Electric melting and boosting for glass quality improvement

In the first part of his article, Richard Stormont looks at how electric boosting can help improve the quality of glass being produced.

Electric melting systems are incorporated into new fuel- or oxy-fuel-fired glass melting furnaces, and a much greater number of boost systems are added, reinstalled or enlarged in the course of furnace repairs. In many of these cases the boost system is still seen primarily as a means of increasing furnace output, to be used only when necessary. But this is to underestimate the potential of electric boosting to influence overall furnace operation, energy consumption and glass quality, as well as just adding energy to the melting process and increasing output.

Glass melting is an energy-intensive process. The net melting energy needed to convert mixed raw material into fully melted and refined glass can be taken as about 520 Kilocalories per Kilogram, or in electrical energy terms, about 0.6 Kilowatt-hours per Kilogram (kWh per kg) of glass. This assumes about 20% cullet, and varies to some extent according to both cullet percentage and glass type. The thermal efficiency of glass melting furnaces varies according to furnace design and glass type, but the best fuel-fired furnaces might have a thermal efficiency of only around 45%, and many have thermal efficiencies of significantly less than this. In this illustration I have assumed a figure of 40%. Clearly in all fuel-fired furnaces more energy is released into the environment as heat loss than is used to actually convert the raw material to molten glass. To save energy in glass melting, we must therefore focus on ways to reduce these heat losses.

The reason for most of this inefficiency is in the basic concept of all fuel-fired or oxy-fuel-fired furnaces. Some level of loss from the bottom and sides of the tank is inevitable, although they can be minimised by good insulation. However as illustrated in Figure 1, the process relies on achieving high flame and superstructure temperatures through oil or gas combustion, with temperatures that must by definition be higher than the glass temperature, and transmitting heat to the glass by radiation and some conduction. The result of this indirect transfer of energy from fuel to glass is high heat losses from the superstructure of the furnace and high losses in the residual waste gases, even if heat recovery systems such as regenerators or recuperators are used.

DIRECT MELTING ENERGY

So how can we get melting energy more directly into the glass? The most effective method is by the use of immersed electrodes in the form of either electric boosting or all-electric melting. With immersed electrodes in the glass connected to a suitable power supply and transformer, we can pass an electric current through the glass, releasing heat energy directly into the glass itself, with no significant losses in the process.

Of course we have to ensure that the heat released into the glass by electrodes does not adversely affect other aspects of the furnace performance, for instance by creating convection currents in the wrong places or causing short cut flow paths that reduce effective residence time in the furnace. Selection of the optimum number, positions, spacing, size, immersion and connection arrangements for boosting electrodes all contribute directly to the difference between an efficient and an inefficient boost system design.

In electrical energy terms, again at about 20% cullet levels, the theoretical net melting energy requirement is about 0.6 kWh per kg of additional glass melted by the boosting system. In many boost systems the actual figure is substantially higher, however with today’s best boosting technology we regularly see actual boost system energy requirements of 0.48 kWh per kg, or 20 Kilowatts of continuous power input per additional tonne per day (tpd) of glass. This apparent ‘super-efficiency’ is entirely due to the fact that a well-designed boost system can actually improve the operational efficiency of the fuel-firing heat transfer through beneficial convection currents and increasing the effective minimum residence time, as well as adding melting energy to the process.

So electric boosting can be a highly effective way to reduce overall energy consumption. In Figure 2 we see the typical net melting energy and the energy losses in a 200 tpd unboosted fuel-fired furnace. In this
example we have a total energy consumption of about 1300 KiloCalories per kg of glass. If we then compare that with an electrically boosted furnace in which 75% of the glass is melted by the fuel-firing and 25% by a modern Convection Current Control boosting system, as illustrated in Figure 3, then due entirely to the efficiency of the boosting we find that total energy consumption might fall to around 1080 KiloCalories per kg, an energy saving of 17%.

Of course a comparison of melting energy costs in this example will depend on the relative costs of fuel (gas or oil) and electricity for the boost system. In capital cost terms it can be significantly cheaper to build, for instance, a furnace with an unboosted output of 150 tpd and install a 50 tpd boosting system, giving a total output of 200 tpd, rather than to build a furnace with an unboosted capacity of 200 tpd.

