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A CFD simulation of melting furnace for the production of stone wool

Simulation provides substantial information about the melter's operating conditions

Gamma Meccanica's R&D department is constantly researching new solutions to improve the overall performance of equipment, production capacity and reliability while developing environmentally sustainable processes and applications to benefit its customers.

The most recent example is the study of a new electric melter (see Fig. 1a). The company purchased the ANSYS Fluent software to perform a computational fluid dynamics (CFD) simulation of an electric melter for the fusion of basalt and dolomite rocks (see Fig. 1b).

Fig. 1 - Left - Electric melter. Right - Detail of the fusion of basalt and dolomite rocks.

The use of a mathematical model allows an in-depth understanding of the operation, optimizing the geometric characteristics such as the center-to-center spacing of electrodes or of their depth of immersion in the melt.

The CFD model

Gamma Meccanica conducted a CFD simulation on a 7 ton/h electric melter (see Fig. 2a).

The actual geometry was imported via a STEP in SPACECLAIM. Reasonable simplifications were applied to reduce the mesh size. The resulting geometry (Fig. 2b) was parameterized. Several geometric parameters are the subject of these studies:

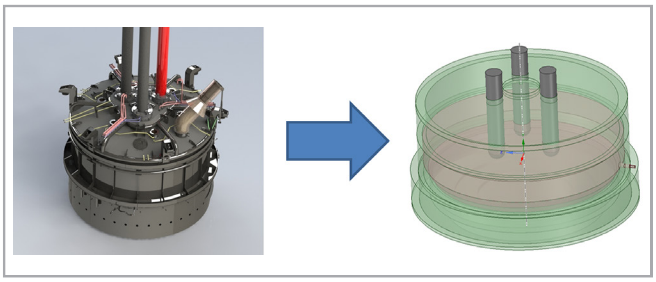

Fig. 2 - Left - Rendering of the electric melter. Right - Simplified 3D geometry in SpaceClaim

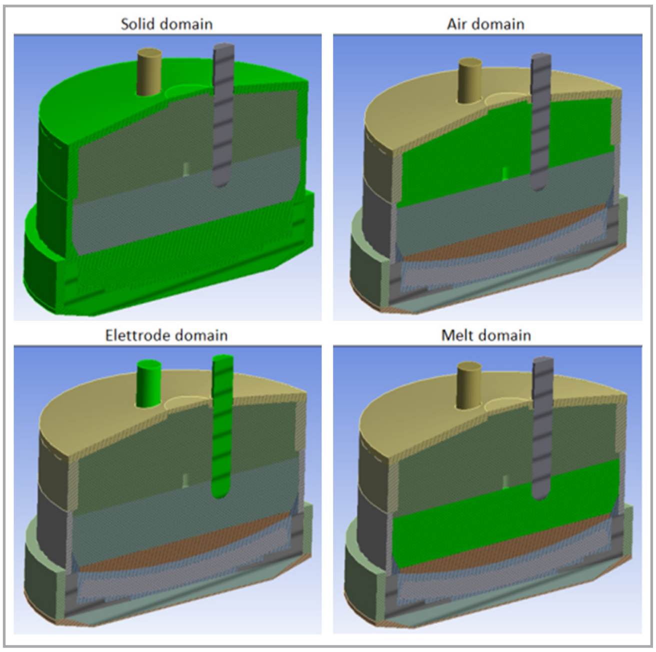

Fig. 3 - Mesh created in ANSYS Workbench

- The electrode diameter
- The electrode depth
- The distance between the electrode axes

The parameters were configured in ANSYS Workbench and a complete tetrahedral mesh of about 3.9M, which is well-suited to a parametric geometry, was created. The mesh was converted into a polymesh (of 0.8M) in ANSYS Fluent. Only one fluid domain, called the melt domain, was used (see Fig. 3). The Air domain was considered as a solid with the thermal properties of air.
A single Fluent case is able to include the electrical physics, the thermal physics and the melt fluid dynamics, if an appropriate configuration, as described in the following paragraph, is used.

