CFD as a tool for Operations: Some Examples

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ABSTRACT

Computational Fluid Dynamics (CFD) is an effective tool for the design and operation of glass production furnaces. Before a furnace is built or rebuilt, it is standard practice to evaluate and optimize the design using CFD, but CFD is also valuable once a furnace is in operation. Johns Manville produces E-glass, C-glass, T-glass and several specialty glass compositions with a large variety of glass furnaces ranging from combustion fired furnaces to over 30 all-electric furnaces. The application of CFD to improve the operation of current glass furnaces is overviewed and examples of varied applications to address operational issues are presented.

INTRODUCTION

The design and construction of glass melters is crucial for obtaining the best campaign performance so it is standard practice to apply computational fluid dynamics (CFD) modeling to evaluate and improve glass furnace designs. However, computer modeling (CFD) can also provide a valuable tool during the operational life of a glass furnace. Typical glass furnace life continues to increase with flat glass furnaces having a campaign life of up to 20 years. Even with the shorter life of a fiberglass furnace campaign, business conditions can change for required throughput and/or product mix. This, as well as furnace life issues as equipment fails or wears out, provide opportunities to apply computer modeling to optimize the operation and life of expensive glass furnace assets. Bubbler failures, batch composition changes, electrode failure and maintenance, recovery from power failures, adjustments to the energy input, and predicted refractory wear are just some of the areas that computer modeling can be applied to evaluate furnace operations. In addition, with the limited point measurements available during operation from thermocouples and other sensors, the three dimensional prediction of the process temperatures and flows from computer modeling provide understanding of the operation and the impact of process changes. This paper will overview a variety of ways CFD can be applied to operational and life issues.

Electrode Maintenance

Over the campaign of a melter with electrodes, maintenance is needed of the electrical system which requires turning off the electrical power. A key to minimizing the production impact during electrode maintenance is to limit the decrease in glass temperatures exiting the melter whether for an all-electric melter or a melter with electric boost. Transient computer modeling provides a tool to evaluate different scenarios to limit the decrease in glass temperatures and plan electrical outages. . Figure 1 shows a plot of the predicted glass exit temperature and recovery from a one hour electric boost shutdown. Variations of increasing the glass temperature before shutdown, increasing the combustion flows and higher than normal electric power levels after the shutdown can all be evaluated to minimize the impact on the glass temperature. If long or multiple electrical power shutdowns are needed, computer modeling can help plan the length of outages and time between outages to minimize process upsets and improve recovery.

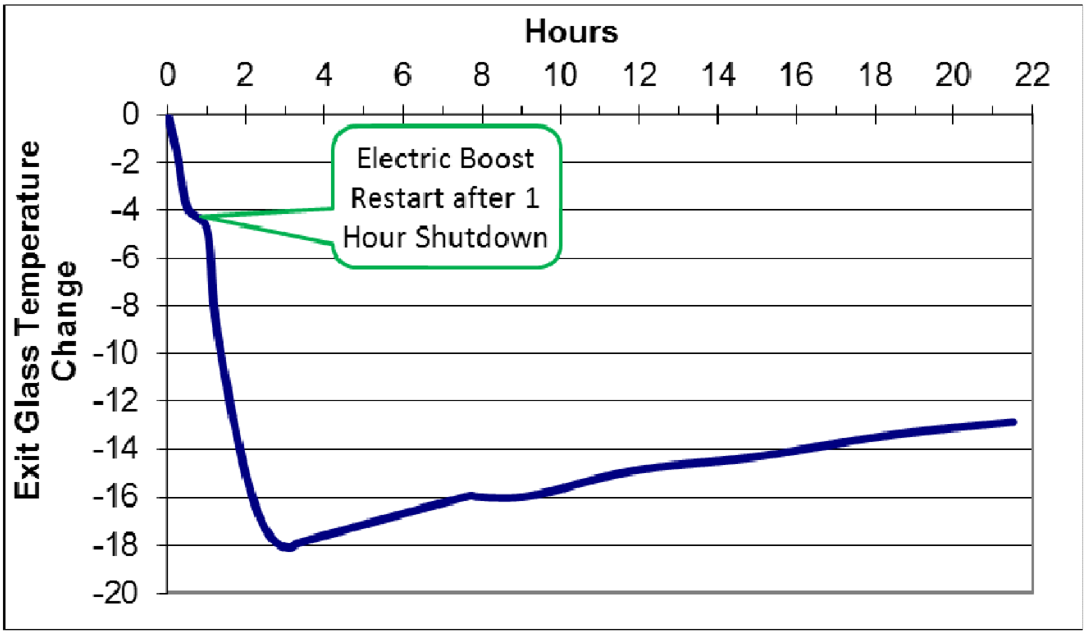

Figure 1: Transient glass exit temperature prediction with electric boost shutdown.

