# When It's Impossible to Take Actual Measurements, Multiphysics Provides the Answers

Extreme heat in a blast furnace makes it impossible to take measurements during certain parts of the process. At TRB we are using simulation along with actual outer temperatures in a blast furnace roof runner to find out how hot it gets inside.

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Blast furnaces, where molten metal reaches temperatures near 1500 °C, create an environment where every possible precaution must be taken to keep workers and production equipment safe. One potential hazard is when the molten metal first leaves a furnace through a taphole and travels through a runner where the slag is separated out (see Figure 1). If left totally exposed, the molten metal could splash and present great danger to operators and tools, or cause a halt in production.

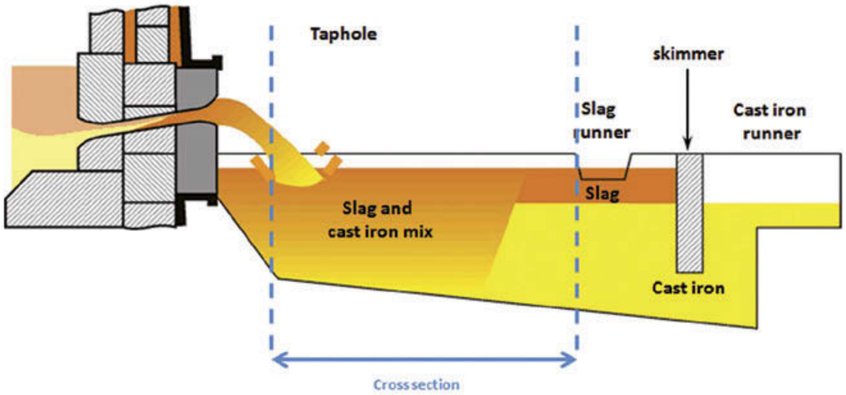


FIGURE 1: Molten metal exits a blast furnace (left) and travels through a runner where slag is separated from the cast iron (right). The cross-section being studied with COMSOL Multiphysics (see Figure 2) appears in the middle zone as indicated.

To contain splashes and provide protection, sections of the runner have a roof whose outer shell is made of cast iron with an inner lining made of concrete. This lining is necessary because, without it, splashing molten metal would quickly melt holes in the cast iron.

The concrete liner is subject to thermal shock as well as corrosion and erosion. A typical operating life for a roof runner is one month, after which time it must be relined. Given that a blast furnace can have two or three or even four taps, and we at TRB have hundreds of blast furnaces, it is clearly to our advantage to design them as economically as possible while maintaining overall safety.

Designing runners has traditionally been an inexact science because we cannot take accurate measurements of what is going on inside them. In the past we used trial and error methods to come up with the best type of concrete for liners and to determine the best thickness. If a liner got damaged too quickly, we simply tried a new combination. Much of these decisions are

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based on the heat the liner is exposed to. However, until now we have had almost no idea of these temperatures. Are they 300 °C, 1000 °C? We just didn't know! We can't place sensors inside because they would be exposed to extreme heat and splashing molten metal, which would destroy these expensive devices. Instead, we turned to simulation with COMSOL Multiphysics and its Heat Transfer Module.

### Pre-Heat the Oven

Under normal operating conditions, the molten metal doesn't enter a runner at room temperature. Thus, the first stage of our simulation was used to pre-heat the simulated runner based on a gas burner at 500 °C. This model also provides the cross-section 2D geometry we used for all further studies (see Figure 2). In the figure, note the two shades of brown, which correspond to two different types of concrete. One is in contact with molten metal and must resist the fluid, corrosion and thermal shocks. In this model, we only consider this inner layer of concrete. The second type of concrete never comes in contact with molten metal and serves as a mechanical frame. To study the pre-heating effects on the concrete, we set the simulation to only use conductive heat transfer, ignore air convection, and to assume a fixed temperature for the gas burner. The results now set the starting point for further investigations.

