How space shuttle technology improves crown emissivity

Thanks to a licensing programme allowing the use of pioneering NASA technology, the glass industry is discovering the benefits of high-emissivity nano-particle coatings for furnace refractories. Stuart Hakes* explains how Emisshield could lead to changes in material choices and furnace design.

Fig 1. For the space shuttle programme, NASA developed various coatings to withstand the re-entry temperatures of up to 1650°C.

High emissivity coatings have been around in various forms for well over 30 years. These products, which contain high emissivity oxide materials were, however, limited to applications with maximum temperatures of less than 1150°C. At higher temperatures, the emissive properties of these coatings decrease steadily to such a degree that they provided no meaningful benefit and were certainly not cost-effective in the glass industry.

For the space shuttle programme, NASA developed lightweight ceramic thermal barrier protection for the shuttle but the maximum service temperature of these materials was not capable of withstanding the re-entry temperatures of up to 1650°C and so various coatings were developed to absorb and re-radiate the heat in the hottest areas to isolate these tiles from the plasma generated on re-entry. For the next-generation Orbitor (***fig 1***), which NASA was developing to replace the existing shuttle, new technologies were developed including improved high-emissivity coatings. With the cancellation of the shuttle replacement, these high emissivity coatings have been made available to other industries through a licensing programme.

Adaptation of technology

Emisshield took this technology and developed specific patented binder systems compatible with many different types of refractory which, when combined with NASA's high-emissivity materials, produce a family of high-performance coatings that maintain emissivities near that of a theoretical Black Body at glassmaking temperatures. These coatings, marketed under the Emisshield brand, were commercially introduced to the glass industry in 2006 by NARCO with FIC (UK) as an authorised sales and marketing partner.

The coatings are applied with a special spray gun and are only 6-8 microns thick (***fig 2***). The precise composition of these coatings is a commercial secret but the coatings are predominantly silica, which will not cause problems in the unlikely event that they are introduced into the glass melt, i.e. they will not cause blisters, stones or discolouration.

Fig 2. Spraying a high emissivity coating on the crown of a furnace.

Emisshield is not an insulator. It is not a barrier to the conduction of thermal energy through the refractory wall. This coating improves the emissivity of the refractory by changing the emissivity of the surface. A typical refractory surface in a glass furnace, at operating temperatures, has an emissivity in the range of 0.4 - 0.6. The application of Emisshield to the refractory increases this to approximately 0.9. This means that around 90% of the energy absorbed by the coating is re-radiated to the cooler glass.

Minimising heat loss

Nowadays, all furnaces have an insulated crown as standard design practice. While this reduces heat loss from the furnace, the amount of heat stored in the refractory is very high and the internal crown refractory material must withstand higher temperatures because the insulating refractory behind it acts as a heat sink and therefore valuable energy is absorbed by the refractories and lost by conduction to the cold face.

Additionally, convective energy held by the furnace combustion gases is lost up the flue. However, when Emisshield is applied to the hot face of the furnace superstructure and crown, radiant and convective energy from the burners and the hot furnace gases are absorbed at the surface of the coating and re-radiated back to the cooler glass. Therefore for Emisshield to be at its most effective, the temperature of the coating surface must be greater than the temperature of the glass, which is always the case when glass batch is being melted and when glass is being refined.

If we go back to basic physics, the formula for the amount of energy re-

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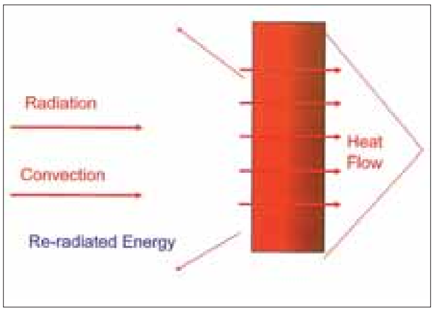
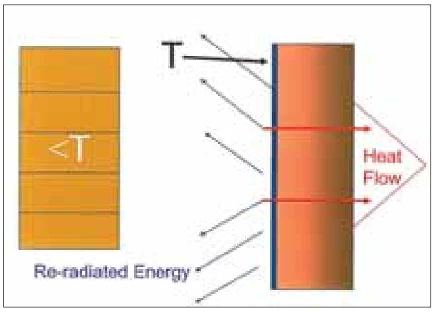


▲ Fig 3. Without Emisshield coating.