Electrode Failures

When electrodes fail during a campaign, the throughput can be negatively impacted. Options to rewire electrodes or change zone settings to compensate can be evaluated. Figure 2 shows process data after electrode wiring was changed to compensate for electrode failures during a campaign. With rewiring, the total available electrical power (purple line) was increased resulting in recovery of lost throughput and glass temperature plus the decrease of previously maxed out crown temperatures. It also shows the glass temperature control improvement with model predictive control (MPC) turned back on.

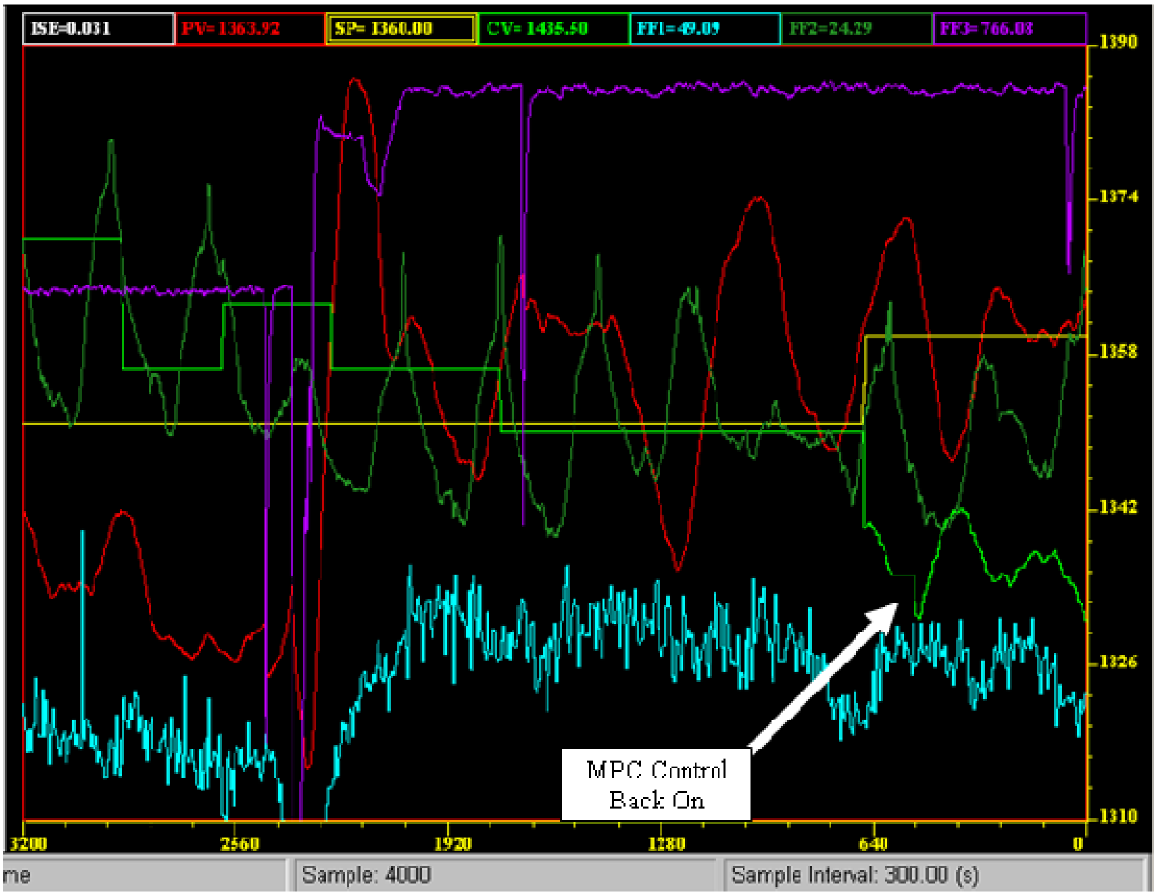

Figure 2: Process data before and after rewiring to compensate for failed electrodes (purple is electric power, red is glass temperature, green is crown temperature, cyan is batch feed).

Another example of electrode issues is shown in figure 3. Here computer modeling is used to evaluate the impact of the loss of the center two electrodes in the first zone. Figure 3 shows the predicted Joulean heat generation for the two different cases. The computer model can provide insight into how to adjust operational parameters to maintain throughput and quality when electrodes fail during a campaign.

