Forehearths for thermal conditioning

DUE TO THE GLASS INDUSTRY'S LONG AND DISTINGUISHED HISTORY, MANY OF THE TERMS USED TODAY NO LONGER DESCRIBE THE EQUIPMENT THEY REFER TO. DEMANDING FORMING PROCESSES AND CONTINUOUS TECHNOLOGICAL INNOVATIONS IMPOSE NOT ONLY HIGHER AND HIGHER PERFORMANCE EXPECTATIONS BUT ALSO FASTER PRODUCTION REQUIREMENTS DOWNSTREAM. THIS ARTICLE TAKES A LOOK AT THE FOREHEARTH AND ITS EVOLUTION, AS EMHART GLASS SAYS, FROM COOLING ZONE TO THERMAL CONDITIONING ZONE.

JOHN MCMINN*
EMHART GLASS

INTRODUCTION

If we discount glass bead production, evidence for which dates back 5,500 years, it is believed that hollow glassware production, in the form of vases, began some 3,800 years ago.

The technique of glassblowing came to us some 2,000 years ago, culminating, admittedly somewhat later, in the introduction of the automatic blowing machine at the end of the 19th century and the invention of the automatic gob feeder in 1923.

Perhaps, because of the glass industry's long and distinguished history, we lack the exciting but confusing acronyms that have blossomed amongst the newer technologies of the 21st century and have to make do with comparatively jaded terminology.

Hence, we maintain terms that no longer reflect the equipment they purport to describe.

We do not work in 'working ends', we do not refine in 'refiners' and the 'forehearth' is no longer a gathering hole in front of the furnace.

It could also be said that we no longer cool in forehearth cooling zones – but rather, we thermally condition the glass by a process in which cooling is but one element.

REDEFINING THE PROCESS

More demanding forming processes such as NNPB, and technological innovations in forming machines such as the new NIS machine, impose higher performance expectations on both the processes that supply the machine and those which it supplies. Faster machines and processes require faster ware handling downstream from the machine. Similarly, faster production requires faster gob delivery and more effective forehearth operations. An innovation in one section of the process should, therefore, be balanced by innovations in the other processes. As a key element in the process, the forehearth not only requires innovation in design but also a reconsideration and redefinition of the role of the cooling zone. The term 'cooling zone' does not adequately describe the intricate processes that occur in the forehearth, nor does it reflect the innovation in refractory engineering, superstructure geometry and flue exhaust controls that are vital to the conditioning process.

In short, it is too simplistic to call a forehearth cooling zone a 'cooling zone' – it is a 'thermal conditioning zone'.

With varying degrees of imagination and success, different forehearth designers have attempted to maximize the conditioning potential of their forehearth designs.

Generally, all forehearth designers accept that the forehearth cooling function is the primary control element in achieving gob temperature and, consequently, this feature is the basis on which most forehearths are designed. Since forehearth superstructure geometry plays a vital role in the cooling function, and hence the conditioning process, the superstructure geometry in general, and the roof block shape in particular, effectively define and identify individual forehearth systems.

Lack of consensus and presence of patents has ensured that an interesting array of cooling solutions has proliferated amongst the major forehearth designers. Ignoring the more esoteric, these can be categorized as radiation cooling, muffle cooling and longitudinal direct cooling. Within varying degrees, each of these designs has individual merits yet, if examined more closely, one can identify weaknesses associated with each design.

They may achieve cooling but do they achieve conditioning? To consider this, we must first define conditioning.

Conditioning is a purely thermal process and can be defined as the achievement of a stable, desired glass temperature universally distributed throughout the vertical and lateral planes of the glass at the entrance to the spout. In isolation, a forehearth cooling system will be unable to satisfy this definition.

Typically, the glass will have lateral and vertical temperature gradients associated with both the flow through the forehearth and the substructure conductive heat losses. Because of the influence of temperature on glass viscosity, the flow differential between the central glass stream and the side glass stream increases, as the glass becomes more viscous towards the channel walls. The aim of the forehearth is two-fold; it must dissipate these gradients and it must stabilize the glass temperature at a level consistent with the requirements of the forming process.

Abstractly, this requires a mechanism that can selectively remove and replace heat from the glass over a variety of tonnage and temperature conditions.