### Is the Air Under the Roof Moving?

Following the pre-heating simulation just described, the next stage of the model studies the first time the molten metal in the blast furnace is tapped and sent through the runner. At this point we obtain the temperature of the air underneath the cover and see how it changes over time. For this, we modeled what happens when we tap the blast furnace and send molten metal through the runner for 75 minutes. Here we did couple the heat transfer by conduction in the solid components of the surface with the flow of the air due to natural convection. In the model it took us 300 seconds of simulated time for the walls in contact with the fluid to reach the same temperature of the metal (1500 °C). Once we reached this condition, conduction took place slowly through the layers, as shown in figure 3.

It is interesting to note that at roughly 500 seconds, the air profile is almost still (see Figure 4), a fact that plays an important role into the subsequent modeling steps. Specifically, we simplify some of those steps by not including the effects of moving

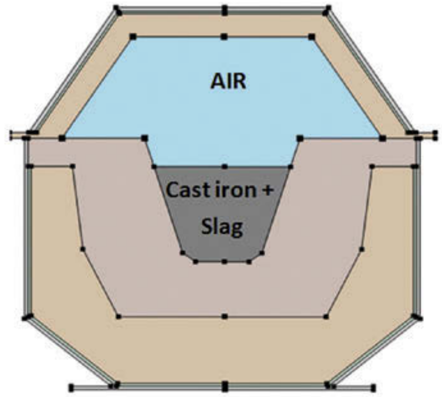


FIGURE 2: 2D geometry of a roof runner. The molten metal comes in contact with a concrete liner, and the outer shell is of cast iron.

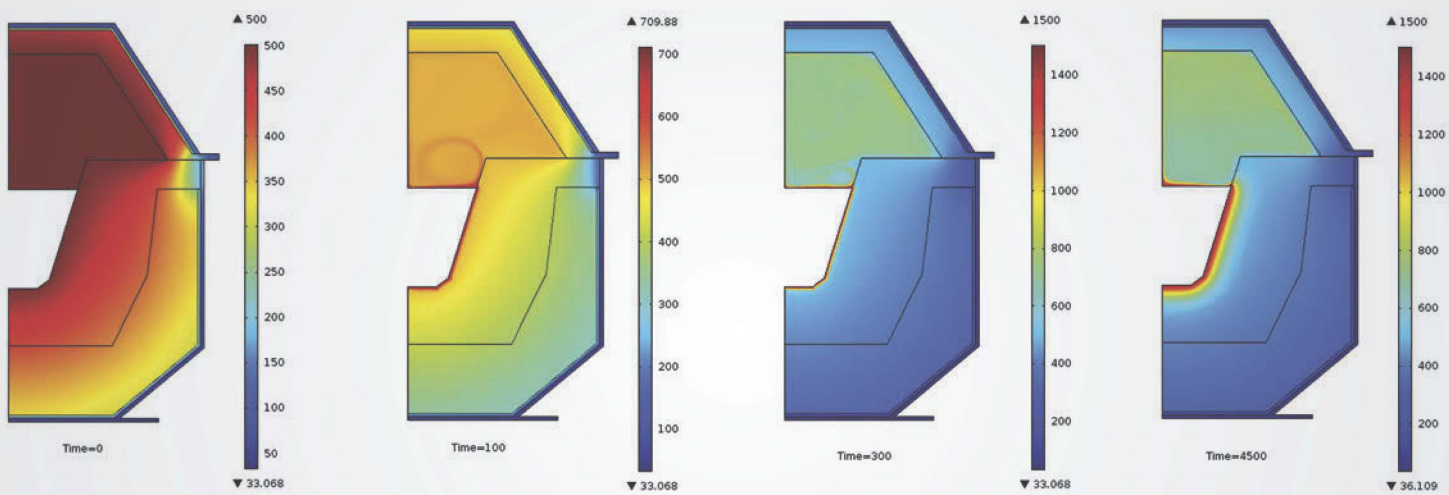


FIGURE 3: Simulation results show that after 300 seconds, the correct condition of 1500 °C is reached and heat transfer occurs mainly by conduction.