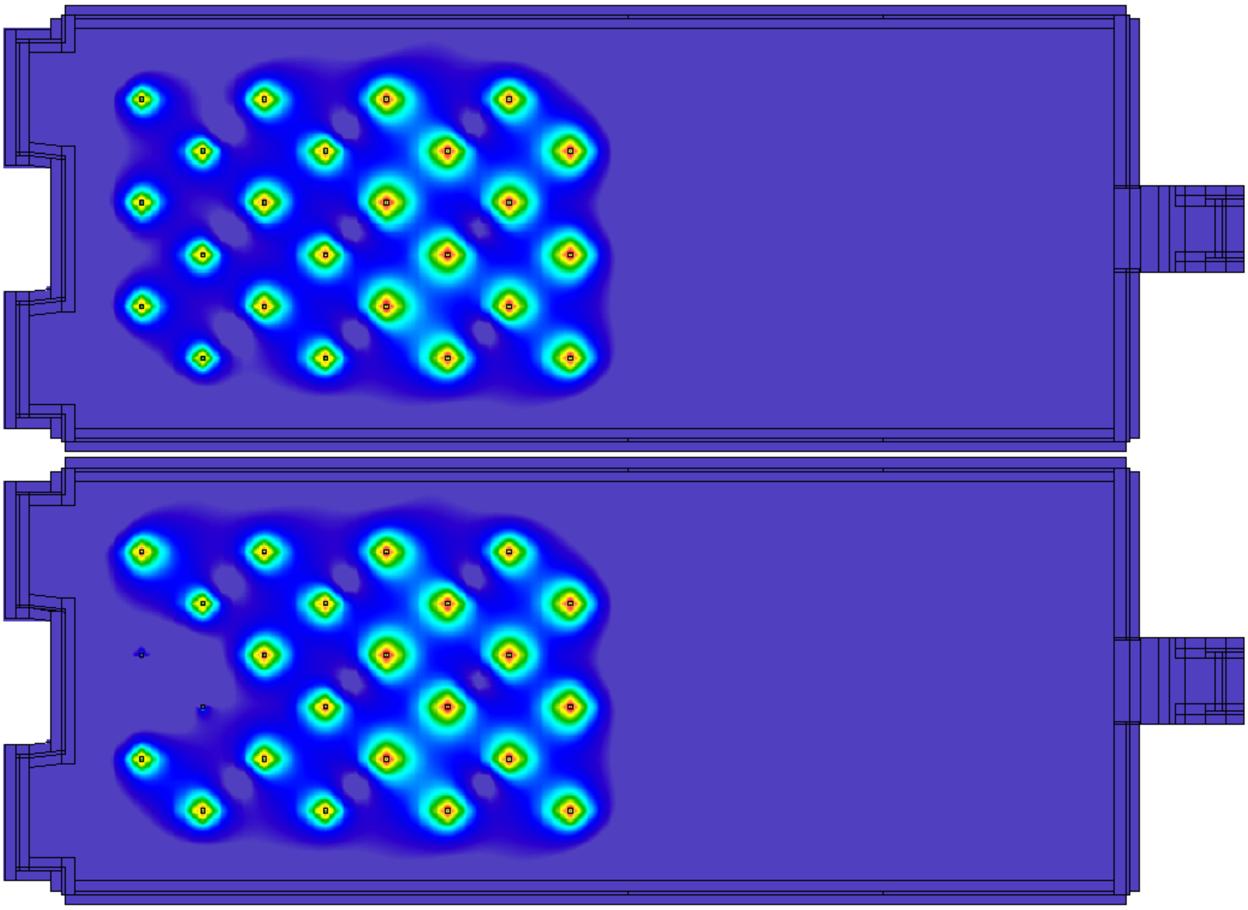

Figure 3: Contours of Joulean heat generation with all electrodes powered (top) and without the two center electrodes in zone one (bottom).

Refractory Life Extension Evaluation

With extended campaigns, refractory wear in non-typical critical areas can be an issue. During a past extended campaign undercutting of the glass contact sidewall and potential collapse became an issue. Computer modeling was used as a tool to evaluate options to decrease the wear rate and stabilize the sidewall. Figure 4 plots the predicted impact of removing insulation and adding cooling for focused key sidewall areas. The model predicted that cooling could be effective in lowering the glass temperature below the liquidus temperature in this localized region enabling devitrification (crystal formation) and stabilizing the sidewall. Cooling was implemented on the melter sidewalls after the CFD evaluation and the campaign was extended without sidewall issues. At the drain, the sidewalls were severely undercut and devitrified glass had developed in the undercut region supporting the sidewall. These findings agreed with the model predictions that had been made several years previously.