Electrical physics configuration

One of the most important properties is the electrical conductivity of the melt. Electrical resistance is a function of:

- the distance between the electrode tips and the iron domain (d)
- the electrical properties of the melt (kele)
- the area through which the current passes (S)

A specific combination of these three parameters defines the electric resistance (Rele) (see Fig. 4a). The Joule effect generated by one electrode is:

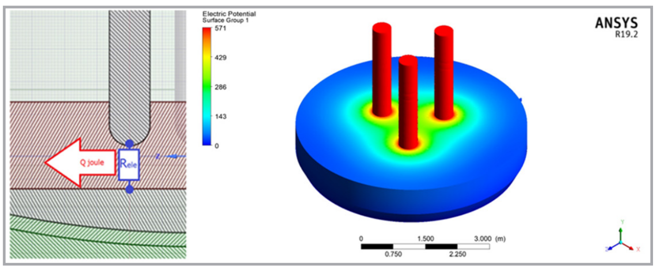

Fig. 4 - L) Electrical resistance between the electrode tips and the iron. R) Field of electrical potential

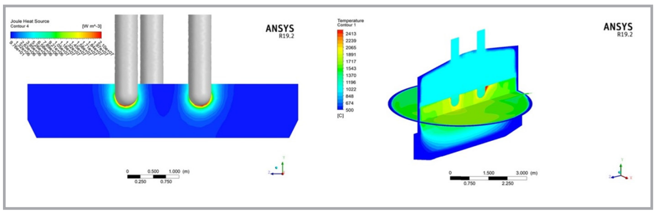

Fig. 5 - Left - Joule heat source. Right - Temperature field

$$P_{ele} = 3P_{joule,elettrode} = 3R_{ele}I^2_{current} \qquad R_{ele} = \frac{d}{s}k_{ele}$$

The electrical model considers that the three electrodes are at a steady state and have a constant $I_{current}$ value (their inflow to the melt domain), which is equal for all the electrodes. K_{ele} is constant and temperature and zero voltage are fixed throughout the solid domain (except in the melt and in the air). The resulting electrical potential is shown in Fig. 4b. These hypotheses derive from some preliminary studies, in which different boundary conditions were tested. Once the electrode distance (d) is set, the K_{ele} was corrected via the preliminary studies to obtain the expected P_{ele}. The electrical potential is shown in Fig. 5.

The thermal physics configuration

In this model, only the melt domain is fluid. The air domain is considered solid, with the standard properties of air. However, the contribution of thermal radiation, due to the high temperature of the melt, is important. A Monte Carlo radiation model was chosen, which allows the solid domain to participate in the radiation. The thermal source term, due to the joule effect (Fig. 5a) is concentrated near the electrode tips, inducing the temperature increase in the melt (Fig. 5b). Appropriately convective boundary conditions (heat exchange coefficient and free flow temperature) are imposed on the external surface of the refractory. The roof of the furnace includes a cooling system that reduces the temperature of the air inside the furnace and controls the formation of a crust on the top of the molten rock. This system is modelled using a negative energy source (to extract the estimated thermal power).

The fluid dynamics configuration of the melt

In the real furnace, solid material is added from seven different inlets (Fig. 6a) at different times during the process (controlled by local measurement of the melt temperature). Quantities of the melt are then removed (Fig. 6b) via a single outlet to maintain

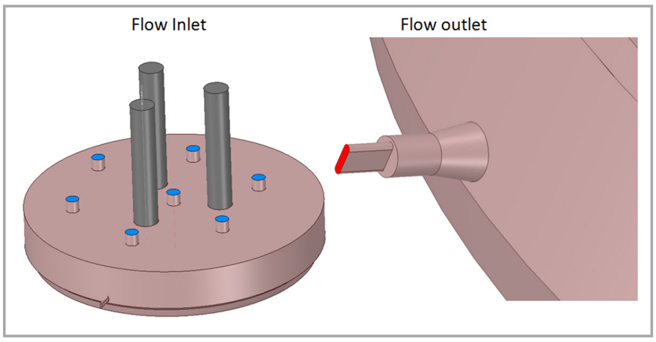

Fig. 6 - Inlet and outlet flow surface

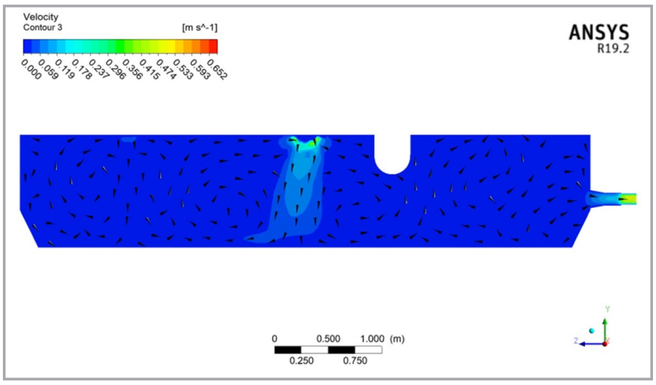

Fig. 7 - The velocity field

a prescribed melt level. A prescribed constant mass flow rate was set in the numerical model in order to use a steady-state simulation. The solidification/melting model in Fluent was used to include the latent heat absorbed by the inflow from these inlets as a result of the phase change from solid to liquid in the melt.