▲ Fig 4. With Emisshield coating.

radiated from a surface is equal to the emissivity of that surface E_c multiplied by a constant (the Stefan Boltzmann constant) multiplied by the temperature difference of the two surfaces (glass T_g and refractory T_r) to the power of 4:

$$Q = E_c \ x \ \sigma \ x \ (T_r^4 - T_g^4).$$

The application of Emisshield in the superstructure increases the radiative component of the glass at the expense of the convected component. The coating absorbs the convective heat from the hot gasses and re-radiates this energy to the glass. The result is less energy being lost up the flue and more energy being used to heat the glass.

The application of Emisshield to the uncoated refractory increases the emissivity to around 0.9 at glass melting temperatures. This means about 90% of the energy absorbed by the coating is re-radiated to the cooler glass surface. This change in the quantity of heat absorbed by the glass will increase significantly. As the furnace is required to operate in a steady state, the fuel is reduced as the quantity of heat going to the melting process is increased and the quantity of heat in the refractory is reduced. This is where fuel savings are made (***figs 3 & 4***).

Depending upon the size of the tank and the way it is operated, fuel savings of up to 10% can be expected. Alternatively, if no change to the amount of fuel to the burners is made, then the pull could be increased in the furnace.

Stable batch and temperature

Most furnace operators would agree that they control the furnace by one of three main factors: The temperature of a thermocouple on the floor; the temperature of a thermocouple in the superstructure; or, more likely, the position of the batch line in relation to the furnace geometry. This is really the critical control parameter. The measurement of temperatures in the floor and superstructure are only a means to achieving a given batch line.

When using the Emisshield coating, if the position of the batch line is maintained at the pre-coated position then fuel will have been reduced. Another critical part of the furnace operation is the temperature of the glass going through the throat and again with the Emisshield coating the glass is hotter, so in order to maintain the same temperature through the throat, fuel has to be reduced. This results in a lower furnace atmosphere temperature and lower flue temperatures.

It is normal to coat both the breast walls and crown of a glass tank with Emisshield prior to the furnace heat-up process, as currently furnaces can only be coated during a cold repair. Development is ongoing to produce a coating that can be applied during furnace operation.

Because of the way that the coating works, by re-radiating to the cooler surface very little heat is conducted through the coating and is absorbed by the refractories behind it, so the degree of crown rise typically experienced during the warm-up of the furnace after rebuild or repair is much less than would be normal without the coating. As the furnace gets hotter, the temperature difference between the crown and the rest of the refractory reduces and therefore the crown will start to rise.

This means that furnace steelwork adjustments are quite different from those on a furnace without a coating, i.e. crown rise occurs much later. This shows the effectiveness of these coatings.

During fill-on the same phenomenon occurs; the temperature difference between the crown and the batch will drop and the crown may settle a little but will then rise again as the batch heats up and eventually melts to glass. The crown will stabilise as production stabilises and at this point it can be sealed. This 'drop and rise' cycle is not a problem – it is just different from the usual crown expansion experience.

Furnaces that are cooled down and repaired with frozen glass in the melter can be sprayed with Emisshield and these will also exhibit little heating of the crown early in the heat-up schedule. As the glass heats and finally melts, the temperature difference will decrease and the crown will rise. Another 'drop and rise' cycle can be expected when the glass batch is introduced. Again, the crown should not be sealed until production stabilises. Furnaces with silica crowns will show less movement with the introduction of batch materials above the quartz inversion temperature.