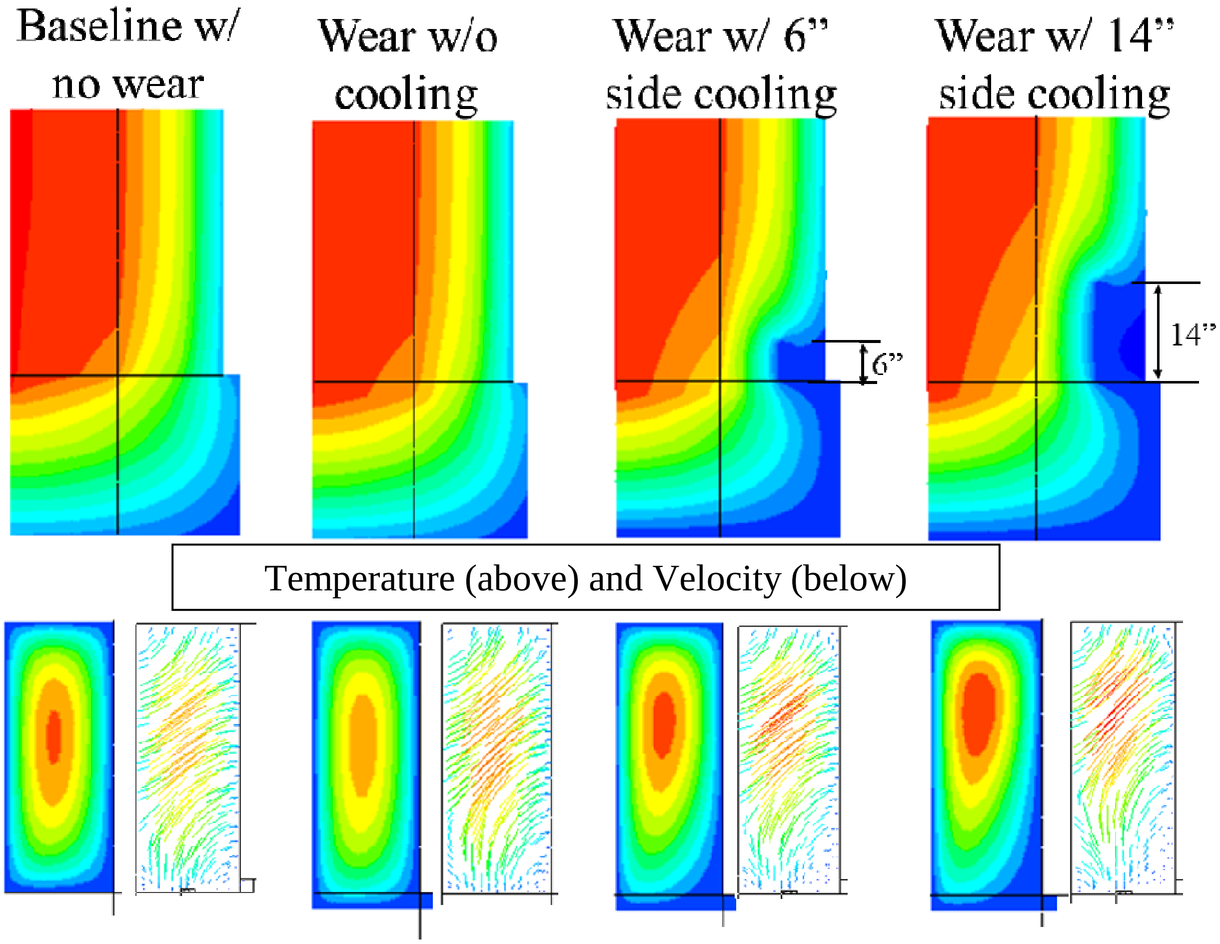

Figure 4: Evaluation of cooling impact on sidewall undercut wear.

Estimating Refractory Wear

Due to the extreme environment within a glass melter, it is difficult if not impossible to measure or observe the extent of refractory wear in the glass contact regions. In cases where signs of high refractory wear are present, CFD models can be used to estimate the remaining refractory thickness based off the internal and external temperature measurements (figure 5).

