Tall crown furnace technology for oxy-fuel firing

An advanced oxy-fuel fired furnace design has been proven to extend the life of silica crowns while achieving high-fuel efficiency and low NOx and particulates emissions. H Kobayashi*, K T Wu*, G B Tuson*, F Dumoulin* and H P Kiewall** show us how.

Rexair, in collaboration with Heye Glas, has successfully implemented an advanced oxy-fuel glass melting technology called “Tall Crown Furnace” technology, to reduce silica refractory corrosion, NOx emissions, SOx emissions and particulate emissions while maintaining the high heat transfer and energy efficiency of oxy-fuel glass melting. The technology has been successfully implemented by HEYE International in the engineering design of three commercial oxy-fuel fired container glass furnaces. The first furnace was lit off in early 1996 and currently has reached a campaign life of about nine years (more than 9000 tonnes of glass pulled per square metre of the melter area) without major silica corrosion problems. The furnace is expected to operate for a total campaign of 10 to 11 years with the original silica crown, with overcoat repair near the end of this period. The furnace has also demonstrated a high heat transfer rate and an excellent energy efficiency with a productivity as high as 3.5 tonnes/d/m² (2.8 ft²/tpd) without electric boost and a specific energy consumption of about 815 kcal/kg (3.3 MMBtu/ton) for flint glass with 60% cullet. The second and the third furnaces have operated about seven and five years respectively with good refractory conditions and furnace performance. A fourth TCF container glass furnace (150 tonnes/d) has been designed recently to rebuild an existing oxy-fuel furnace and is scheduled to start in late 2005.

Silica crown corrosion

Accelerated silica crown refractory corrosion for oxy-fuel firing is caused by a three-fold increase in the concentration of alkali vapour species, especially NaOH and KOH. In some early oxy-fuel furnace conversions, burner design characterised by tall crown height and high burner elevation was developed. By raising the burner height above the glass melt the “hot spots” on the glass melt surface created by the oxy-fuel flames and the gas velocity near the glass melt surface were reduced and the overall alkali volatilisation rate was reduced by about 50%. The low flame momentum of the oxy-fuel burner and the tall crown reduce the circulation of NaOH and other volatile species from the glass melt surface to the crown and the NaOH concentration and the gas velocities near the crown are reduced. Both of these factors contributed to the reduction of the mass transfer rate of NaOH to silica crown and the corrosion rate. Other special design features include partial furnace atmosphere stratification to create more oxidising and lower H₂O vapour conditions near the glass melt using low momentum ultra low NOx burners and a single flue port to optimise energy efficiency.

Reduction of emissions

Since over 80% of particulates emissions are caused by volatilisation of alkali species, the TCF design also reduces the particulate emissions. In Fig 1, measured particulate emissions from regenerative air fired furnaces, conventional oxy-fuel fired furnaces and advanced TCF oxy-fuel fired furnaces are shown as a function of the specific glass pull rate. It is well known that particulate emissions increase sharply with the specific glass pull rate as a result of increased glass melt surface temperatures and higher gas velocity under higher pull rates. A comparison of the data from air fired furnaces and those from conventional oxygen fired furnaces shows about 20 to 30 % reduction of overall particulate emissions under oxygen firing. With the TCF design, shown as “Oxy-Furnace New Design” in Fig 2, particulate emissions were reduced by a factor of two compared to the earlier oxy-fuel furnace design. At a specific pull rate of 3 tonne/day/m² particulate emissions of 0.25 kg/tonne (0.5 lb/ton) were achieved.

The Praxair JL Burner provides a unique design for very low NOx emissions and partial furnace atmosphere stratification. The burner design utilises the patented concept of “deep oxygen staging” and a separate injection of secondary oxygen under the low temperature rich primary flame. The rich primary zone stoichiometry produces a low momentum high luminosity flame for high heat transfer efficiency and the separate secondary oxygen injection produces a long flame with a higher oxygen concentration and a lower water vapour concentration near the glass melt surface. NOx emissions from JL Burners are shown to be approximately 1/3 to 1/10 of those from the conventional oxy-fuel burners.

Heat transfer and fuel consumption

Although the larger distance between the flame and glass melt surface reduces convective heat transfer and direct radiative heat transfer from flame to glass melt, a good heat transfer efficiency is maintained with the TCF design. The bulk gas to glass melt radiative heat transfer increases sharply with the specific glass pull rate as a result of increased glass melt surface temperatures and higher gas velocity under higher pull rates. A comparison of the data from air fired furnaces and those from conventional oxygen fired furnaces shows about 20 to 30% reduction of overall particulate emissions under oxygen firing. With the TCF design, shown as “Oxy-Furnace New Design” in Fig 2, particulate emissions were reduced by a factor of two compared to the earlier oxy-fuel furnace design. At a specific pull rate of 3 tonne/day/m² particulate emissions of 0.25 kg/tonne (0.5 lb/ton) were achieved.

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increase height of the breast walls which are generally very well insulated. Table 1 shows a comparison of the furnace energy balances of a 330 tpd (300 tonnes/d) conventional oxy-fuel fired and Tall Crown Container Glass Furnace.

