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S. K. Sundaram
Editor

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Edited by
S. K. Sundaram

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Foreword

The 74th Glass Problem Conference is organized by the Kazuo Inamori School of Engineering, Alfred University, Alfred, NY 14802 and The Glass Manufacturing Industry Council, Westerville, OH 43082. The Program Director was S. K. Sundaram, Inamori Professor of Materials Science and Engineering, Kazuo Inamori School of Engineering, Alfred University, Alfred, NY 14802. The Conference Director was Robert Weisenburger Lipetz, Executive Director, Glass Manufacturing Industry Council, Westerville, OH 43082. The themes and chairs of five half-day sessions were as follows:

Batching and Forming
Phil Tucker, Johns Manville, Denver, CO and Ken Bratton, Emhart Glass Research Inc., Windsor, CT

Glass Melting
Glenn Neff, Glass Service, Stuart, FL and Martin Goller, Corning Incorporated, Corning, NY

Modeling, Sensing, and Control
Bruno Purnode, Owens Corning Composite Solutions, Granville, OH and Larry McCloskey, Toledo Engineering Company, Toledo, OH

Refractories I
Matthew Wheeler, RHI US LTD, Batavia, OH and Thomas Dankert, Owens-Illinois, Perrysburg, OH

Warren Curtis, PPG Industries, Pittsburgh, PA and Elmer Sperry, Libbey Glass, Toledo, OH

Refractories II
Andrew Zamurs, Rio Tinto Minerals, Greenwood, CO and Martin Goller, Corning Incorporated, Corning, NY

Preface

In continuing the tradition that dates back to 1934, this volume is a collection of papers presented at the 74th Glass Problems Conference (GPC) published as the 2013 edition of the collected papers. The manuscripts included in this volume are reproduced as furnished by the presenting authors, but were reviewed prior to the presentation and submission by the respective session chairs. These chairs are also the members of the GPC Advisory Board. I appreciate all the assistance and support by the Board members. The American Ceramic Society and myself did minor editing and formatting of these papers. Neither Alfred University nor GMIC is responsible for the statements and opinions expressed in this volume.

As the Program Director of the GPC, I enjoy continuing this tradition of serving the glass industries. I am thankful to all the presenters at the 74th GPC and the authors of these papers. The 74th GPC continues to grow stronger with the support of the teamwork and audience. I appreciate all the support from the members of Advisory Board. Their volunteering sprit, generosity, professionalism, and commitment were critical to the high quality technical program at this Conference. I also appreciate continuing support and leadership from the Conference Director, Mr. Robert Weisenburger Lipetz, Executive Director of GMIC. I look forward to working with the entire team in the future.

S. K. SUNDARAM
Alfred, NY
January 2014

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It is a great pleasure to acknowledge the dedicated service, advice, and team spirit of the members of the Glass Problems Conference Advisory Board in planning this Conference, inviting key speakers, reviewing technical presentations, chairing technical sessions, and reviewing manuscripts for this publication:

Kenneth Bratton—*Emhart Glass Research Inc. Hartford, CT*
Warren Curtis—*PPG Industries, Inc., Pittsburgh, PA*
Thomas Dankert—*Owens-Illinois, Inc., Perrysburg, OH*
Martin H Goller—*Corning Incorporated, Corning, NY*
Uyi Iyoha—*Praxair Inc.,Tonawanda, NY*
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Elmer Sperry—*Libbey Glass, Toledo, OH*
Phillip J. Tucker—*Johns Manville, Denver, CO*
James M. Uhlik—*Toledo Engineering Co., Inc., Toledo, OH*
Mathew Wheeler—*RHI US LTD, Batavia, OH*
Andrew Zamurs—*Rio Tinto Minerals, Greenwood, CO*

Batching and Forming

LONG TERM RESULTS OF OXY FUEL FOREHEARTH HEATING TECHNOLOGY FOR E-GLASS FIBERS

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ABSTRACT

This paper presents the long-term results of ALGLASS ForeHearth (FH) 2-6 kW burner technology in four industrial installations of E-glass fiber and borosilicate container glass industries. ALGLASS FH is an oxy combustion technology developed for glass forehearth that addresses the difficulties encountered in glass forehearth. The ALGLASS FH burner is based on an innovative method for fuel injection with a swirl effect to control flame length (200 to 300 mm). The burner geometry and external body can be easily adapted to customer refractory blocks to meet desired energy profile. Burner robustness, reliability, its flexibility to control flame length and primary energy savings have been confirmed through these references.