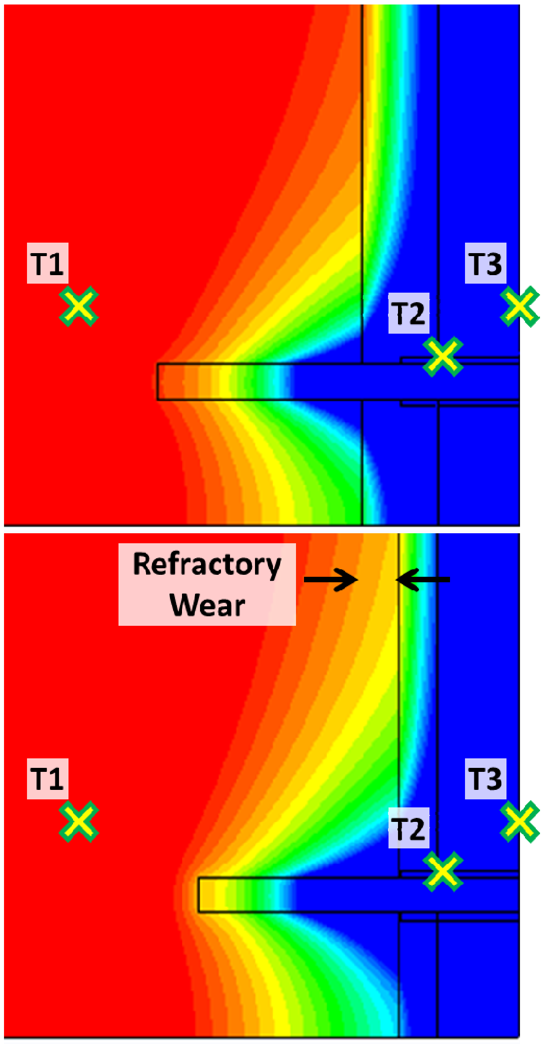

Figure 5: Temperature contour plot with original (top) and worn refractory wall (bottom).

Banked Conditions and Recovery

During the event of a recovery due to banked conditions required by repairs or a prolonged power failure, modeling can be performed to provide estimates on the time required to heat the glass to a temperature where glass flow will occur and when electrodes can be powered on. In these conditions, transient modeling is required which greatly increases computational time, but provides the information for both design of systems to address these issues and the recovery time. Figure 6 shows a transient prediction for a “frozen” throat recovery with heat from the melter and channel. Once the glass reaches an elevated temperature allowing high enough electricity conductivity, the throat electrodes can begin to provide power and aid in the heating of the glass.

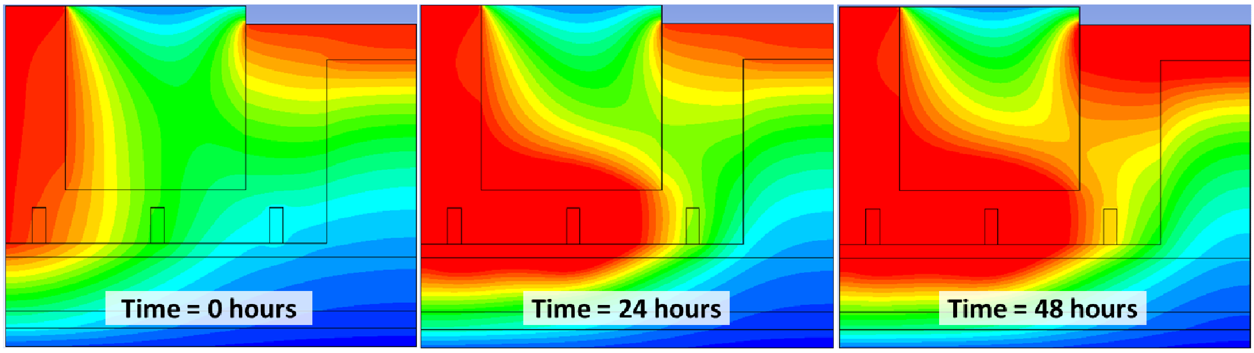

Figure 6: Temperature contour of transient model at time 0, 24, and 48 hours.

Batch Composition and Delivery Change

Changes in the batch composition or equipment used to deliver batch into the melter can change the batch density and entrained air within the batch. By changing the parameters and setup of the model, the effect of these changes can be observed and the operating condition of the melter adjusted to maintain glass quality and throughputs (figure 7).

