Numerical Simulation of the Multiphase Flow in the Blast Furnace Main trough: Influence of Flow Characteristics in the Wearing of the Refractory lining

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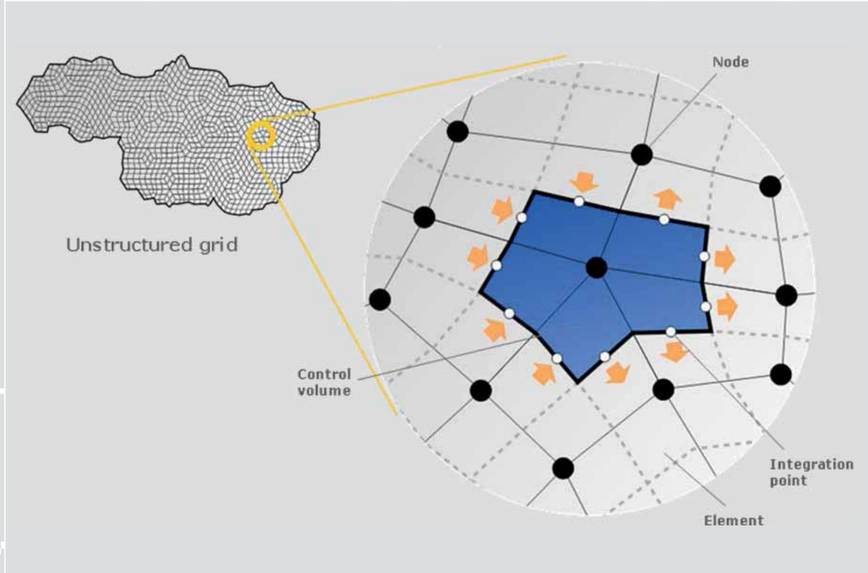
Main Goal

To better understand the reasons of the severe refractory wearing in the blast furnace main trough. The day-by-day observation demonstrates that the severe wearing of the channel happens in the impinging region. It is not yet well understood the role played by the flow parameters in this wearing process.

Strategy :

To numerically solve the 3D two-phase flow model of molten steel and air. Promising results were obtained and some comparisons are made with experimental data obtained from the steel industry.



Unstructured grid (left) with a zoom (right) showing the elements, control volume and nodes. Control volumes are formed by sub-elements.

Physical Problem

The free jet flow from the blast furnace impinges on the main channel free surface creating a very complex re-circulating flow of air, slag and steel. The problem under analysis makes the assumption that the slag is well mixed with the steel, what allows a two-phase flow model of steel and air be solved. Another important assumption considers the flow isothermal, of course, a condition not encountered in the steel making process. Since the influences of the flow characteristics in the refractory lining is the goal, the energy equation is not solved. Steel and air is considering an homogeneous fluid of air and steel. The domain encompasses the free jet from the blast furnace and the main channel where a complex re-circulating flow happens in the wearing region.

Physical Properties and Boundary Conditions

ρ_{iron}	ρ_{air}	μ_{iron}	μ_{air}	$\sigma_{\alpha\beta}$
7000 kg/m³	1.185 kg/m³	5.0 x10^{-3} Pa.s	1.83 x10^{-5} Pa.s	1,35 N/m

Local	Description	Condition
Tap hole	inlet	7.5 m/s with 10 degree
Refractory wall	wall	No-slip for momentum and wall-law for k and ε
Cast-iron outlet	Opening: Pressure	$p=0$ Pa; $I_{turb}=1$ %
Far field	Opening: Static Pressure for Entrainment	$p=0$ Pa; $r_{air}=1$; $I_{turb}=10$ %

Governing Equations

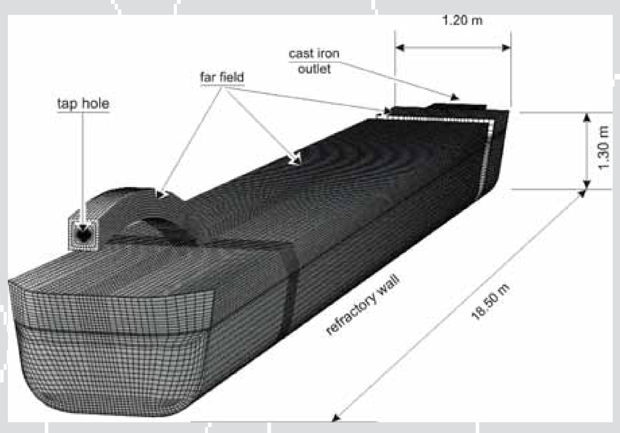
The mathematical model is described by the mass conservation equation, volume conservation of phases, a single momentum equation, since the model is considered homogeneous, and the turbulence equations for the (k-epsilon) model.