CONTRIBUTING TO GLASS QUALITY

Just as there are often substantial differences in the energy efficiencies of different designs of boost system, so there are big differences in their contribution to glass quality – the two are closely linked. The key is in the electrode arrangement and the energy release pattern that the electrodes create in the furnace, which in turn directly affects temperature profiles, convection currents, flow paths and residence time. Understanding the distribution of energy release from immersed electrode systems is crucial in boost system design.

Any electrode system releases energy directly into the glass, making the application of boost energy fundamentally much more efficient than the indirect heat transfer from the top firing. Whatever steps are taken to create the desired furnace temperature profiles by means of the top firing, radiant heat transfer from flames and superstructure is multi-directional, resulting in imprecise temperature profile creation in the glass. By contrast, electric boost system energy release can be highly focussed.

Boost system design, and in particular electrode positioning, is therefore extremely important in determining conditions in the glass bath. A poorly designed boost system will create adverse convection currents, perhaps conflicting with hot spot convection created by the top firing. It may also result in reduced residence time by promoting forward convection currents, affecting glass quality. It will certainly require an excessive amount of electrical energy in relation to the additional glass being produced, simply to overcome the design limitations of the system itself.

A well designed boost system creates convection currents that co-operate with the actual or desired effects of the top firing and uses the electrical energy release pattern to increase the minimum residence time, improving glass quality in terms of seed, stone losses and homogeneity. Most importantly, by releasing the boost energy in a way that actually helps the top firing to perform its function better, today’s best boost systems can require significantly less electrical energy input than is theoretically required for the additional glass produced.

CONVECTION CURRENT CONTROL

The Convection Current Control (CCC) boosting concept (see Figure 4) was developed in the 1980s and has been continuously refined since. Consistent with the approach of designing the boost system to co-operate with the top firing, most or all of the boost energy is applied by means of electrodes in the hot spot area of the furnace. The object is to create or reinforce hot spot convection, promoting long-range convection currents. The action of the thermal barrier effectively prevents un-melted material from reaching the throat and increases minimum residence time by preventing the short-cut movement of glass along the surface. The reverse convection current also helps to keep the batch back and the slow circulation of glass improves heat transfer from the top firing.

One case history that demonstrates the effect of boost design on both energy efficiency and glass quality is a 90 m² UVA green container glass furnace which was originally equipped with an electric boost system supplied by the furnace designer. After about two years of operation Electroglass was invited to review the boost system design and operation and subsequently to completely redesign the system. The original system was designed to apply the majority of the boost energy in the melting end of the furnace. The Electroglass recommendation was to abandon the melting end electrodes and to install additional hot spot area electrodes to create a CCC configuration. The result was an immediate reduction in boost energy consumption of almost 20% and a 94% reduction in seed count (as illustrated in Figure 5), combined with a 60°C reduction in bottom temperature.

So, to make a real impact on glass quality as well as energy consumption and environmental protection in the energy-intensive process of glass melting, we should be making better use of technologies already available in the electric boosting of fuel-fired furnaces. In Part 2 (in the next issue of Glass Worldwide) I will look at all-electric
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In the concluding part of his article, Richard Stormont investigates all-electric melting and electric forehearths and their contribution to glass product quality, as well as energy conservation and the environment.

**Thermal Efficiency**

The first part of this article explored the beneficial effects that electric boost can have on convection currents, heat transfer, temperature homogeneity and residence times – all of which contribute to glass quality and energy efficiency. The logical next step, then, is to consider all-electric melting.

In all-electric furnaces the entire melting energy is applied by means of immersed electrodes, with gas being used only for the initial heat-up of the furnace, or as an emergency heat source in case of a prolonged power cut. Most such furnaces operate ‘cold top’, with the raw material being distributed evenly over the melting surface of the glass, forming an insulating batch blanket (as shown in Figure 1). Melting and refining essentially take place in one continuous vertical process, with glass being drawn through a throat at the bottom of a relatively deep melting tank.