**Glass experience**
The TCF technology has been successfully implemented by HEYE International into the engineering design of three commercial oxy-fuel fired container glass furnaces. The first 350 tonne/day furnace was built at Obernkirchen, Germany and lit off in early 1996 and currently has reached a campaign life of about nine years (over 9000 tons of glass pulled per square metre of the melter area) without major silica corrosion problems. It is expected to operate for a campaign of 10 to 11 years with the original silica crown of 375mm thickness, with overcoat repair near the end of this period. HEYE International commissioned a second tall crown oxy-fuel furnace for green glass in 1998 in the Netherlands. A third tall crown oxy-fuel furnace for melting amber glass was commissioned in April 2000 in Obernkirchen.

The first furnace melting flint glass feeds two IS 20-section double gob forming machines producing 11 and 0.33l mineral-water bottles. From the start-up on, the furnace has melted the desired amount of flint glass with excellent glass quality. Seed counts are on average below 20/oz. The two forming machines pull 330 tonnes per 24 hours on average. The furnace is operated with approximately 60% cullet powder of external cullet. Energy consumption figures are better than expected. The average consumption is around 3.35 ml/kg of glass (800 kcal/kg) which results in melting costs lower than those all other conventional furnaces in operation. This capacity and consumption is achieved at a pull rate of more than 3 tonne/m² and without any electric boosting.

Concerning emissions, all expectations have been more than fulfilled. Measurements show emission figures between 0.5 kg NOx/ton and 0.35 kg NOx/ton of glass using natural gas containing about 11% N₂, well below the German regulation of 500 mg NOx/m³ of fuel gas (converted to 0.7 kg NOx/ton of glass based on same mass-flows of NOx).

**Summary**
Tall Crown Furnace design has been demonstrated to reduce corrosion of silica crown by reduced volatilisation of alkali vapours from glass melt and batch. The life of a TCF oxy-fuel fired container glass furnace is now expected to be over 10 years. The TCF design with Praxair JL Burners reduced NOx and particulate emissions substantially, while providing excellent heat transfer characteristics.

**References**
1. Kobayashi, H., KT Wu, GB Tuson, F Dumoulin, and HP Kiewall, HEYE International GmbH, Obernkirchen, Germany, Tel +49 5724 1288. Email: info@heye-international.de; Website: www.heye-international.de.

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**Table 1. Energy balance comparison.**

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<tr>
<th></th>
<th>Conventional Oxy-fuel</th>
<th>Tall Crown Oxy-Fuel</th>
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<tbody>
<tr>
<td>Glass Pull Rate (tpd)</td>
<td>330</td>
<td>330</td>
</tr>
<tr>
<td>Cullet ratio (% charge)</td>
<td>30 30</td>
<td></td>
</tr>
<tr>
<td>Flue gas temperature (F)</td>
<td>2620 2600</td>
<td></td>
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<tr>
<td>Fuel Input (MMbtuh)</td>
<td>53.14 53.28</td>
<td></td>
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<tr>
<td>Energy Outputs (MMbtuh)</td>
<td></td>
<td></td>
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<tr>
<td>Energy to batch reactions and glass</td>
<td>24.64</td>
<td>24.64</td>
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<tr>
<td>Tank &amp; Furnace wall heat loss</td>
<td>6.60</td>
<td>6.84</td>
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<tr>
<td>Flue gas sensible and latent heat</td>
<td>21.90</td>
<td>21.80</td>
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<tr>
<td>Total</td>
<td>53.14 53.28</td>
<td></td>
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<tr>
<td>Specific Energy (MMbtu/ton)</td>
<td>3.86</td>
<td>3.87</td>
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**Distributor and forehearth mixture heating system**

HORN has had many years of experience with heating feeders and distributor channels, using a mixture of gas and air produced by Venturi mixers and combined using Venturi and injection mixers. However following customer requests, in 1988 HORN started to develop a new mixture heating system.

The resultant new Cora (constant ratio) mixture heating system has been used for distributors, forehearts and burners with air casing, such as wide and constant control range, low maintenance and optimum combustion. The system is designed to be integrated without difficulty into almost any mixture heating system.

Forehearth and mixing systems that do not work constantly can have pressure fluctuations, which lead to poor combustion and therefore to reduced glass quality. The essential features of the Cora system compared to conventional systems are:

- The forced mixing of gas and air takes place in a specially designed mixing pipe. This ensures excellent mixing of gas and air quantities for minimum throughput.
- The adjusted air quantity flows through a differential pressure orifice gauge. The differential pressure which results and which is influenced by the throughput rate is fed into a special ratio controller, which adjusts the corresponding gas quantity proportionally to the respective air quantity.
- Adjustment of the required air quantity is made by a directly driven motor control valve with a control cone that has linear KV value.
- In case of an unacceptable mix pressure, a gas safety stop valve is integrated into the ratio controller to enable safety gas cutoff of the control section.
- Admission pressure of combustion air can be constantly controlled and adjusted using a thyristor-controlled combustion air fan.

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