INTRODUCTION

Accurate control of molten glass flow temperature in forehearth is crucial to achieve the right conditions, including viscosity at the gob[1]. Air-fuel combustion and electric heating are proven and robust technologies in container and fiber-glass sectors. However, CO_2 and NO_x emission regulations, increase in fuel costs, and production flexibility requirements are pushing glassmakers to investigate new technologies such as oxy-fuel and radiant burners. Oxy-fuel is a mature technology for melting[2]. While literature is abundant on oxygen combustion for melting[3], only a few long-term results on the use of oxy-fuel in glass conditioning during "on the fly" conversion have been published.

Oxygen combustion entails increasing the oxygen concentration in the oxidizer that reacts with the fuel (e.g. natural gas, fuel-oil, coal, synthetic gas). When air is fully replaced by industrial grade oxygen (purity level varying from 80 to 100%, the remaining part being nitrogen and argon), the air burners must be replaced by dedicated oxygen burners. A challenge in glass forehearths is its low available space for retrofitting from air to oxygen combustion. For instance, in a cross-fired furnace, air burners consist of 2 m wide air channels (1.5 m high) with underport installed fuel injectors that let space for changing to oxy fuel burners with a refractory block of 250 × 250 mm. In forehearths, air burners are installed almost one next to the other. Hence, the oxygen burners' implementation must comply with this available space.

Flame length with oxygen combustion is usually smaller (up to 30% shorter), while the energy released is 3.5 times higher. An optimum oxygen burner must be able to meet such challenges. The burner must also allow for the establishment of a flame without producing a hot spot above the glass flow in order to avoid potential temperature heterogeneity. Further, the flame geometry must be adapted to avoid any flame-to-flame impingement and crown overheating. ALGLASS FH burner has been developed by Air Liquide by taking into account all such specifications[4]. It is compatible with commonly used refractory materials in forehearth such as mullite, AZS and sillimanite.

ALGLASS FH achieves a theoretical thermodynamical fuel saving of 60% when compared to combustion with cold air. In addition, the following benefits have also been observed:

- Better flexibility in energy profile; better control of process
- Lower maintenance
- Safer operation i.e., reduced risk of flashback
- Decreased thermal NO emissions
- Up to 60% reduction in CO_2 emissions

This paper presents the results obtained with ALGLASS FH technology on four industrial installations of existing air-fired and oxy-fired forehearth leg and conditioning zones. As many of fiberglass furnaces are already using oxygen combustion (> 50% of glass furnaces in Europe[5]), operators feel comfortable with its use. For this reason, three of the four references presented in this paper are focused on E-glass. The technology has also been installed in a borosilicate glass forehearth (perfume bottles) with demonstrated benefits on temperature control and fuel savings.

THE ALGLASS FH TECHNOLOGY

The ALGLASS FH burner design is based on a pipe-in-pipe technology that uses a method for injection of fuel with a swirl effect to control flame length. Oxygen injection surrounds the fuel injection (See the design in Figure 1). In order to cover typical needs of glass conditioning processes, the burner power ranges from 2-6 kW (6.8-20.5 MBTU/hr) and the burner external body/geometry can be adapted to fit most customer refractory blocks.