These hypotheses allow the modelling of a continuous flow, and the evaluation of the average velocity field (see Fig. 7) from the inlet to the outlet of the melt domain.

Results

After setting a base case (DP0), three different design points (DP1-DP3) were tested. Fig. 8 shows the distribution of the temperature fields in these four different cases:

- base case (DP0),
- increasing the axle spacing (DP1)
- increasing the depth (DP2)
- decreasing the diameter of the electrodes (DP3)

It is possible to see that a reduction of the distance between the electrode tips and the iron domain induces a reduction of the temperature near the electrodes (due to the lower electrical resistance).

The relative position between the inlet and the electrodes also appears to be important to achieve a homogenous distribution of the temperature inside the melt. Fig. 9 shows the temperature ranges of the melts on the z-x plane. The flow lines from the inlet, colored according to the intensity of the joule effect, show that the DP1 configuration was able to generate a more uniform temperature in the highlighted area, compared to the DP0.

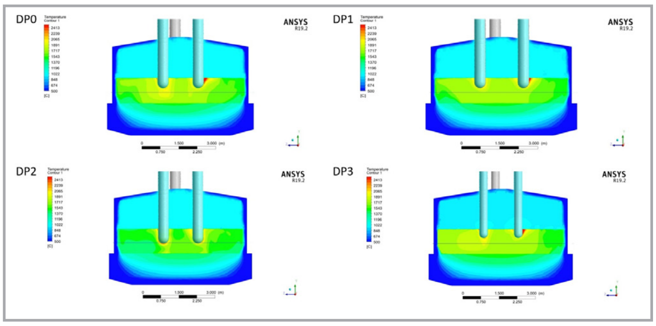

Fig. 8 - Effect on the temperature fields of changing the configuration of the eletrodes

Conclusion

This paper presents a numerical model for a melting furnace for stone wool. The numerical model was designed using ANSYS FLUENT. The model includes all the main aspects of the real process (the electrical field, the heat transfer process and the fluid dynamics of the melt).

The CFD simulation provided a lot of information about the operating conditions of the electric melter while considering the hypothesis of the dissipation terms. A proper validation on site in the field will enable us to obtain a more reliable setup of the model, to reflect reality as closely as possible.

For more information
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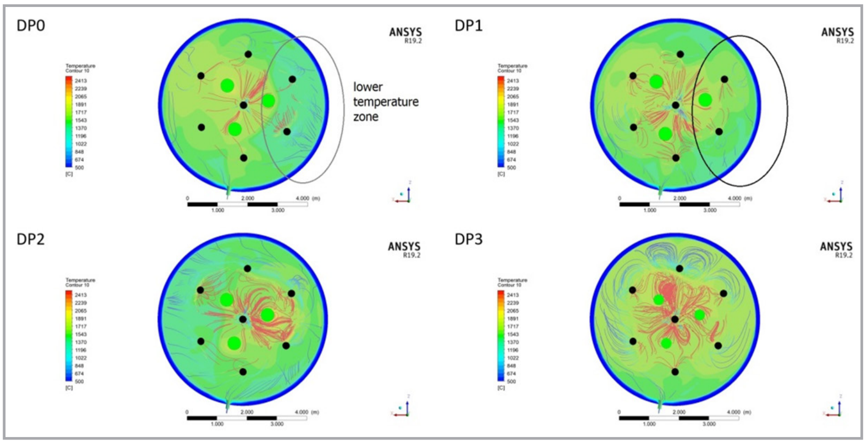

Fig. 9 - The contour of the temperature field of the different design points. Flow lines represent the joule heat source.

About Gamma Meccanica

Gamma Meccanica is one of the world leaders in mineral wool production lines, both of individual machines and of complete lines for the production of mineral wools, namely stone wool and glass wool.

The company also manufactures special lines to produce pipe sections and stitched mattresses, lamellar production lines, ceramic fiber machinery, and stone wool and glass wool hydroponic production lines.

Gamma Meccanica's machinery offers a combination of high performance and advanced technology. It meets and exceeds customer requests by constantly improving quality and energy efficiency, by means of technological evolution and high levels of technical support, in compliance with the strictest environmental standards.