THERMAL CONDITIONING OF GLASS IN THE EMHART GLASS 340 FOREHEARTH

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Preparatory to any design process, one must first define the issues and conditions that will affect the project's goals. In forehearth design, most decisions are based on well-known mathematical and engineering principles. In this paper, Emhart Glass introduces an approach to producing better glass quality over a wide tonnage range based on advanced conditioning in the forehearth.

1 - INTRODUCTION

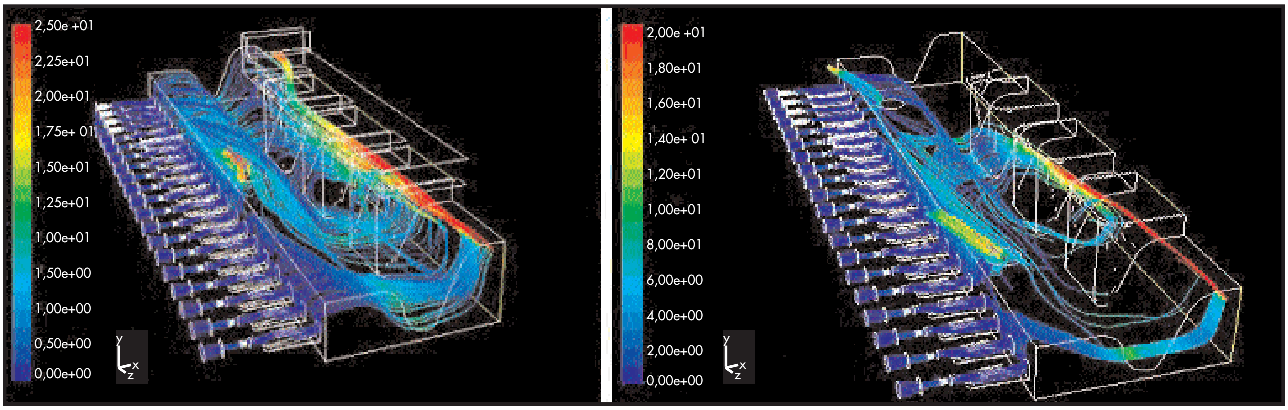
1.1 First Steps

In the forehearth, we have a body of glass containing thermal gradients flowing through a refractory channel through which the outer boundaries of the glass lose heat through conduction. In this case, heat gained or lost by the glass is primarily through radiant heat transfer to and from the glass surface. Typically, the glass will have lateral and vertical temperature gradients associated with both the flows 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.
Other factors such as glass flow, structural heat loss, asymmetric heat loss, influence from adjacent forehearths and furnace related fluctuations conspire against thermal conditioning in the forehearth and contribute to the creation of thermal gradients within the glass. The key forehearth design requirement is to dissipate these gradients while reducing the bulk temperature of the glass and stabilizing it at a level consistent with the forming process requirements. To reduce the bulk glass temperature to a level consistent with operational prerequisites, some form of cooling is necessary. To dissipate the thermal gradients within the glass some form of selective cooling and heating is vital.

1.2 Redefining Roles

As a key element in the process, the forehearth requires both innovations in design, and 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 refractory engineering, superstructure geometry and flue exhaust controls that are vital to the glass conditioning process. "Cooling zone" is an overly simplistic term applied to the complexities of a thermal-conditioning zone.
So what do we mean when referring to conditioning? It is a purely thermal process that can be defined as the achievement of a stable, desired glass temperature universally distributed throughout the vertical

Fig. 1 - Models of three-flue & five-flue forehearth configurations.



and lateral planes of the glass at the entrance to the spout. In and of itself, a simple forehearth cooling system requires that the glass entering the forehearth is sufficiently hotter than what is required for exiting temperatures.

Forehearth designs always attempt to maximize conditioning potential. It is generally accepted that the forehearth cooling function is the primary control element in achieving and controlling gob temperature. This capacity is the basis for most forehearth designs. Superstructure geometry also plays a vital role in the cooling function, and in the glass conditioning process. In fact, superstructure geometry and roof block shape effectively define and differentiate individual forehearth systems.

True conditioning 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. The amount of heat input (or removal from) the glass surface is defined by the Stefan-Boltzman law.

$$Q = e\,\sigma\,A\,(T1^4 - T2^4)$$

Where e is the emissivity, s is the Stefan Boltzman constant and A is the area being radiated to or from. The amount of heat radiated is dependent on the glass surface (T1), and the relative temperatures of the forehearth roof block (T2). Therefore, by controlling the refractory surface temperature, one can control the amount of heat taken from (or input to) the glass. So, while cooling the forehearth superstructure will only produce glass cooling, selectively cooling or heating different parts of the forehearth superstructure will produce glass conditioning.