The benefits provided by ALGLASS FH burner were first demonstrated in a pilot furnace. It was shown that flame structure and length can be controlled. The reactants velocities help to control and set the location of the hottest area (or hot spot) of the flame. This parameter is critical to preserve the integrity of both refractory block and burner injector. Selection of suitable swirl effect is important to obtain efficient combustion characteristics. Figure 2 illustrates the principle of the swirl effect on fuel injection. If the mixing between reactants occurs too rapidly (strong swirl), it can lead to shorter flames and localization of the hot spot within the refractory block. This configuration can cause overheating/melting of the block and/or to the degradation of the burner injector due to formation of soot (or carbon) deposits on the burner injector. Sooting gradually changes the flame shape, making the flame shorter and/or less centered within the hole of the block. This can cause flame impingement on the burner block and result in damage to the burner block. On the other hand, when the mixing between fuel and oxygen occurs too slowly (weak swirl), the flame is not robust enough and there is the possibility of inadequate mixing of fuel and oxidizer, which can lead to soot formation on the burner injector.

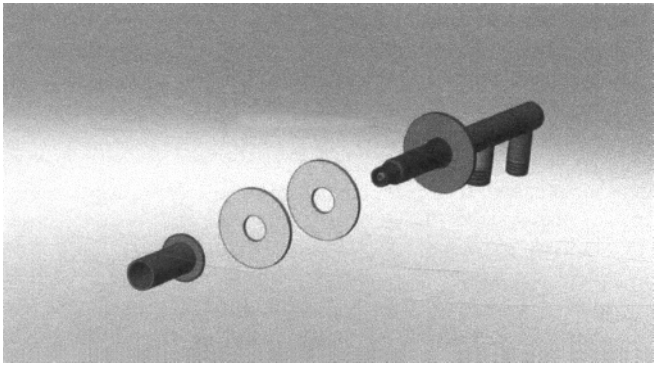

Figure 1: A 3-D scheme representing the ALGLASS FH pipe in pipe burner with fuel (left) and oxygen (right) inlets

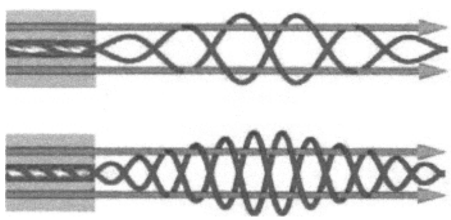

Figure 2: Scheme symbolizing the fuel (red color) and the oxygen (blue color) flows when the power changes; thanks to the swirl effect, the reaction between reactants takes place in the same area which leads to the same flame length

The swirl effect helps to maintain the hot spot of the flame at the same location even when the burner power is varied within a wide range. For example, when the power increases, the swirl effect on the fuel injection also increases which, in turn, increases mixing between the reactants, thus avoiding change in the flame length and the location of hot spot. Figure 2 illustrates the principle of the swirl effect on fuel injection.

Another benefit of this ALGLASS FH design is its capability to improve and optimize heat transfer to the glass. The flame hot spot is localized outside the refractory block by design, but not too far from the block outlet. Consequently, the maximum heat is transferred to the glass close to the forehearth walls to compensate for heat losses through the walls of the forehearth line and to improve the homogeneity of the glass.

Pilot furnace trials have demonstrated the following advantages:

- Compatibility with different refractory blocks materials: AZS, mullite and sillimanite burner blocks have been tested and showed no issues when operated with burner power < 1.5 times nominal.

- Adaption to different customer block geometry: in pilot furnace atmosphere, no perturbations of flames or soot deposits were observed.
- Zero maintenance: in a clean environment, such as a pilot furnace, the burners have been tested during several weeks at 1400°C (block temperature) without observable damage.
- Eliminate safety risks due to reactants premixing: thanks to separate injection of gas and oxygen, flashback inside natural gas line cannot occur. Moreover, the swirl allows a perfect start-up even at low power avoiding flame lift-off.