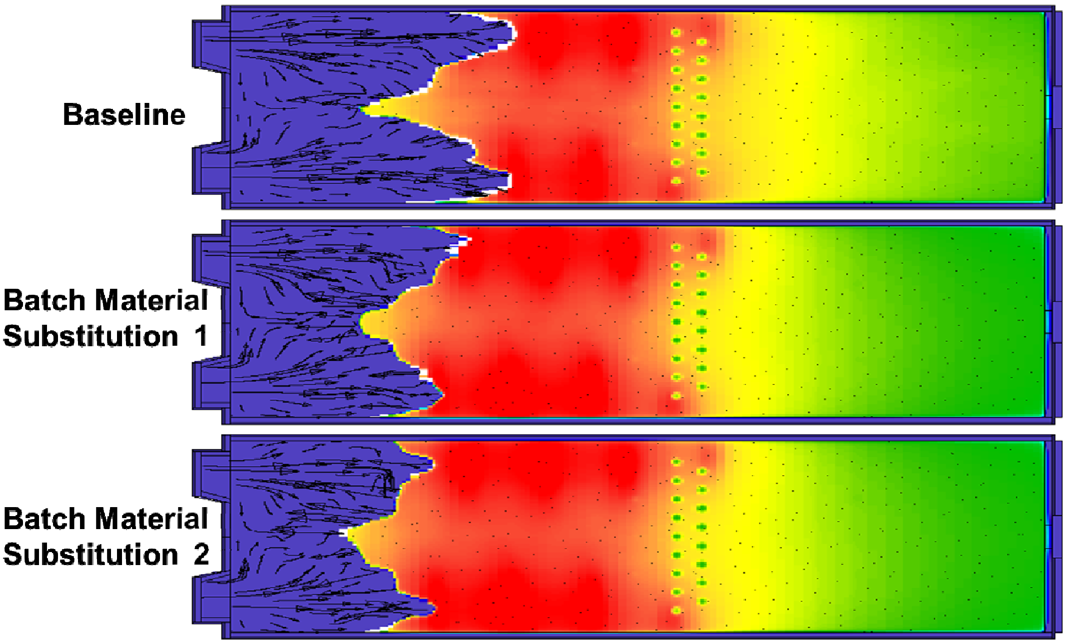

Figure 7: Variation in predicted batch shape with batch material variation.

During steady operation, it may be desired to alter the batch shape in order to shift it towards the center or sides of the melter, or improve symmetry if bubblers or electrodes fail. CFD modeling allows for the batch chargers to be biased and the resulting batch shape observed before implementation within the melter (figure 8).