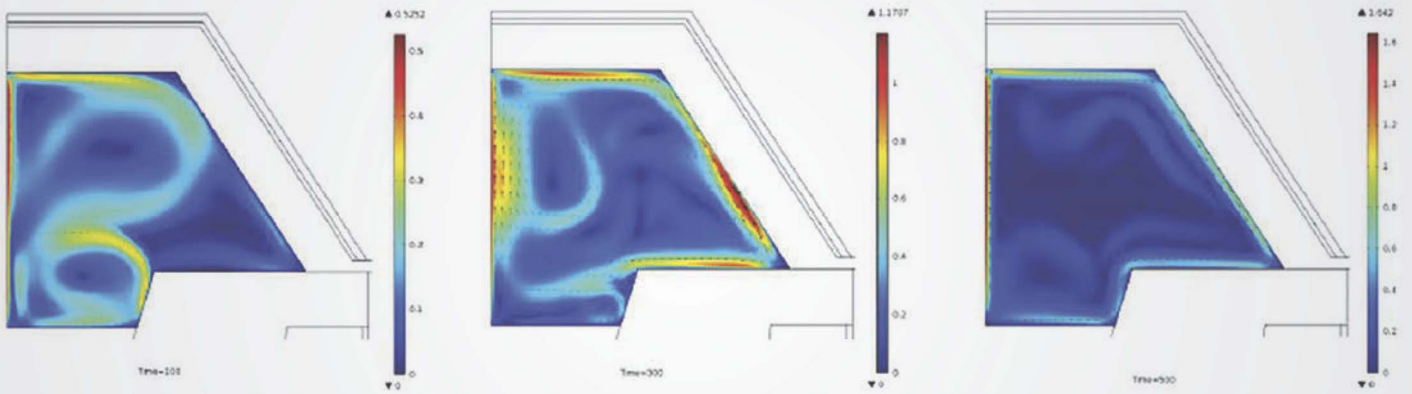

FIGURE 4: During the first tap, the simulation performed with COMSOL Multiphysics shows that after 500 seconds air under the roof runner is almost still.

air, which would not add significant information.

## Simulating a 7-Day Heating Cycle

Studying the first tapping, however, does not allow time for the entire runner to heat up and thus does not provide results we can verify in practice, which was our ultimate goal. To approximate how an actual blast furnace operates, the next stage consists of having molten metal flow through the runner for 75 minutes, then having it remain empty for 75 minutes, and cycling through this for seven days of simulated time. As just mentioned, this stage does not include air convection; we set the temperature on the inner walls that are in contact with air to the temperature determined in the previous step.

However, there was one assumption we made thus far that could affect results, so we wanted to refine our model. Specifically, in the previous model we set the temperature of the air interface to the liner at a fixed value of 500 °C. However, when the metal stops flowing, the temperature of the bottom liner does not instantly drop from the 1500 °C of the metal to the 500 °C we had specified. We went to yet another simulation stage like the previous one with one big difference. When there is molten metal, we set the temperature at the fluid-liner interface to 1500 °C; when there is no metal, instead of setting it to 500 °C, we made it thermally insulated.

