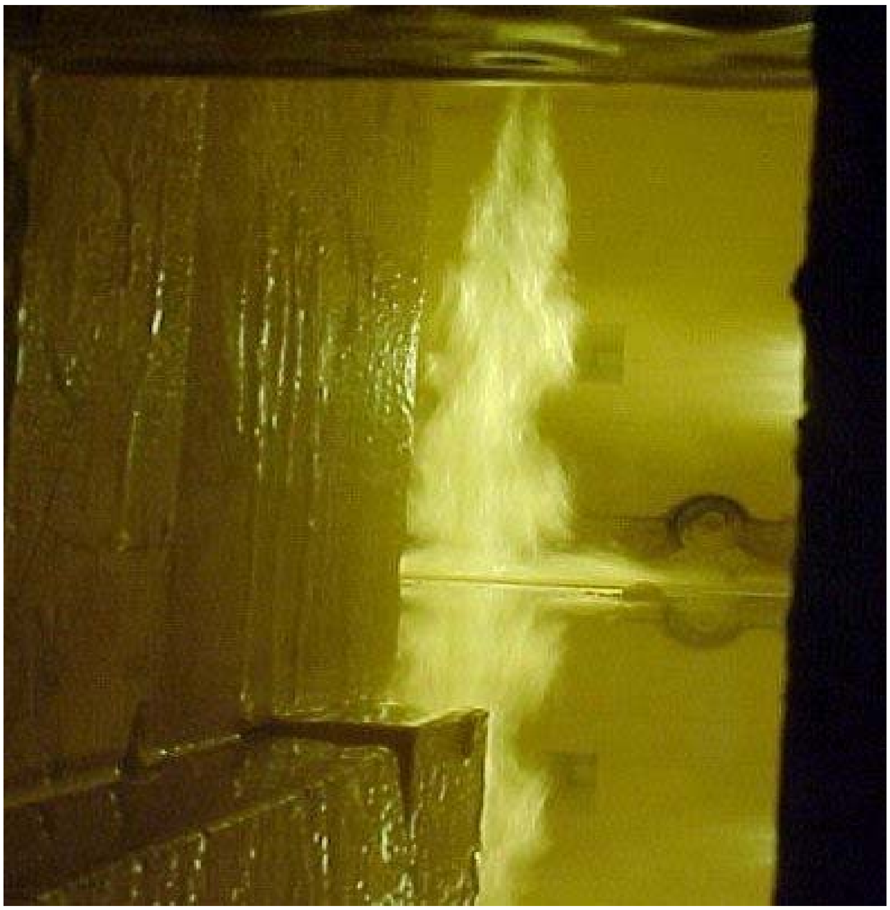


Figure 10 CGM Oil

The second CGM installation was on a float furnace that was being boosted using conventional zero port oxy oil burners. By replacing the zero port burners with two CGM oxy oil burners at the same fuel flowrate, the batch line receded by 0.25ports. The crown temperature was reduced by 10°C and the dog-house bottom increased by 5°C. The CGM technology also enabled an oil flow reduction on the air-fuel port fires. Through changes in furnace combustion flow dynamics, the oxygen levels on the first two ports were increased with a corresponding reduction in carbon monoxide.

The CGM oil burner has now been installed on a total of four furnaces on TV, float, PDP and specialty float. In all cases there was no change in glass composition and no negative impact on quality.

The CGM oil burner is, in all cases, at least equivalent and, in most cases, more efficient than conventional horizontal oil burners. The significant benefit results from the ability to locate the CGM burners almost anywhere in the furnace, whereas horizontal burners are limited to available space.

For example, a float furnace as shown in Figure 11 that has already been boosted utilising horizontal zero port burners is limited to using enrichment or lancing on the air fuel ports to sustain production as the regenerators continue to deteriorate.   Whilst retaining the zero port horizontal burners, it is possible to block off port one and install two CGM oxy oil burners.

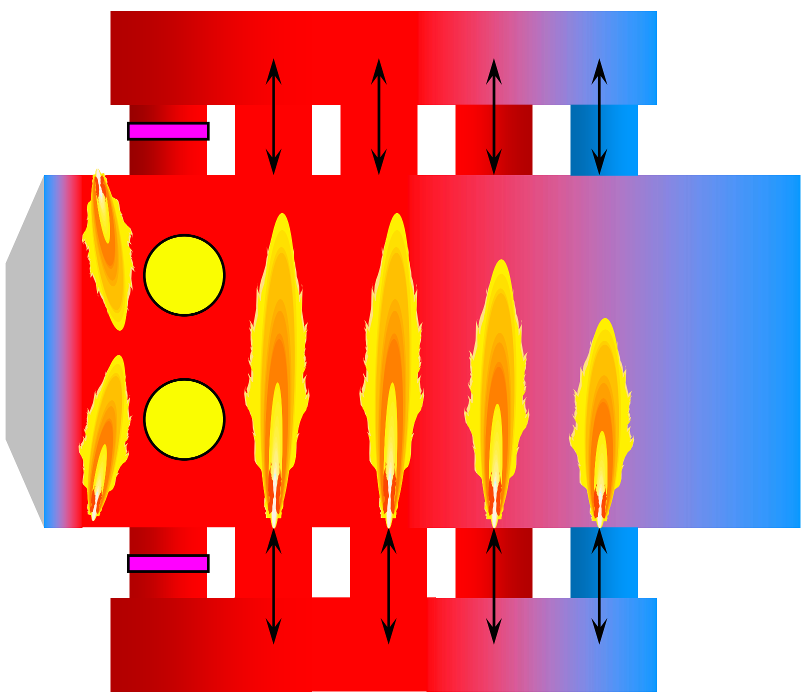


Figure 11 – CGM Oil Recovery on a Float Furnace

SUMMARY

From general enrichment to specific oxy fuel boosting, oxygen can be used to recover or boost both production and glass quality from an existing air fuel furnace. Enrichment is the most simple and cost effective method of using oxygen either from a liquid or waste oxygen source. Lancing is more specific in the location of the oxygen injection and is therefore more efficient but more costly. Boosting either by Hot Spot or Zero Port is an effective way to achieve an increase in furnace through-put.

BOC's Convective Glass Melting (CGM) technology has proven effective in float furnaces in a zero-port boost or hybrid configuration as a furnace life-extender or load-recovery agent. At Pilkington's commercial facility, using the CGM system resulted in 51,000 tonnes of load recovered in a span of 14 months.

The CGM technology is an advanced glass melting technology, patented by BOC. It uses oxy-fuel burners, located in the crown of a glass furnace, to significantly increase furnace capacity and improve glass quality. It can also be used to extend the life and improve the performance of ailing furnaces. CGM was developed by BOC in partnership with Owens-Corning in 1996, and has since been applied to float, container, tableware, television, and fiberglass sectors, in furnaces ranging in size from 16 to 700 tons per day.

The BOC Group (NYSE:BOX), the worldwide industrial gases, vacuum technologies and distribution services company, serves two million customers in more than 50 countries. It employs 44,500 people and had annual sales of some $7 billion in 2003. Further information about The BOC Group may be obtained on the Internet at <http://www.boc.com>

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Neil G Simpson August 18, 2004