To implement this mechanism, an understanding of the importance of glass surface and superstructure refractory surface is crucial. In a dynamic control situation, all heat input to the glass or removed from the glass occurs through the glass surface. In addition, the amount of heat input to, or removed from, the glass surface is defined by the Stefan-Boltzman law:

$$\mathbf{Q = e\,s\,A\,(T1^4 - T2^4)}$$

Where *e* is the emissivity, *s* is the Stefan Boltzman constant and *A* is the area being radiated to or from. Clearly, the amount of heat radiated is dependent on the relative temperatures of the forehearth roof block (T2) and the glass surface (T1), and, therefore, by controlling the refractory surface temperature, one can con-

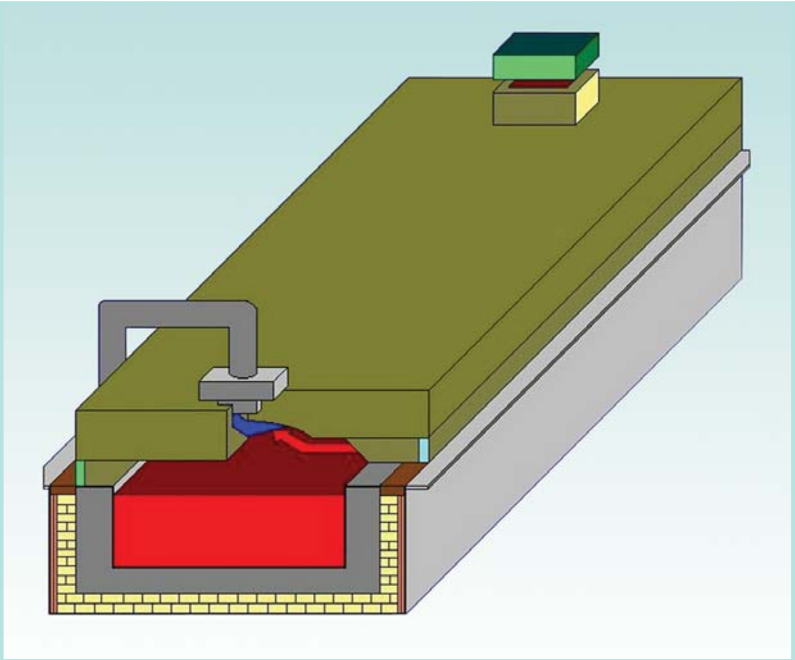

Fig. 1 Direct forced cooling forehearth

trol the amount of heat taken from or input to the glass. Cooling the forehearth superstructure will therefore produce glass cooling; selectively cooling different parts of the forehearth superstructure by different degrees, however, will produce glass conditioning.

CONDITIONING SOLUTIONS

Although we can add heat through the combustion system and we can take heat out using the cooling system, the engineering issues associated with selectivity or directionality of heat removal and replacement are considerable.

It is not simply a matter of optimizing the cooling and heating elements in isolation. It is necessary to understand how each of these elements interact within the forehearth and how the superstructure geometry and exhaust configuration affect this interaction.

Most forehearth designs employing longitudinal, direct forced convection cooling cannot achieve optimum conditioning primarily because no mechanism exists to provide separation between heating and cooling inside the forehearth chamber.

DIRECT COOLING

In the example of a direct cooled forehearth (see Figure 1), the superstructure geometry has no mechanism for concentrating the combustion at the sides of the forehearth or for containing the cooling air within the centre. Also, the single exhaust configuration promotes mixing of the combustion gases and the cooling air since the combustion is forced into the centre of the forehearth prior to being exhausted through the common flue. Because of this inherent mixing, it is not possible to selectively heat or cool specific areas within the forehearth or to effectively regulate the amount of heating or cooling applied to a particular area.

Consequently, the cooling zone will act to reduce the bulk glass temperature but will not effectively condition the glass.

The response time associated with direct cooled forehearths is desirable in a forehearth cooling system but, in order to achieve thermal conditioning, a mechanism is required to separate and target the heating and cooling elements within the forehearth.

There are currently several muffle-cooled forehearth designs, typical of which is that illustrated in Figure 2.

removed from the glass can be controlled. Unlike the direct air-cooling configuration, muffle-cooled forehearths, such as the *Emhart Glass 540*, guarantee separation of the cooling and heating components.