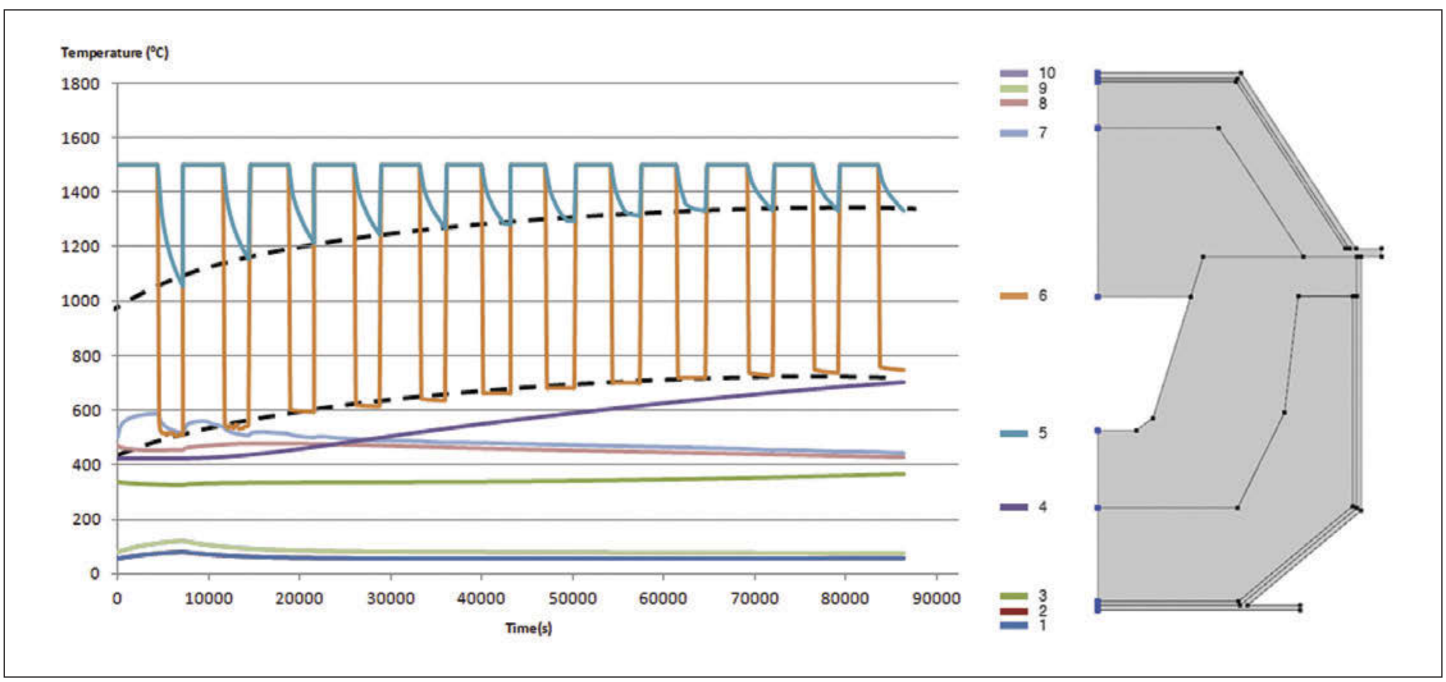


FIGURE 5: Results for 24 hours of simulated time. Trace 6 and 7 follow the temperature of the air at the interface with the molten metal and the top inner liner, respectively.

We then ran this model for 24 hours of simulated tapping and pauses. The results are shown in Figure 5.

Trace 6 follows the temperature of the air at the interface of the molten metal where it reaches (top dotted line) the set level of 1500 °C; without molten metal the temperature of the air alone drops off until it reaches roughly 750 °C (bottom dotted line). We can note that this temperature is much higher than the 500 °C from previous models. Trace 7 follows the temperature of the air where it comes in contact with the top inner liner, and that temperature starts to level off at roughly 430 °C after 24 hours.

Finally, we extended the study to a full week to see what temperature the outer cast iron shell would eventually reach. To make simulation time reasonable, we simplified this by setting the air temperature to the value found at the end of the previous stage; this is valid because Figure 5 shows that the interior air temperature has essentially stabilized. Similarly, we set the temperature at the fluid contact edges to the results in Figure 6. After another six days of tapping and breaks, we saw that the outer shell reaches a temperature of roughly 80 °C.

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## Verify Our Simulation to Optimize the Roof Runner

To verify the model, we took thermal imaging photos of an actual roof runner (see Figure 6). We found that its temperature, 76 °C, was in reasonably good agreement with the model. Next, we opened up a roof runner and used imaging techniques to measure the temperature of the liner (see Figure 7). We realize that when you open the cover, the temperature inside will rapidly drop, so the actual temperature inside during operation will be higher. In Figure 7, the hottest temperature is 300 °C, which gives us reasonable confidence that our simulated temperature of 430 °C (Trace 7 of Figure 5) is sufficiently accurate for our immediate purposes since we estimate a temperature drop of around 100 degrees. We had no idea whatsoever what this temperature was going to be and now, thanks to simulation, we reached an accurate calculation within 10 °C. The simulation has given us considerable understanding of what is going on inside the roof runner.