In forehearth operation, the ability to selectively control refractory and glass surface temperatures is a key requirement of forehearth design. Although one can add heat through the combustion system, and can take heat out using the cooling system, there are substantial engineering issues associated with selectivity or directionality of heat removal and replacement.

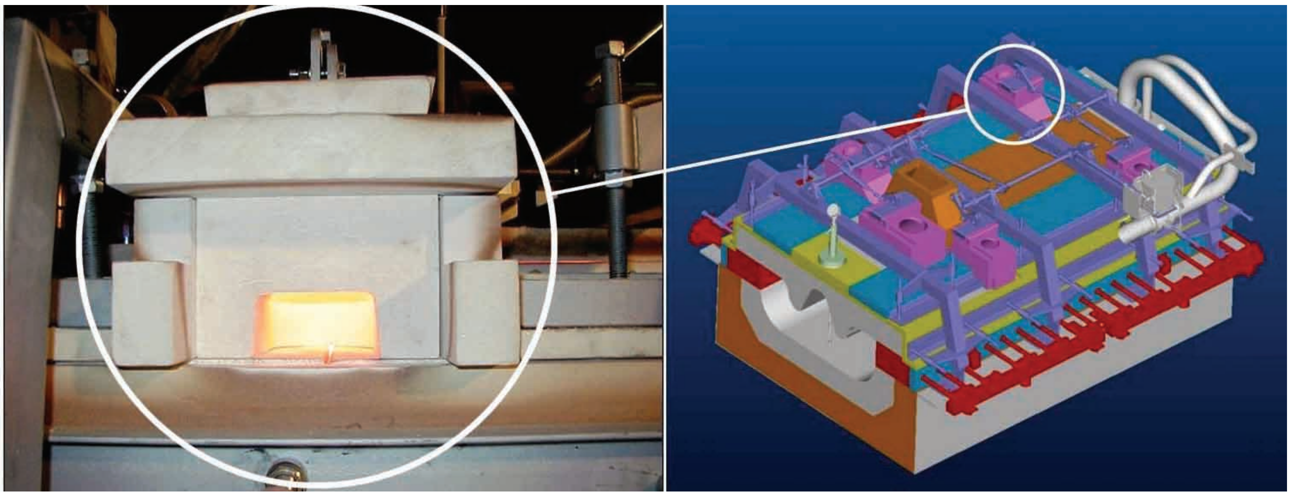
2 - MODELLING THE 340 FOREHEARTH DESIGN

The forehearth roof block is a critical design element. The roof block acts not merely as a refractory cover but as a separator, a radiator and a combustion chamber pressure regulator. The roof block, and the configuration of its flues, will determine the effectiveness of both the cooling and heating functions within the forehearth.

While the roof block is of unarguable importance, the number, position and geometry of the flue exhausts largely determines the flow paths of the cooling air and combustion gases within the forehearth. Figure 1 represents a comparative study of a three-flue and a five-flue configuration. In the three-flue design, cooling air is forced longitudinally (in the direction of glass flow) within the forehearth chamber.

The three flues are controlled as a means to separate the cooling and heating components. Separation of heating and cooling is required to maximize the effect of each input and to regulate the selectivity aspect of radiation control. In the Emhart Glass 540 Forehearth, separation between cooling air and combustion gases is guaranteed by virtue of the muffle cooling system, this assures that superior temperature control can be achieved in an energy efficient manner. In direct-cooled forehearths, however, separation is not guaranteed. Early test results from the 340 Forehearth development project indicated that the direct cooled three flue design exhibited a degree of separation, but that it did not give the separation and control required to satisfy the project aims of maximizing the heat removal and thermal condi-

Fig. 2 - The 340 Forehearth flue exhaust control.



tioning potential of a forehearth.
Mathematical modeling of various flue configurations, positions and geometry were studied to identify an optimum configuration. The five-flue configuration shown above formed the basis of the 340 Forehearth. This design employs a unique simultaneous dual cooling system that combines muffle cooling and direct forced convection cooling. Both systems operate concurrently in cooling mode, and are fed from (and controlled by) a single cooling air control valve mounted in the cooling ducting.
The flue configuration consists of a central flue positioned at the end of the zone directly above the central glass stream, with two additional flues positioned directly above the side combustion areas on each side of the forehearth. The superstructure is configured with a separate, uncontrolled flue to exhaust the muffle cooling system airflow.
While the dual cooling system and sophisticated flue controls provide an exceptional cooling power and have clear applications in high tonnage production, their benefits can be exploited to allow the use of much higher grades of insulation in the forehearth substructure. Lower substructure heat losses result in improved thermal homogeneity levels and also enable the forehearth to stabilize more rapidly - for instance at job change.
Control of the five flue exhausts determines the longitudinal and lateral flow of cooling air and combustion gases within the forehearth chamber. This in turn controls the relative surface temperatures of the glass stream and the forehearth roof blocks. This capability provides a powerful mechanism to selectively add or remove heat from the glass, thus assuring tight control of the thermal conditioning process.