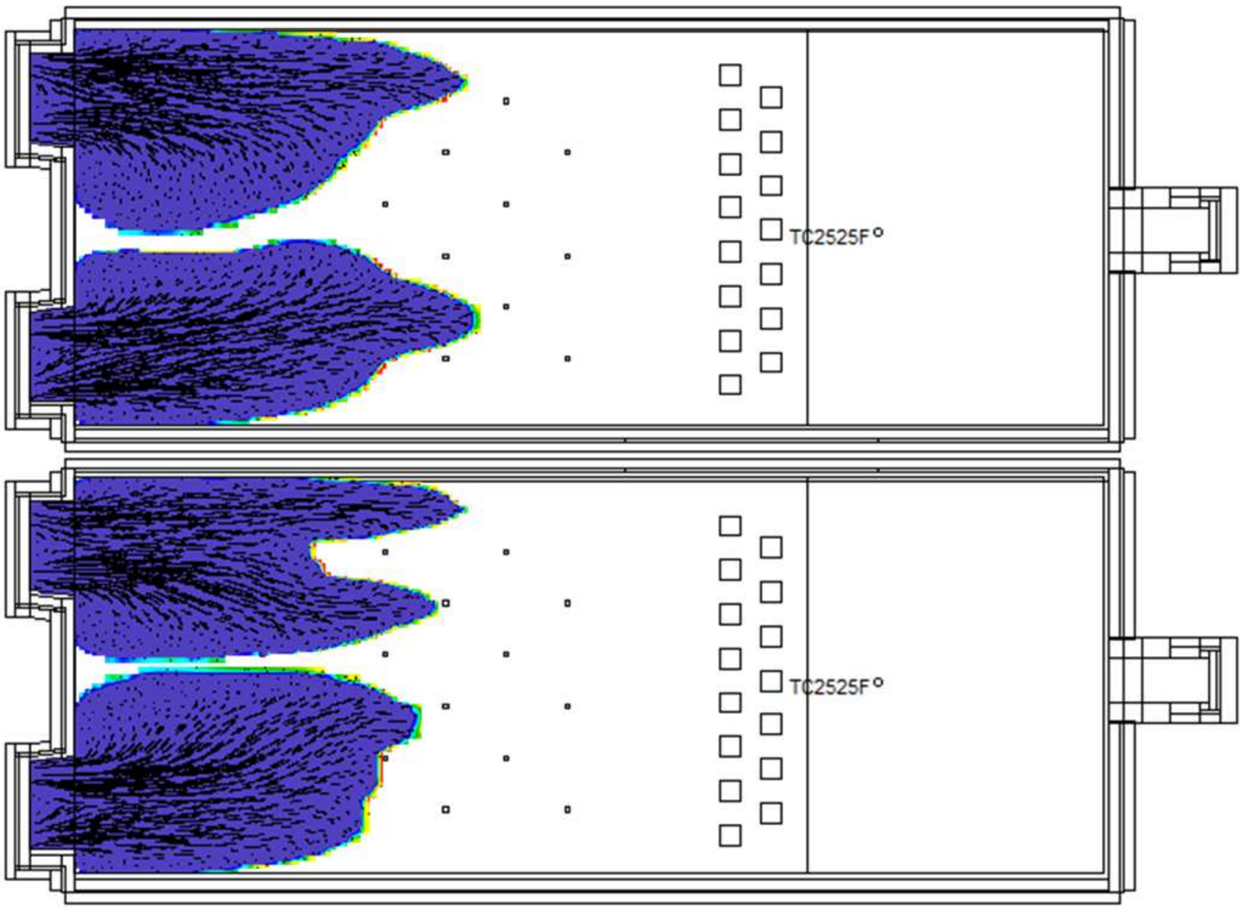

Figure 8: CFD batch shape for different batch charging conditions.

Adjusting Energy Input

Throughout the campaign of a melter, it may be desired to adjust the energy profile delivered to the glass via the combustion burner profile or electric boost profile. Figure 9 compares two different combustion burner setups. CFD modeling is used to show the resulting residence time, melt index, energy efficiency, flow patterns, and batch shape as the energy profile is changed.