In combination with the 540 roof block, the profile of which is designed to concentrate the combustion at the forehearth sides, this cooling zone design combines separation with a degree of selectivity of heat input/removal and therefore conforms in many respects, to our definition of a conditioning zone.

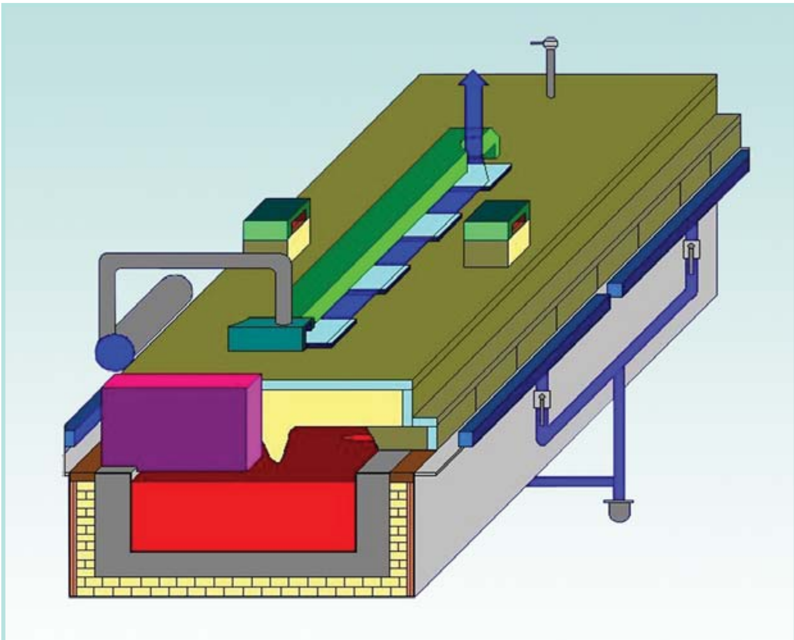

Fig. 2 Muffle-cooled forehearth design

MUFFLE COOLING

Muffle-cooled forehearths operate using heat transfer plates embedded in the forehearth superstructure above the central glass stream. The plates are covered by a longitudinal refractory muffle extending over the length of the cooling zone.

The muffle is fitted with a cooling air injector. In operation, the central glass stream radiates heat to the cooling plates, which, in turn, are cooled by the airflow passing through the muffle.

By automatically controlling the flow of the cooling air through the muffle, the amount of heat

The physical isolation of the cooling air in muffle-cooling designs, however, presents an operating overhead. Firstly, the amount of heat removed from the glass is proportional to the surface area of the cooling plates.

Consequently, the roof block area between successive cooling plates does not contribute to the cooling process. (The same argument can be applied to radiation-cooled forehearths where heat loss is through large openings positioned longitudinally along the centre of the forehearth roof.)

Secondly, the typical response times associated with muffle-cooled forehearths are generally less than those for a similar-dimensioned direct-cooled forehearth. Many of the current forehearth designs have been available for 20 years and, whilst some designers have introduced alternative combustion systems and many have established more complex control strategies, few have changed their basic forehearth superstructure configuration.

Although improving the combustion or control system can produce some improvement in forehearth performance, these alone cannot compensate for a flawed forehearth design.

EMHART GLASS 340

Through extensive mathematical and physical modelling, an optimum roof geometry, flue configuration and cooling and combustion exhaust diameters have been identified. This configuration has been implemented on the new *Emhart Glass 340* forehearth.

This design employs a unique simultaneous dual cooling system in which a combination of muffle cooling and direct forced convection cooling is used. This configuration provides the forehearth with an unprecedented degree of cooling power. However, the high cooling capacity is not merely to cater for large tonnage production. The ability to remove large quantities of heat from the glass allows much higher grades of insulation to be used in the substructure.

Higher insulation levels reduce structural heat losses, significantly improve conditioning at lower tonnages and also provide a faster settle time at job change. This increase in cooling capacity can be exploited to increase the tonnage range over which an individual forehearth can operate. The same argument is also applicable for extending gob temperature and entry temperature ranges.