PREPARATION FOR INDUSTRIAL TRIALS

In order to prepare for each industrial trial, the customer's burner block (corresponding to the specific forehearth line) was first installed and tested with ALGLASS FH burners in the a pilot furnace without glass. The following thermal diagnostic equipment was used:

- Thermocouples – to measure the longitudinal temperature profile at the top of the burner block. This helps to determine the position of the hot spot.
- Pyrometer – to measure radial temperature profile of the refractory block around the outlet hole. This allows to assess the homogeneity of the heat transferred all around the block and also to verify that there is no damage to the front face of the block.
- Temperature sensors - installed at the chamber bottom to simulate industrial glass surface temperature. This helps to understand the temperature profile, hence heat transfer to load.
- Pressure sensors – for both natural gas and oxygen inlets.

From the pilot furnace tests, the optimal range and recommended burner power were identified, resulting in improved heat transfer to the glass while minimizing the risk of damage to both refractory block and burner injector.

In addition to these experimental studies, numerical simulations were also made with in-house computational fluid dynamics (CFD) software called ATHENA[6]. This tool was used for two main purposes: to test the effect of burner parameters on fluid flow and radiation that are normally difficult to measure experimentally and to simulate full forehearth operation and study the thermal interaction of the burner with forehearth. Turbulence, combustion and radiation models included in ATHENA software have been validated for swirled oxy-combustion, through comparison of measured and calculated data.

INDUSTRIAL RESULTS

Reference 1: Burner trials in leg zone of fiberglass forehearth

The ALGLASS FH technology was implemented in the conditioning leg of an E-glass fiber manufacturer in Europe; previously, the conditioning leg was operated with premixed air fuel burners. The oxy-fuel burner was operated in a range of 5 kW (17 MBTU/hr). During this trial several issues were observed:

- Variations in the customer refractory block opening for burner. As a mitigation strategy, the ALGLAS FH burner was equipped with "auto centering" modules to have the burner straight even if the opening is not straight.

- Burner material issues possibly related to high metallic body temperatures. Three burners were equipped with three thermocouples each and the temperatures were recorded. The temperatures were in the expected range with the burner tip being hottest. To reduce any possible risk of overheating, the burner body material was changed to a high heat resistance material.
- Temperature increase at one burner. Upon inspection, it was found out that the high-density energy release by the flame inside the long and narrow refractory block channel could not be dissipated to the surrounding refractory and has caused the issues.

The geometry of the prevailing burner refractory block at the customer site is critical for the success of the ALGLASS FH implementation in a refining zone or conditioning leg. During the operation, the easy installation of the burner was positively noted as well as no adverse effects on glass quality.

Reference 2: Full conversion of a conditioning zone of fiberglass forehearth

In 2006, Air Liquide started a partnership with one of its customers to apply ALGLASS FH technology in one of its forehearth lines. Implementation of the technology initially focused on the conditioning zone. The trial objectives were: (i) to evaluate the firing flexibility of ALGLASS FH burner to forehearth demand; (ii) to check the robustness of the technology during several months' operations, and (iii) to quantify the impact of the technology on the thermal behavior of the forehearth.

In order to prepare for the trials in the chosen zone of the conditioning channel, where the temperature of the glass is close to 1,250°C (2,282°F), a representative refractory block from customer was installed and tested in the Air Liquide pilot furnace for several hundreds of hours. The burner was tested in the range 2-6 kW in order to evaluate the differences in temperature profiles (Figures 3 and 4). Because the burner must fit within the customer's burner block, the burner inlet required some minor modification, in order to fit with the block geometry. The trials also provided an opportunity to verify the installation procedure.

Figure 3 shows the temperature profiles measured on the block top for three different powers. Although the power of the ALGLASS FH burner increases, the maximum temperature remains below 1,300°C (2,372°F) and the profile remains similar. Figure 4 presents the temperature profiles measured on the bottom of the chamber of the pilot furnace. The temperature close to the block outlet also remains close to 1,250°C (2,282°F) - demonstrating that the location of the hot spot does not change when power varies from nominal to 1.5 times nominal. When the power is increased, a more homogeneous temperature profile is obtained up to a distance representing the middle of the channel.