It should be noted that the coating is not effective on fused cast AZS materials as these exude a glassy phase which renders the coating less effective. Bonded AZS refractories are, however, easily coated and perform very well.

Current applications

Currently, there are more than 28 furnaces that have been coated worldwide. Most of these are in the USA but some in Mexico, UK, Holland and Germany. Virtually all of these furnaces are owned by multinationals that are leaders in their field. Approximately half of the furnaces are oxy-fired and the other half are conventional natural gas. Products range from standard soda-lime containers, tableware, 'E' glass, 'C' glass and sodium silicate.

This large body of furnaces is clearly demonstrating that up to 10% fuel savings are achievable. The first furnace coated with Emisshield was a fibre furnace and this has now been in operation for nearly three years and the coating is still effective.

A very significant feature of this furnace, which melts a boron-containing glass, is that the furnace continues to show the effectiveness of the coating after three years as the fuel savings are still showing. Behind this lies a very significant fact to do with the financial payback of the coating.

It would be normal to expect high rates of wear on this furnace due to both the action of the boron as well as other glass raw materials and the oxygen firing. This means that the rate of wear/erosion of the furnace superstructure has been reduced. We have no idea how long this coating will be effective but after three years we can say that it could have a significant effect

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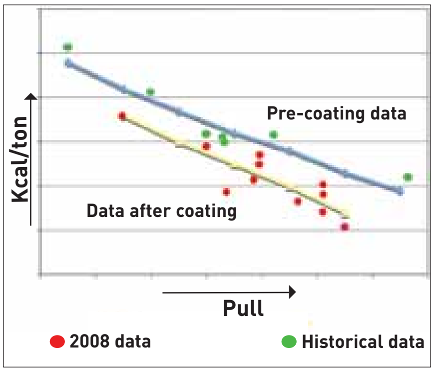

▲ On the left, a bonded AZS refractory plate coated with Emisshield and dried.
On the right, the same plate after firing at 1400°C.

on the types of refractory used in the crown and also the thickness. The use of Emisshield coating not only saves fuel but also increases furnace life.

FIC (UK) believes that as well as this conventional approach to the use of the coating on the inside surfaces of the furnace (non-glass contact) there are also good technical reasons to consider Emisshield on the external surfaces of the furnace, i.e. the coating will work in reverse. The coating will draw heat through the refractory and radiate it more effectively to the air. To this end, FIC (UK) is seeking companies that will trial the coating on either the exposed flux line area of the soldier blocks or on the throat area.

It is a practice in most glass companies that the flux line soldier block cooling is not used for approximately the first 12 months of the furnace life. The reason for this is that the effectiveness of the cooling is not good initially and in fact is believed to hasten the corrosion of the flux line internally. FIC (UK) believes that the reverse radiation effect of Emisshield could slow down corrosion for longer and further delay the use of wind cooling. Initial laboratory tests would seem to support this view. The problems described earlier of using Emisshield on fused cast AZS are not applicable as the external face is usually not hot enough for the exudation of the glassy phase. If these initial simple tests are borne out over the life of the furnace, it is possible that one day we might see not only a reduction in the electricity to run these fans for shorter periods, but possibly even the elimination of sidewall and throat cooling entirely. Both of these features have yet to be proven with the cost of installation and a trial being extremely small.

FIC (UK) believes that the future of glass melting with these coatings will become standard due to the benefits of 10% fuel savings, which also reduces CO_2 emissions as well as SOx and NOx. The extra furnace life could lead to significant changes in material choices and possibly furnace design. Currently, there is a forehearth system in operation using these coatings in reverse and showing useful results.

The use of the coating on the forming machine and annealing lehrs is also being investigated and trials are about to be undertaken. Nano-particle coatings may not have gone into space with the Orbitor but they are certainly the future of the glass industry. ■

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