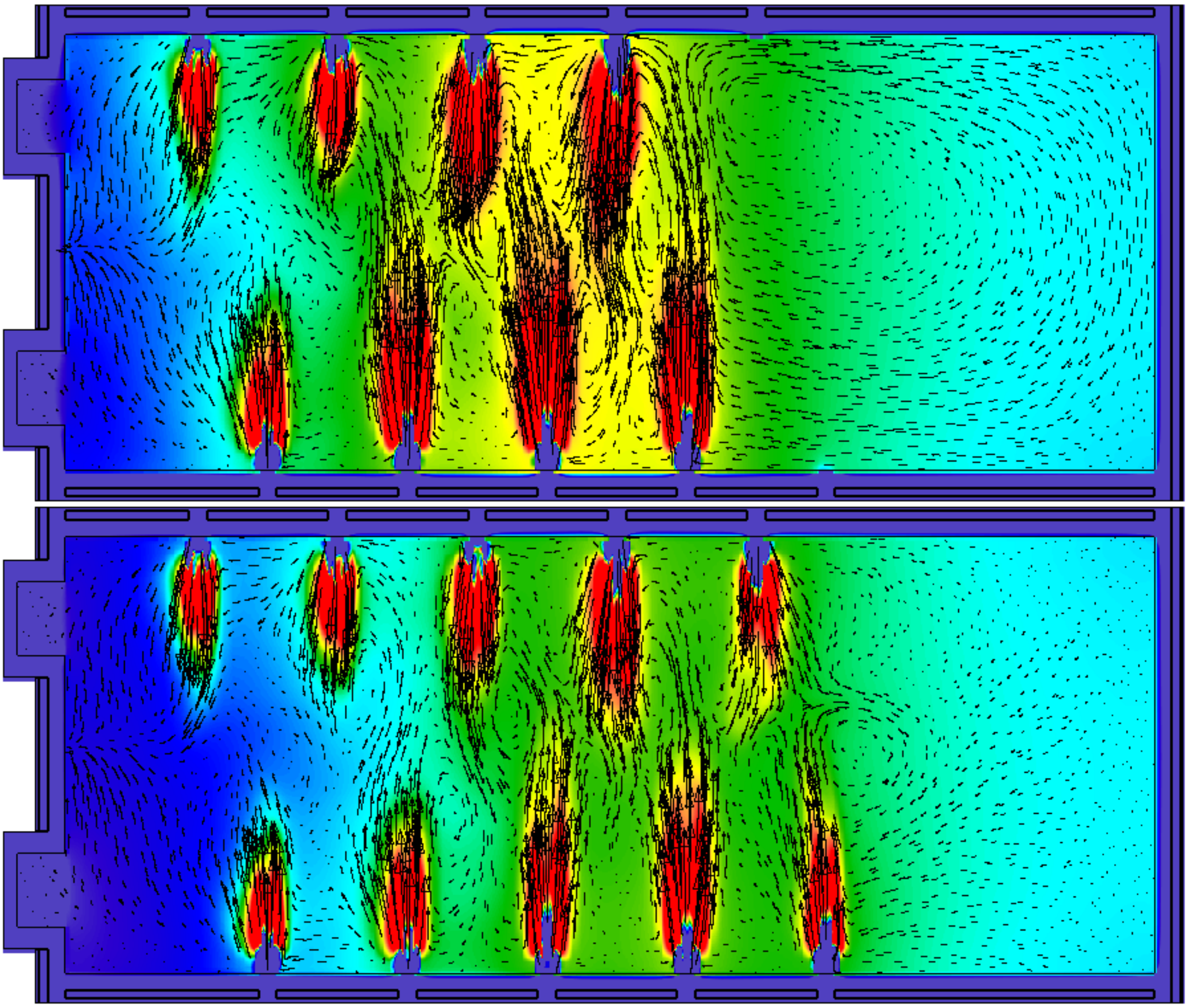

Figure 9: Temperature contour at burner cross section comparing combustion flow profiles.

Bubbler Operations

During a melter campaign, a bubbler can be damaged leading to complete blockage of flow. This can result in changes to the melter flow pattern, temperature distribution, and glass quality. For the scenario shown in figure 10, it is important to know if a shortcut will be created in which glass can flow directly out of the melter greatly reducing the residence time and glass melting quality indexes. These shortcuts can be found by looking at the particle trace with the shortest residence time. In addition, the flow rate of the bubblers can be varied to observe the impact on the furnace performance and predicted glass quality indexes.

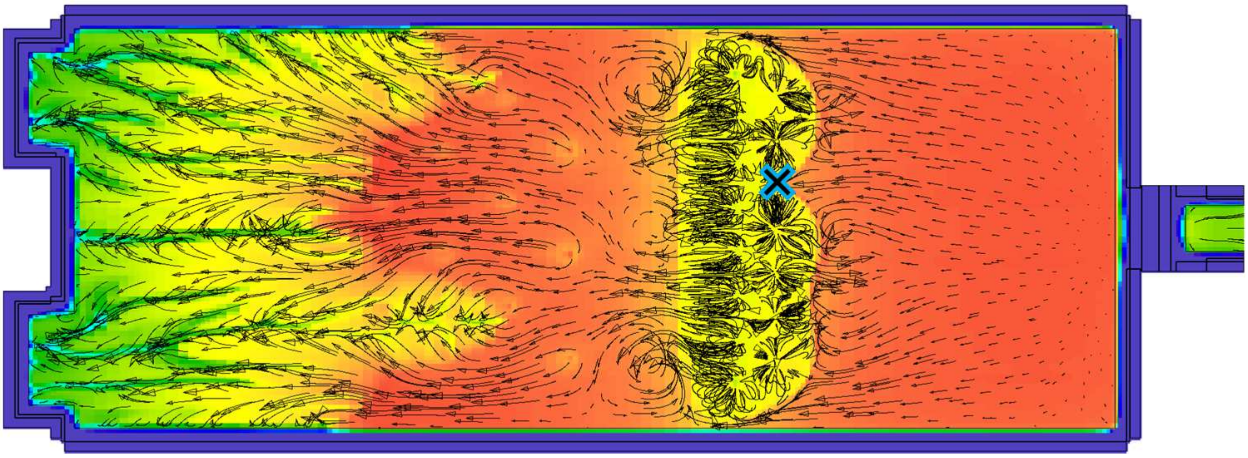

Figure 10: Temperature contour with missing bubbler marked with an "X".

CONCLUSIONS

In conclusion, there are numerous possible CFD applications to improve the operation and deal with operational issues throughout a campaign. These CFD applications demonstrate that CFD modeling can be used for much more than initial furnace design and can positively affect the operations of a melter after startup. By using the results of CFD modeling, an accurate prediction of the effect of various changes can be observed and the magnitude of a melter upset can be reduced due to maintenance and operational changes. CFD results can also show a much more detailed picture of internal melter conditions and operation relative to finite temperature measurements.