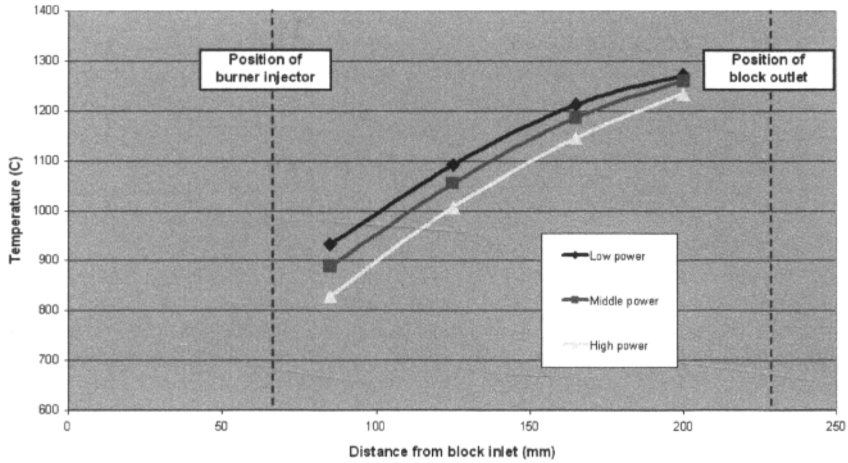

Figure 3: Graphic – Tests in the AIR LIQUIDE pilot tests – Temperature profile on block top when the ALGLASS FH burner was operated at three different powers inside the customer's refractory block – for E glass fiber process

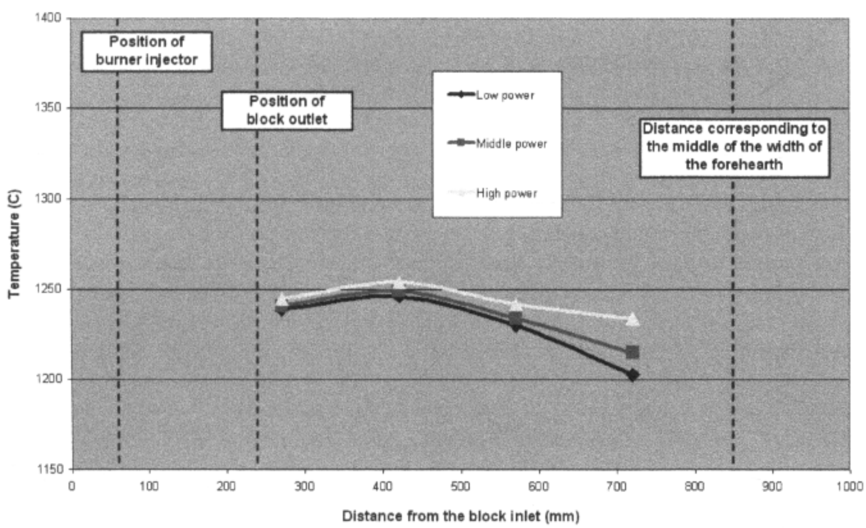

Figure 4: Graphic – Tests in the AIR LIQUIDE pilot tests – Temperature profile on chamber bottom when the ALGLASS FH burner was operated at three different powers inside the customer's refractory block – for E glass fiber process

The industrial trial period with 12 ALGLASS FH burners took 18 months. ALGLASS FH burners were implemented in a conditioning channel. The burners were ignited and used with an oxygen/natural gas ratio very close to stoichiometric conditions. The flame was checked through peepholes; it remained well centered inside the block. In the beginning, there had been minor random deposits looking like glass noted in the lower side of the burner body. However, no further deposition issues were notes after the initial start up.

Figure 5 shows pictures of one ALGLASS FH burner: on the left side, the burner is operated inside the forehearth line, the well centered flame inside the refractory block can be noticed; on the right side, the burner was pulled out for inspection after several weeks of continuous operation; there was no sign of burner damage or glowing injector.

