Glass-Making Goes from **Art to Science**

Modeling glass furnaces helps improve batch transition time and reduce product defects.

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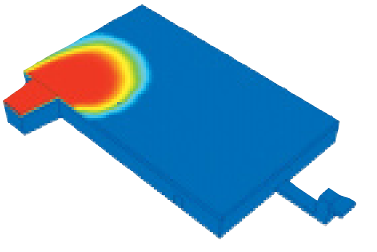
To create glass from its raw materials is to invest in both the art and the science of the process. Glass is a fascinating engineering material with unique properties; however, producing it can be a complex undertaking and is often thought of as an art. As a result, commercial glassmakers strive continually to understand the science of its manufacture in order to optimize and improve the process. As one such manufacturer, PFG Building Glass in South Africa is using FLUENT computational fluid dynamics (CFD) software to model the flow inside its glass furnaces, track processing defects and improve overall production systems.

At the basic level, glass-making consists of three steps. The first is melting a blend of raw materials, which can include sand, limestone, soda ash, feldspar and saltcake. The next is refining, in which bubbles contained within the molten raw materials are removed. Finally, there is conditioning, in which the glass is cooled to a suitable working temperature. There are various methods of accomplishing each step that affect the process differently. Different glass compositions require different operating envelopes, due to the change in physical and chemical properties.

Because glass-making requires furnace temperatures of 1500 degrees C (about 2700 degrees F), heat transfer and chemical diffusion dominate the process kinetics, and the reaction tank itself is slowly dissolved by the molten glass. These factors make experimental studies difficult. As an alternative, simulation arises as a good way to understand how furnaces behave and how process improvements can be made.

Using the 3-D version of FLUENT software and the pressure-based solver, PFG Building Glass developed a CFD solution for steady-state glass processing conditions. The company created a simplified initial simulation, one that did not include any time-dependent events.

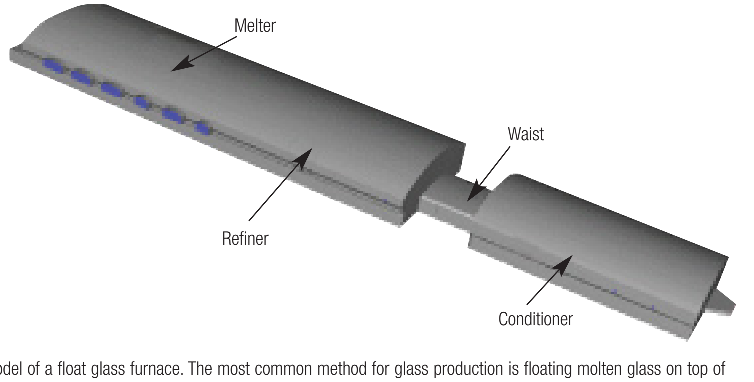


Contours of batch species fraction in the glass domain of a container furnace. The red area represents the introduction of a new species into the glass flow.

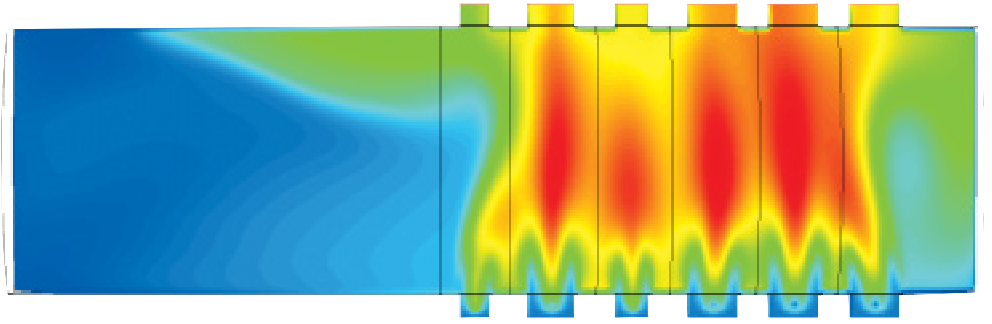
Once these simulation results were acquired, time-dependent events, such as color transitions, were incorporated into the simulation and accounted for by switching to the transient solver in the FLUENT product. To simulate this more complicated type of process, PFG enabled the species transport model in FLUENT software and incorporated its own batch models via user-defined functions (UDFs) for the species properties, boundary conditions and sources. These additions allowed the team to observe factors such as mixing.