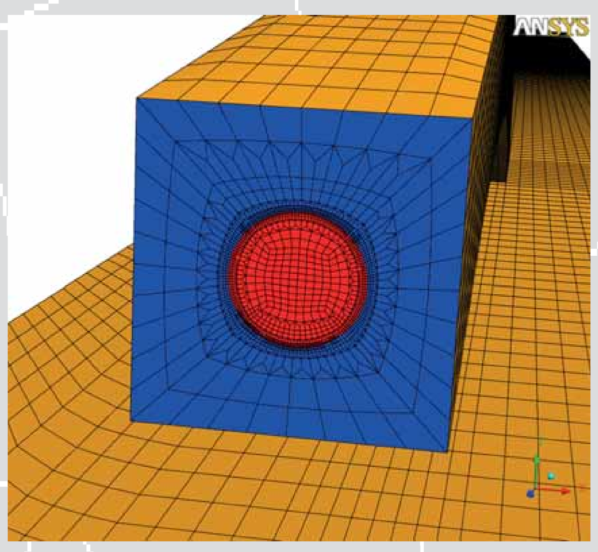
$$\frac{\partial\left(r_\alpha\langle\rho_\alpha\rangle\right)}{\partial t}+\nabla\cdot\left(r_\alpha\langle\rho_\alpha\rangle\langle\mathbf{u}\rangle\right)=0 \qquad \sum_{i=1}^{2} r_\alpha=1$$

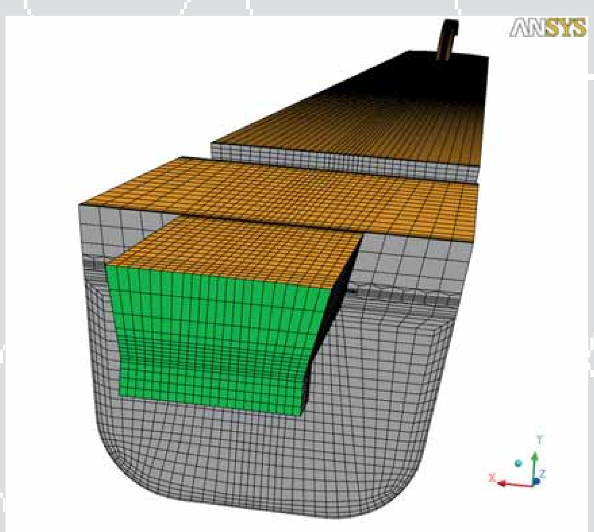
$$\frac{\partial\left(\langle\rho\rangle\langle\mathbf{u}\rangle\right)}{\partial t}+\nabla\cdot\left(\langle\rho\rangle\langle\mathbf{u}\rangle\otimes\langle\mathbf{u}\rangle\right)=\nabla\cdot\left(\mu_{eff}\left\langle\nabla\mathbf{u}+\nabla\mathbf{u}^T\right\rangle\right)-\nabla\langle p\rangle+\left(\langle\rho\rangle-\rho_{ref}\right)\mathbf{g}+\mathbf{m}_i^\sigma$$

$$\frac{\partial\left(\langle\rho\rangle k\right)}{\partial t}+\nabla\cdot\left(\langle\rho\rangle\langle\mathbf{u}\rangle k\right)=\nabla\cdot\left[\left(\mu+\frac{\mu_T}{\sigma_k}\right)\nabla k\right]+\left(P_k-\langle\rho\rangle\varepsilon\right)+T_\alpha^k$$

$$\frac{\partial\left(\langle\rho\rangle\varepsilon\right)}{\partial t}+\nabla\cdot\left(\langle\rho\rangle\langle\mathbf{u}\rangle\varepsilon\right)=\nabla\cdot\left[\left(\mu+\frac{\mu_T}{\sigma_\varepsilon}\right)\nabla\varepsilon\right]+\left(C_{\varepsilon1}P_k-C_{\varepsilon2}\langle\rho\rangle\varepsilon\right)+T_\alpha^\varepsilon$$







Full geometry of the channel with its grid (top left), the free jet flow entrance domain and grid (top right) and the outlet with the correspondin grid.