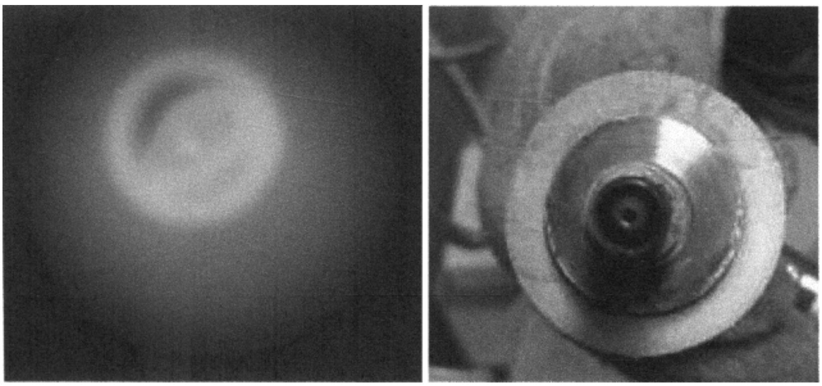

Figure 5: Pictures of one ALGLASS burner: operated inside the E glass fiber forehearth line (left side) and pulled out for inspection after several weeks of operation (right side)

During the entire 18-month period of operation, the flame shape remained consistent and there no damage to the burner blocks was noted. Furthermore, due to pull rate variation, the burner power was changed by 50% of its nominal rate. The temperature of glass and channel were checked and the energy profile easily adapted to overcome potential overheating. Today, the forehearth is operated with around 100 ALGLASS FH burners since April 2010.

Reference 3: Full conversion of a leg of fiberglass forehearth

The E-glass producing customer was interested in assessing the performance of the ALGLASS FH technology - with regard to robustness and fuel savings. The customer ran trials of the technology first in the refining zone and then later in the two legs of the conditioning zone and fuel savings. For the refining zone, 8 ALGLASS FH burners were trialed for one month, starting in October 2010.

As with the earlier trials, in order to prepare the trials in the refining zone, where the temperature of the glass is close to 1,285°C (2,346°F), a representative refractory block from customer was installed and tested in the AIR LIQUIDE pilot furnace. The required power was known; therefore, the burner was tested within this range to appreciate the differences in terms of temperature profiles. See Figures 6 and 7 for pilot furnace results.

Figure 6 shows the temperature profiles measured on the block top for three different powers. Although the power of the ALGLASS FH burner increases, the maximum temperature always remains below 1,304°C (2,380°F) and the profile remains similar. Figure 7 presents the profiles of temperature measured on the bottom of the chamber of the pilot furnace. The temperature close to the block outlet remains close to 1,298°C (2,370°F) - demonstrating that the location of the hot spot remains fixed.

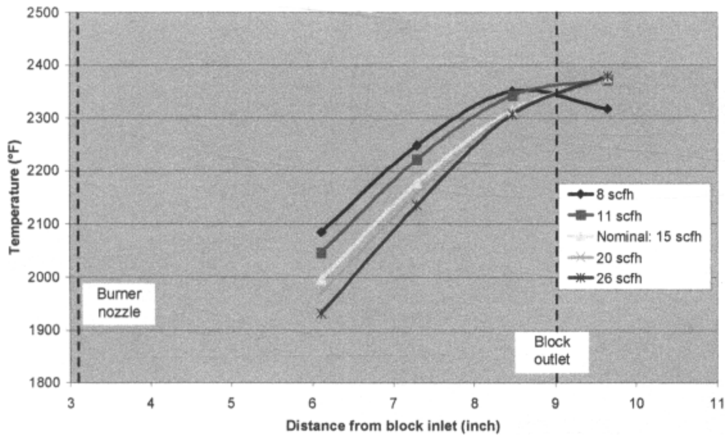

Figure 6: Graphic – Tests in the AIR LIQUIDE pilot tests – Temperature profile on block top when the ALGLASS FH burner was operated at five different powers inside the customer's refractory block – for E glass fiber process