We were surprised when we found the temperature inside the cover is between 400 °C and 500 °C; we had expected it to be much higher. Until now, our concrete liners have been very thick, but thanks to simulation we have learned that we have likely overengineered them. Although we haven't factored in the roof wear mechanism, simulation provided us with great insights: we know now that we can reduce the thickness of concrete on roof runners. Besides saving the cost of raw materials in future roof runners by making the liner thinner, if they are lighter they will also be easier to maneuver, which will improve production rates. ■

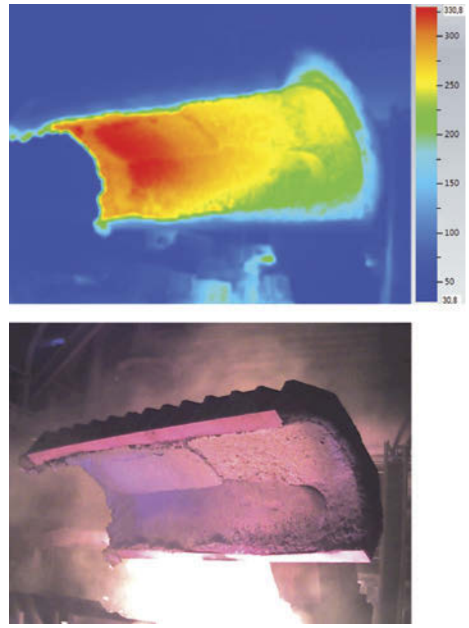

FIGURE 7: Thermogram of the inside of a roof runner (top) and a standard photograph from the same angle (bottom).

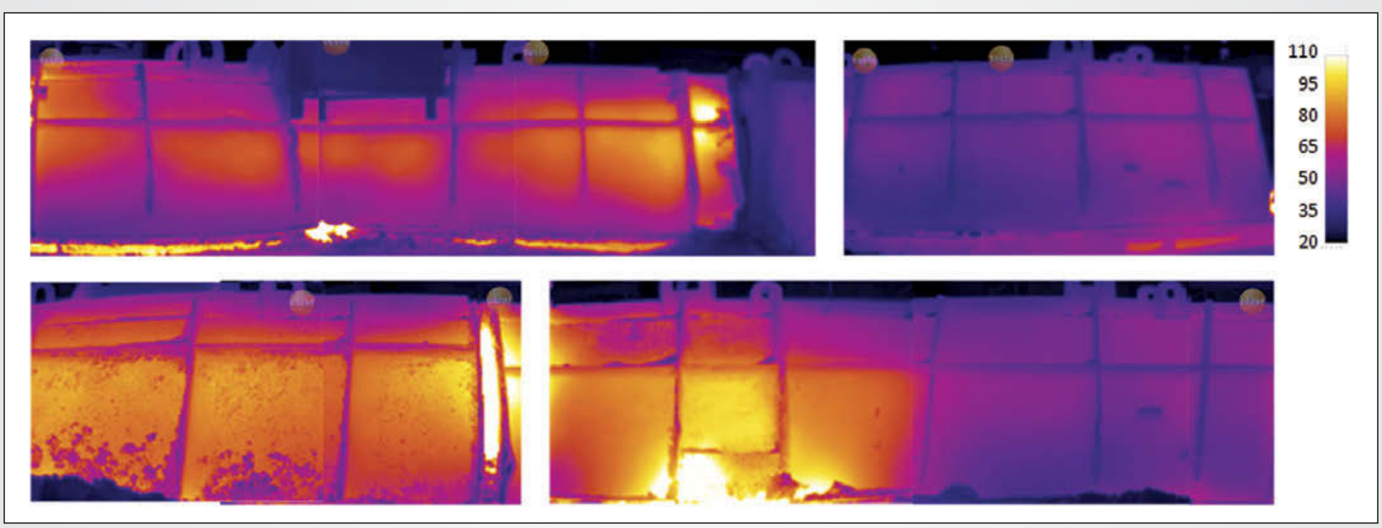


FIGURE 6: Thermogram of an actual roof runner.