However, the introduction of a dual cooling system in isolation need not necessarily deliver the potential cooling power or contribute to the thermal conditioning process. A mechanism is required to contain and control the cooling air and combustion gas flow within the forehearth and should provide separation between the direct cooling airflow and the combustion gases. It should also be capable of influencing the areas over which the cooling air and combustion gases operate.

In the 340 forehearth, this is achieved using a sophisticated, automatically-controlled flue exhaust system working in combination with the 540 roof block.

The 540 cooling section roof block effectively divides each cooling zone into three separate longitudinal areas.

The central area is used to house the muffle cooling plates and, in the 340 design, is also used to contain the direct cooling air flow. The two outer areas are used to contain the combustion gases when operated in cooling mode.

Each 340 cooling zone is equipped with five automatically-controlled flue exhausts which, in conjunction with the cooling air control valve and the combustion gas control valve, can be adjusted to direct the flow of cooling air and combustion gases, both longitudinally and laterally within the forehearth chamber. This control provides the mechanism to selectively input or remove heat from the glass and ensures tight control of the thermal conditioning process.

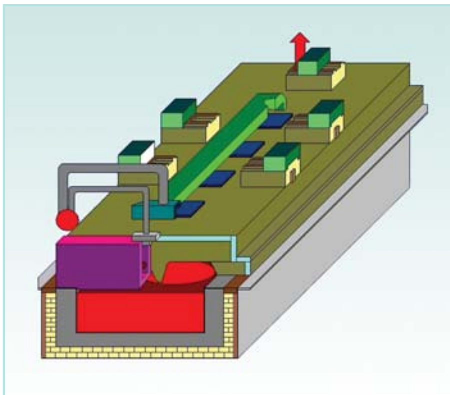

Fig. 4 Emhart Glass 340 in cooling mode

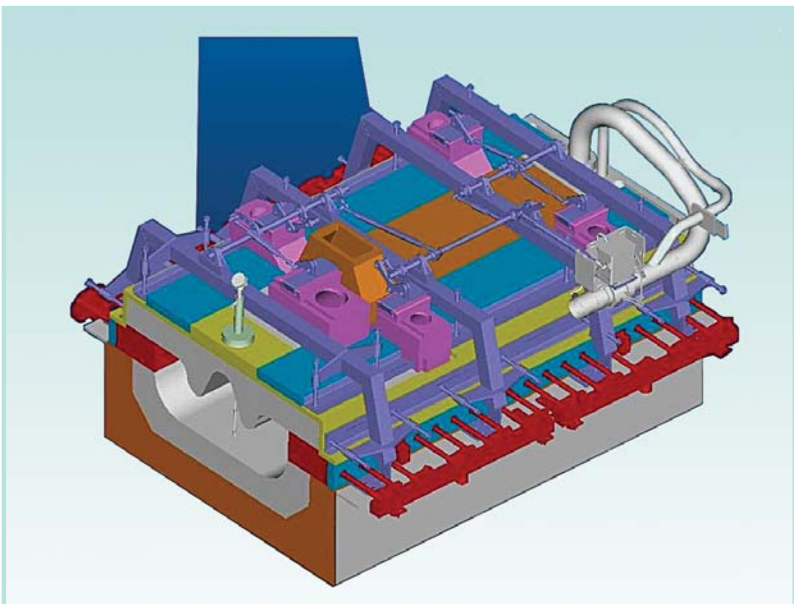

Fig. 3 Emhart Glass 340 forehearth

To understand the operation of the system, it is helpful to consider the forehearth operating in either of two modes.

OPERATING MODES

Cooling

In cooling mode, both cooling systems operate concurrently and are fed from, and controlled by, a single cooling air control valve mounted in the cooling ducting.

Because of isolation of the cooling air, the muffle cooling air flow rates are higher than those employed in the direct cooling system. Both cooling systems have dedicated exhaust systems.

The muffle cooling air is exhausted through an uncontrolled flue at the end of the muffle, and the direct cooling air is exhausted through a centrally located damper system at the end of the zone. The position of the direct cooling damper is automatically controlled and is dependent on the flow rate of the cooling air. The side dampers are also automatically controlled and their position determined by the cooling air flow rate. As the system transitions into heating mode, the cooling air flow rate to the dual cooling system will lessen and the central and side damper openings will decrease. The system is configured so that although all side dampers are closed when operated in heating mode, the central damper remains partially open to facilitate the exhaust of the combustion gases.