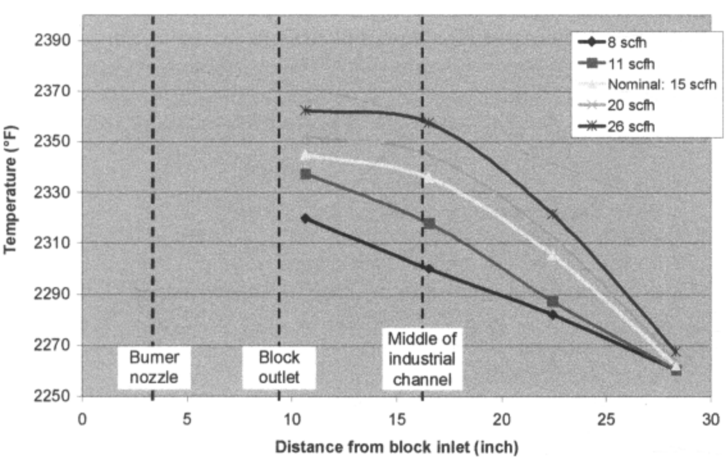

Figure 7: Graphic – Tests in the AIR LIQUIDE pilot tests – Temperature profile on chamber bottom when the ALGLASS FH burner was operated at five different powers inside the customer's refractory block – for E glass fiber process

Industrial operation of around 50 ALGLASS FH burners in the entire forehearth leg began in November 2010. ALGLASS FH burners were implemented in a 609 mm to 304 mm (24" to 12") roughly wide zone of the conditioning channel. The burners were ignited and used with an oxygen/natural gas ratio very close to stoichiometric conditions. After a short troubleshooting phase (clogging and deposits), all the burners have been run successfully, without further issues.

As with the previous references, the trials showed no adverse effect on burner refractory block or glass quality (e.g. reboil). It was also noted, that the flame length was constant over varying natural gas flow rates, ensuring that the hot spot remained outside of the refractory block. Robustness of the burner was assessed through regular visual inspections, which showed no deposits and clean burner bodies and tips.

<u>Reference 4:</u> *Conversion of one zone in a borosilicate glass forehearth*

A glass manufacturer specializing in the production of borosilicate container glass for the cosmetic industry wanted to improve the quality of the glass while having the ability to control the very low thickness of certain ranges of bottles. When using air combustion, reboil issues in the forehearth line occurred, particularly in the zone downstream of melter exit, where the glass temperature is close to 1,300°C (2,372°F).

In preparation of the oxy-conversion, CFD calculations were performed using ATHENA software to choose the best conditions for the trials: The main results of simulations relating to the ALGLASS FH technology showed that a global power close to 50-53 kW (170-180 MBTU/hr) was suitable for oxy-combustion.

Figure 8 shows the interactions of heat transfer between two face-to-face flames, which occur in the case of air burners (top side of the figure); generating a temperature close to 1,700°C (3,092 F) near the crown of the forehearth. Using ALGLASS FH burners, (bottom side of the figure) the temperature near the crown would remain close to an acceptable level of 1,500°C (2,732°F). Figure 9 presents one part of the zone downstream of the melter exit; the impingement between flames occurs with air burners (left side of the figure) and the temperature of the glass surface does not appear uniform along the width of the chamber. The temperature reaches 1,600°C (2,912 F) in the middle of the channel, which represents a significant risk of glass reboil.

Using ALGLASS FH burners (right side figure 9) the temperature of the glass surface appears homogeneous in the area close to the channel walls, whereas the maximum temperature reached in the middle zone is not higher than 1,400°C (2,552°F), preventing the glass reboiling phenomenon.

In the AIR LIQUIDE pilot furnace, the customer block was operated and temperature profile of the block indicates that the hottest level is around 1,325°C (2,417°F) and positioned outside of the block. The temperature profile on the chamber bottom of the pilot furnace shows that the temperature remains quite uniform and very close to 1,300°C (2,372°F) near the block outlet and into the half-width of the industrial forehearth line; indeed, the energy is homogenously transferred towards the bottom of the chamber. The temperature of the block, around the outlet hole, is only 20-25°C higher than the chamber bottom.