The energy efficiency of such furnaces can be very much higher than fuel-fired furnaces because, while there are still some losses from the substructure, there are very low losses from the superstructure. Due to the insulating properties of the batch blanket in a well-designed all-electric furnace, the superstructure temperature can typically be little more than 100°C (212°F). The result is a thermal efficiency that can be over 70% even in a small electric furnace of 10 tonnes per day (tpd), and can reach 85% in a large electric furnace.

**Relevance to Small Furnaces**

The difference in energy efficiency between fuel-fired and electric furnaces is particularly important in the case of relatively small furnaces. Figure 2 shows that as furnace size decreases, the energy efficiency of electric furnaces remains very high, whereas the efficiency of fuel-fired furnaces drops dramatically and can be less than 20% in small furnaces.

The batch blanket in an all-electric melter does much more than reduce heat losses, leading to improved energy consumption. A key advantage of the cold-top electric melter is that everything that goes into the batch stays in the glass, apart from the gases released from the melting process, which permeate out through the batch blanket. Losses of batch constituents such as fluorine, boron, lead, various relatively volatile refining agents and other constituents are virtually eliminated.

In an Electroglass fluoride opal electric melter in Germany, the loss of fluorine between batch and glass is just 3%. This not only reduces batch costs, as the losses do not have to be compensated for by increasing the batch quantities, but has a direct effect on glass quality as glass composition is predictable and consistent. So all-electric melting can lead to energy efficiencies of up to 85%, consistent glass quality, with no environmental pollution and furnaces that are silent in operation.

**Widening the Product Range**

Electric glass melting furnaces have been used mostly for special glasses, but in the conclusion the author explores the potential for using them for a wider range of products.
and particularly glasses with significant volatile constituents such as fluoride opal glasses, borosilicates and lead crystal. However, as world energy costs recently moved against gas and oil and in favour of electricity, there is greatly increased interest in large all-electric furnaces for conventional glasses for containers and other products. Figure 3 shows a 250 tpd Electroglass all-electric furnace which, when melting flint container glass, requires just 710 Kilowatt-Hours of electricity per tonne of glass, equivalent to a thermal efficiency of 85%.

Energy consumption, combustion gas emissions and glass quality are other benefits of forehearts used in many sectors of the glassmaking industry – remarkably, while most glassmakers know how much energy they are using in their melting furnaces, a surprising number take little notice of the energy used in their forehearts.

As with electric melting furnaces, well-designed all-electric forehearts can have exceptionally high energy efficiencies. In a typical container glass application under normal operating conditions, a modern electric forehearth may only require a total power input of 15 to 25 Kilowatts to properly temperature control and condition 90 tpd of glass.

Significant reductions

In 2008 Hite Industries, a Korean container glass producer, installed two Electroglass all-electric forehearts, one with a 36-inch and one with a 48-inch channel (see Figure 4), as direct replacements for gas-fired forehearts and reduced its forehearth energy costs by over 70%. Electric forehearts are also completely silent in operation and emit no polluting combustion gases. Radiant profile heating and radiant centre-line cooling allow excellent temperature control and response, eliminating the effects that combustion gases can have on the glass and eliminating forced air cooling, which can introduce impurities as well as creating undesirable surface chilling effects.

So to make a real impact on glass quality, energy consumption and environmental protection in the energy-intensive process of glass melting and conditioning, perhaps we should be making better use of technologies already available: electric boosting of fuel-fired furnaces, all-electric melting and electric forehearts. Glass product quality, as well as the world’s energy supplies and the environment, will benefit from this responsible approach to glass production.

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Figure 1: Most such furnaces operate “cold top”, with the raw material being distributed evenly over the melting surface of the glass, forming an insulating batch blanket.

Figure 2: As furnace size decreases, the energy efficiency of electric furnaces remains very high, whereas the efficiency of fuel-fired furnaces drops dramatically and can be less than 20% in small furnaces.

Figure 3: A 250 tonnes per day Electroglass all-electric furnace, the largest in the world, with a thermal efficiency of 85% when melting flint glass.

Figure 4: In 2008 a container glass producer in Korea installed two Electroglass all-electric forehearts.