3 - ENGINEERING THE 340 FOREHEARTH CONCEPT

The next step in the design process was to convert the mathematical model into engineering reality. The importance of flue control was identified as a critical factor in the operation of what was to become the 340 Forehearth. Various flue and damper block control mechanisms were considered in terms of their controllability and linearity. Vertically lifting damper blocks have been used in forehearth design for many years but the degree of flue control afforded by this mechanism was limited.
Exhaust control was restricted to a narrow damper range and even within this range control was inadequate. Suspended damper arrangements were adopted, but they produced only moderately improved results. The main problem was that the degree of controllability of each design decreases with increasing damper opening. To achieve the degree of flue control required for optimum forehearth control, a more precise and linear damper control was vitally important.
The 340 Forehearth utilizes a flue and damper arrangement (fig. 2) in which the damper and flue block remain in contact throughout the damper opening cycle. In this system, the flue exhaust opening is directly proportional to the damper position - resulting in vastly improved flue control. The potential wear problems associated with contact between flues and damper blocks were addressed by selecting appropriate flue and damper block refractory materials.
In operation, the flue opening can be accurately and linearly controlled by modulating the damper position on the flue block via a control shaft attached to the superstructure steelwork. Limiting the contact area between the flue and damper block minimizes the frictional resistance associated with such an arrangement. The lower frictional resistance is associated with a lower torque requirement and allows the cooling control system to be configured without the need for the additional counter balance systems used on other multi-damper forehearth configurations.
In cooling mode, the central flue is used to control the exhaust of the direct cooling system. During heating mode, with the side dampers fully closed, the central flue is used to exhaust the combustion gases. The side dampers are controlled automatically, and their position is determined by the cooling airflow rate. Since no operational advantage can be gained from controlling the muffle cooling exhaust, no damper system is used on the muffle system.
The lower temperatures associated with damper and flue blocks often cause damper blocks to become coated with condensates from the glass and combustion gases. In a moving damper system, the potential exists for the condensates to dislodge from the damper blocks and contaminate the glass stream. In the 340 Forehearth, each of the five flues has been designed with a unique condensate remover and trap. As the damper moves on the flue block, the condensates are scraped from the damper surface and deposited into a secondary chamber within the flue block. Access to this chamber is provided through a side entrance to allow the condensates to be removed during normal forehearth maintenance.
The ability to survive the aggressive environment of the forehearth roof without the need for frequent adjustment or maintenance was fundamental to the design of the 340 Forehearth damper control system. This system utilizes three interlinked control shafts. Each damper is connected to a control shaft using lever arms and rapidly adjustable shaft connectors. Modulation is achieved via a linkage from the main control shaft to an actuator. Linkages between the main control shaft and the other two shafts provide the same degree of control to all three shafts. Once commissioned, the damper systems and control mechanisms require no further adjustment. Additionally, the use of high temperature bearings and materials

provide a maintenance free system.

4 - CONCLUSIONS

The 340 Forehearth goes into production.

The first 340 Forehearth was successfully commissioned in the USA at the beginning of January 2003 on a line producing 1.5 litre green, flat-sided wine flasks. The advantages of the system were clear and immediate and were measurable in terms of thermal homogeneity and increased pack rate. The results of the mathematical modeling have been verified and the innovation of the cooling control system proven. This forehearth has now operated over a variety of production conditions and has consistently produced thermally conditioned and stable glass. The system is attracting great interest from three continents.

The steps from concept to a commissioned forehearth took 12 months of study, design, innovation and trial. Design issues and operational conditions were clearly defined and addressed in the project's goals. Advanced glass conditioning concepts were mathematically modeled and then tested under production conditions. The result is the Emhart Glass' addition of the options provided by the 340 Forehearth's broad-range operational capabilities to those offered by the established 540 and the low tonnage 240. With this range of product solutions, Emhart Glass is ready to address all market requirements.