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**All-electric forehearth developments**

In a two part article, Grahame Stuart considers the design advances and benefits of all-electric forehearths for both volatile and non-volatile glasses. Part one focuses on the conditioning of volatile glasses, with an emphasis on fluoride opal and borosilicate, while also looking at ancillary systems that can be included in a new or existing forehearth design to further benefit the overall conditioning process.

Conditioning of volatile glasses such as fluoride opal and borosilicate presents the forehearth designer and glassmaker with many challenges. The aggressive nature of these glasses is one of the biggest hurdles that both designer and operator must overcome. Loss of constituents through volatilisation affects final glass quality. This can, of course, be overcome by increasing the amount of fluorine or boron in the batch to compensate. However, this approach is not only costly from a raw materials standpoint but also increases the chance of wear on surrounding refractories, as well as posing a significant health and safety risk to operators. Furthermore, it does not solve the problem of chemical inhomogeneity, resulting from surface volatilisation.

**SEALED FOREHEARTHS**

In order to overcome these problems, some forehearth designers have used submerged cover tiles to prevent the glass being conditioned from coming into contact with the atmosphere. However, this approach introduces an additional problem by increasing the surface area of refractory in contact with the glass. Basic physics tells us that heat rises. Therefore, it is accepted that the hottest glass in a forehearth is at the surface, in contact with the submerged cover tile. The upward drilling effect of this hot glass attacks the underside of the submerged cover tile, increasing the wear rate. This, in turn, increases the levels of refractory contamination that must be dealt with in order to prevent it having an impact on the final production.

A further challenge is the effective heating and cooling of 'sealed' forehearths. Immersed electrodes are commonly used for primary heating, with either an electric or gas heated muffle chamber to counteract superstructure losses. The designer is faced with a choice of water-cooled advanceable electrodes or non-advanceable dry electrodes. In many cases, combinations of both are used; however in borosilicate glasses, where a risk of reboil exists, it is normal for only dry electrodes to be used.

Cooling of the glass in sealed forehearths is accomplished through either adjustable dampers in the forehearth superstructure or in some designs, forced air cooling applied within the muffle chamber. Effective cooling is a challenge; too much cooling applied in one area, particularly forced air cooling, can create steep temperature gradients, which can cause cold glass to ‘cling’ to the glass contact face of a submerged cover tile, increasing the risk of glass quality problems. A steep thermal gradient also increases the risk of cracking of the refractory cover tile, which can lead to refractory falling into the glass and also volatile vapours escaping from the forehearth, all of which result in poor glass quality and require costly, time-consuming replacement of the damaged cover tiles.

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*A piece of worn superstructure refractory from a fluoride opal forehearth.*

A typical sealed forehearth.

*One of the many Electroseal forehearths in operation today.*

*Damage caused by harmful vapours on a fluoride opal forehearth.*
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DESIGN WITH MULTIPLE BENEFITS

Many years of experience in conditioning volatile glasses has resulted in the present generation of Electroglass Electroseal foreheaths. These have been designed to combat the problems mentioned above, while at the same time reducing energy consumption, simplifying operation and maximising production yield. Many are in operation today in both fluoride opal and borosilicate production lines. In many instances, they are conditioning glass produced in an Electroglass all-electric furnace.

The first major feature of the Electroseal forehearth is the different approach to cover tile design. As mentioned, immersed cover tile designs are intended to prevent volatilisation. However, they increase the glass contact refractory area by anything up to 40%, meaning increased risk of refractory cord and related production problems.

Electroseal overcomes these problems by using an interlocking cover tile design that is above the glass surface, leaving a small gap in which initial volatilisation occurs until the atmosphere becomes saturated. Once saturation is reached, further volatilisation is minimal. Actual operating data has shown that in fluoride opal production, a total fluorine loss from batch charging to production of less than 3% is readily achievable. The interlocking design also ensures that the amount of aggressive vapours released from the forehearth through refractory joints is kept to an absolute minimum. This is an extremely important consideration, given the highly corrosive nature of vapours, which readily consume both refractory and surrounding bracing steel.

CAREFUL HEAT DISTRIBUTION

Many volatile glasses require very careful temperature control to prevent reboil or devitrification, which can impact increased ware rejections through the generation of seed and blister. Immersed electrode heating is used to prevent large thermal gradients along the forehearth.

Electrode selection is very important and varies from one glass type to another. In a borosilicate glass where the risk of reboil is at its greatest, for example, it would be typical to use dry-type electrodes throughout the distributor and forehearth system, the reason quite simply being that water-cooled electrode holders, however well designed, increase the risk of ‘cold spots’ along the forehearth side which, in turn, can lead to homogeneity problems.

Dry electrode design is an important part of the overall Electroseal concept. Considerable time has been spent developing a dry electrode that removes the risk of dissimilar metal contact, a problem associated with several other designs available today. Contact between dissimilar metals can lead to galvanic reaction, with the generation of DC voltage resulting in the formation of oxygen-rich seed that, when generated so late in the conditioning process, is likely to be present in the product. A further and potentially more serious problem associated with dissimilar metal contact is the risk to the molybdenum electrode from oxidation, which can ultimately lead to electrode failure.

The Electroglass dry electrode design features a high temperature stainless steel outer sheath, electrically isolated from the molybdenum electrode, which makes no contact with any other metals throughout its length. This design ensures that no dissimilar metal contact is possible, removing the risk of dc-generated seed and the oxidation problems associated with it. Many hundreds of these electrodes are manufactured every year, not only for new systems and rebuilds but to also replace other designs that have suffered failures or have caused glass quality problems.