Heating

The side damper configuration ensures that in heating mode, all combustion gases are forced across the full width and length of the zone. Exhaust of the combustion gases is achieved through the central flue and damper arrangement.

Damper control is a crucial element in the 340 forehearth and, by necessity, a sophisticated damper control mechanism is employed.

This mechanism is designed to be maintenance free. Damper position is controlled through three control shafts mounted on the bracing steelwork. The lever arms that connect the damper blocks to the control shafts are attached to the control shafts using quick-release fasteners. These components allow fast and simple alignment of the lever arms.

The maximum and minimum required stroke for each damper block is set during commissioning using turnbuckles in the damper linkages. The flue blocks are designed with raised refractory runners on which the damper blocks slide. The width of these runners ensures the frictional forces between the flue and damper blocks are minimized and therefore no expensive damper counterbalance systems are required. Contact between the flue and damper blocks provides much more accurate exhaust area control than can be achieved using a suspended or vertically lifting damper arrangement. Refractory wear tests were conducted to ensure the correct combination of refractory materials have been chosen for the flue and damper blocks. The flue and damper block arrangement also has a self-cleaning damper feature in which the dampers are cleaned of condensate residue.

This residue is collected in a separate chamber in the flue block from which it can be easily removed.

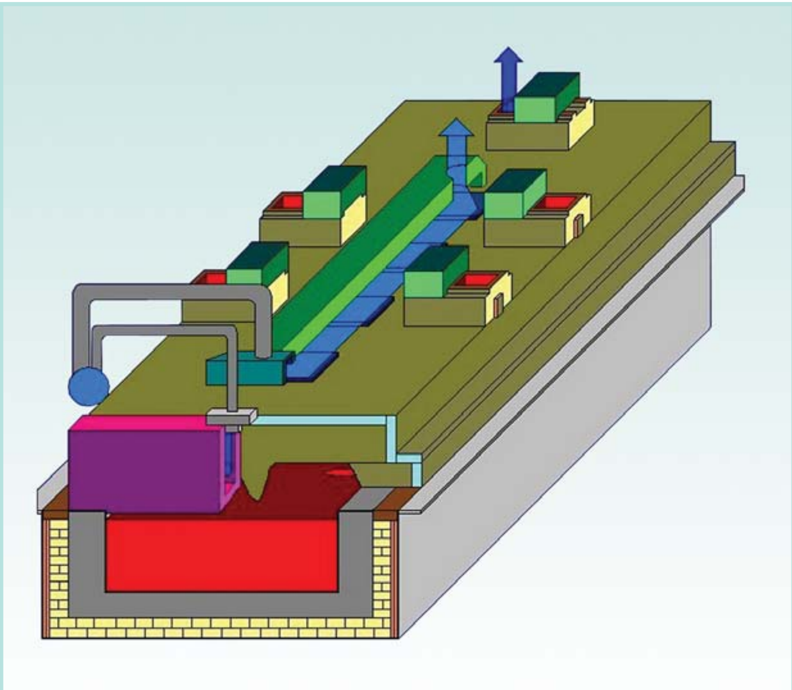

Fig. 5 Emhart Glass 340 in heating mode

SUCCESSFUL DEBUT

The first 340 forehearth system was installed during Christmas 2002 at a prestigious glass plant in the United States that produces soda-lime green 1.5-litre wine flasks. The initial results have confirmed the model predictions and the 340 forehearth has already provided unprecedented thermal efficiency values and highly significant increases in pack rate. After a period of observation and analysis, the 340 forehearth will be commercially available during 2003.

This is a significant advance in forehearth design and the 340 now joins the well-established Emhart Glass 540 and the recently introduced *Emhart Glass 240* forehearth to provide a range of forehearths which reflect the different operational requirements of high-, medium- and low-tonnage production.

Whether in the future we will refer to cooling zones as ‘conditioning zones’ is, based on previous precedent, unlikely.

The 340 cooling zones will still be called ‘cooling zones’ but, now, they will be thermally conditioning and not merely cooling.

*PRODUCT MANAGER FOREHEARTS
EMHART GLASS