Apart from the glass flow itself, what happens in the combustion space above the processing glass is very important. Combustion that occurs in this region of the furnace is a heat source for melting and heating the glass mixture. In order to include this region in the analysis, PFG incorporated combustion, radiation and turbulence modeling into the simulation. By including these factors, the model complexity was greatly increased.

The combustion space model and the glass flow model then were



Model of a float glass furnace. The most common method for glass production is floating molten glass on top of molten tin, thus giving it the name “float glass.” This process results in the formation of plates or ribbons of glass.



Contours of temperature in the combustion space over the melter region of an oil-fired, six-port float glass furnace. Red areas identify regions of higher temperature.

combined into a coupled simulation, making use of the FLUENT non-premixed combustion model, discrete ordinates (DO) radiation model and realizable k-ε turbulence model. Further UDFs were used to define the material properties and source terms. For boundary conditions, it was important to maintain the glass zone as a laminar zone and the combustion zone as a reaction zone.

The quality of the final glass product is influenced by the presence of small bubbles, which manufacturers try to remove from the batch during a refining phase because bubbles can lead to discrete faults in the final product. There are numerous sources that can lead to an unacceptable rise in the number of faults. Using simulation for defect tracking has helped PFG to pinpoint the areas that are most probably the origin for the faults. PFG accomplished this with the reverse particle tracking capability in the FLUENT product. By defining tracking locations throughout the glass fluid domain and using the FLUENT discrete phase model (DPM), PFG was able to examine a particular particle's flow path history and determine statistically probable fault positions in the final glass ribbon.

One other complication of a batch process is the transition from one batch to another, which involves moving the complete furnace glass volume. Usually the transition process takes a number of days. As a result of factors driven by this transition time, glass that does not fall within approved specifications is produced with an associated loss of revenue. Any reduction in transition time is, therefore, of great value. PFG has been able to partially model this transition process using FLUENT software, leading to modifications in operating procedures.

The use of CFD modeling has led to a better understanding of glass flows and combustion conditions inside glass furnaces. This has allowed PFG Building Glass to achieve its objective of producing high-quality glass at the lowest possible price, while also maintaining long furnace life, all without a hit-and-miss approach. Product quality has improved as a result of defect tracking, and losses have been reduced as the process has become more of a science than an art. This experience and the models drawn up allowed PFG to simulate planned expansions before they were installed and, thereby, eliminate problem areas before installation. ■

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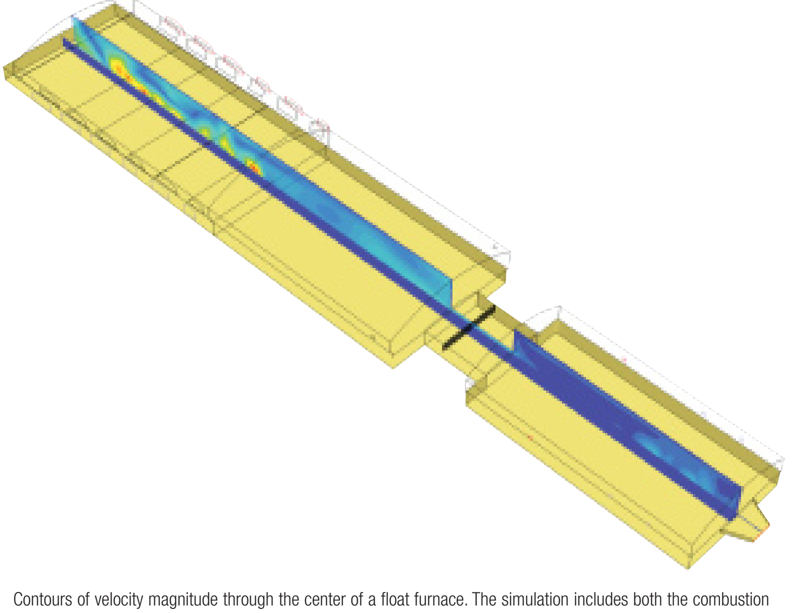

Contours of velocity magnitude through the center of a float furnace. The simulation includes both the combustion space above the glass melt and the melted glass itself.