In addition to immersed electrode heating, the Electroseal features an all-electric muffle. This is designed to compensate for superstructure heat losses and uses robust ‘U’ heating elements. These elements are divided into control zones along the forehearth length.

COOLING ONLY WHERE NEEDED

Ultimately, the purpose of a forehearth is to cool and condition glass to the parameters required by the forming process. Each Electroseal forehearth is designed such that it can achieve the required forming temperature with minimum power input and without the need for forced cooling which, as already mentioned, can be detrimental to cover tile life.

The Electroseal design incorporates dampers that allow radiant heat release along the forehearth centreline where the glass is hottest. It is possible for an individual damper to shed around 8kw of heat at rated output when fully open and an individual forehearth may have up to seven dampers, meaning a wide forming temperature pull range can be achieved, without the application of excessive power.

SIMPLE CONTROL SYSTEMS

As with all Electroglass control systems, the Electroseal is designed to be operator-friendly. With a minimal amount of training, it is possible for an operator to make full use of the forehearth control and monitoring systems.

The primary control system, a Scada-based PC, offers simple, informative screen designs, centred around an image of the forehearth allowing the operator to change temperature and power setpoints on simulated PIDs. Long-term trending of all operating parameters becomes a useful tool when wishing to replicate settings to suit a particular job. A secondary control system offers a complete back up should the Scada fail. This system consists of analogue metering, automatic PID and manual control of power to all zones and thyristor bypass controls should a failure occur.

The Electroseal forehearth, with its special cover tile arrangement and profile heating elements. Electrodes have been omitted for clarity.
MARKET SUCCESS
Numerous Electroseal forehearths are now in service, conditioning various glass types including fluoride opal, borosilicate and lead crystal. Products include tableware, kitchen ware, decorative pieces, flaconnage, containers and lighting glass.
Several systems are currently under design or construction and demand looks set to continue.

ANCILLARY SYSTEMS
Many of the Electroseal forehearths designed to date feature other Electroglass technology that can be used on existing forehearths, either gas or electric and can, in most cases, be installed during operation.

The Electroglass level sensor offers real time glass level information and is accurate to within ±0.1mm. It features a refractory probe block assembly that requires the minimum of maintenance and has no need for water or air cooling. There are no moving parts and no calibration is needed to compensate for changes in operating temperature or glass composition. Three variants of the probe block are now available, making it easy for the system to be incorporated into an existing production line.

Two control options are available, the first being a simple level sensor that displays real time glass level and offers an output to an existing control system to allow the glass level information to be used by an existing glass level control system. The second is a fully integrated glass level control system, featuring high and low glass level alarms, limited trending and an HMI touch screen display.

Refractory wear is a major cause of glass quality problems and the aggressive nature of glasses such as fluoride opal means that refractory wear can impact on glass quality after just a few months of operation. Glass contaminated with zircon and other refractory constituents tends to move along the forehearth bottom very slowly and presents itself in production as cord and also, in the case of fluoride opal, a discoloring of the finished product.

One solution adopted by some glassmakers is to add stirrers in the conditioning section to help break up the cord and disperse it throughout the product. Although this approach can be quite successful in some glass types, it cannot overcome the problem of discolouration in fluoride opal production. Stirrers also increase the amount of maintenance required on the forehearth as they involve motors, gearboxes and other moving parts which must be lubricated on a regular basis. Also, refractory stirrers themselves will wear, adding to the contamination of the glass and further increasing maintenance as periodic replacement is required.

An alternative approach successfully used by Electroglass is to install its continuous controlled drain system in the forehearth, close to the end of the conditioning section. The drain system consists of two parts. The first is a free-standing control panel housing a small transformer and thyristor unit, analogue metering and a PID controller. The second, the drain assembly itself, is constructed of high temperature stainless steel and has a number of air and water cooling circuits that can be adjusted in order to start, control and stop glass flow. Encased within the drain body is a replaceable heating element housed in a special refractory sleeve, complete with thermocouple. The drain tube itself is produced from either platinum or an alloy of platinum and rhodium and is sized to suit the individual application.

The operating principle is simple; testing has shown that slow, continuous draining of glass is by far the best way of drawing off refractory contaminated sludge glass. Fast draining has a tendency to draw off more of the hot, well conditioned glass which has a much lower viscosity, meaning that contamination of the product still occurs. Therefore, the Electroglass drain system is designed to drain at a rate of typically approximately 240kg/day. This is achieved firstly by designing a suitably sized drain tube using glass viscosity and temperature data supplied by the customer and secondly, through the use of the flexible control system for control of flow rate.

The drain is started by removing the water cooling from several of the cooling coils. Power is then applied to the heating coil in order to raise the temperature of the drain nose and drain tube. Once glass flow starts, the drain temperature is reduced gradually using a combination of water and air cooling until the required glass flow rate is achieved. At this point, element power control is set to automatic and the PID controller monitors the temperature of the drain body and adjusts the power output to the heating element in order to maintain the correct temperature and therefore, correct flow rate.

Although the drain is intended for continuous operation, some glassmakers prefer to use the drain intermittently, switching on for short periods to clear sludge glass collected in the trough, machined into the glass contact face of the channel block. The Electroglass drain can be installed during forehearth operation by employing special drilling techniques that allow the creation of a trough within the forehearth. This ability is extremely useful when glass quality problems occur part way through a normal campaign and can help avoid the expense of shutting down and partially rebuilding the forehearth in order to incorporate the glass contact refractory modifications needed to make best use of the drain system.

Part two of Grahame Stuart’s review will be published in the next issue of Glass Worldwide and will concentrate on non-volatile glasses, with particular emphasis on high capacity conditioning of soda-lime container glasses.

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