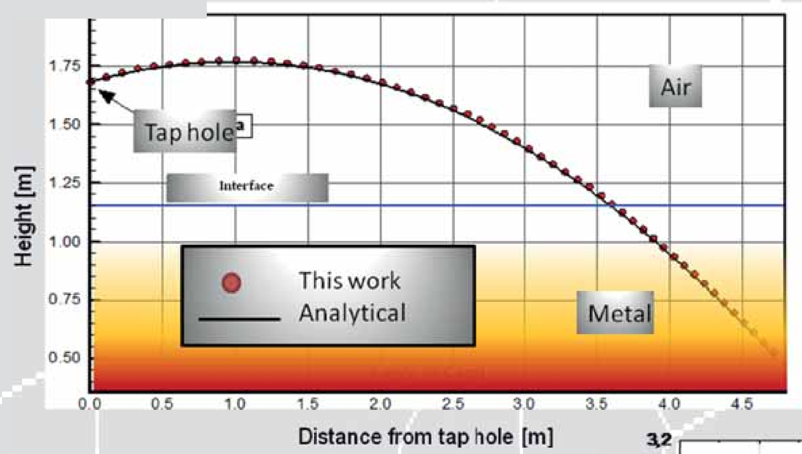
Numerical Method

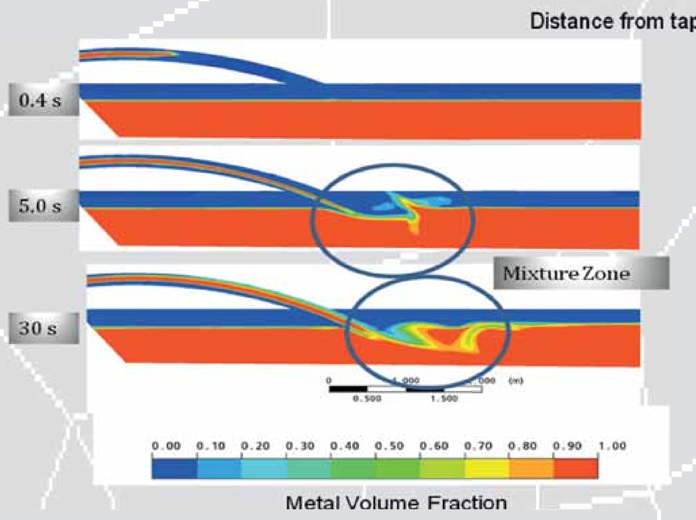
The ANSYS CFX software is used for the solution of the two-phase flow. Just for the sake of completeness, the numerical method embodied in the CFX code is the Element-based Finite Volume Method (EbFVM), a cell-vertex method which constructs the control volume joining parts of the elements furnished by the grid generator. The pressure-velocity problem is solved in a coupled fashion and high order interpolation function is employed to reduce numerical diffusion.

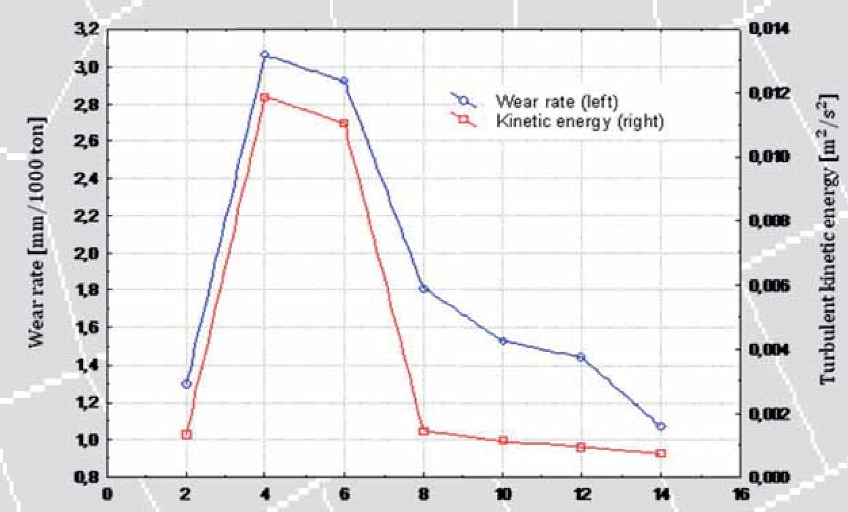
Results

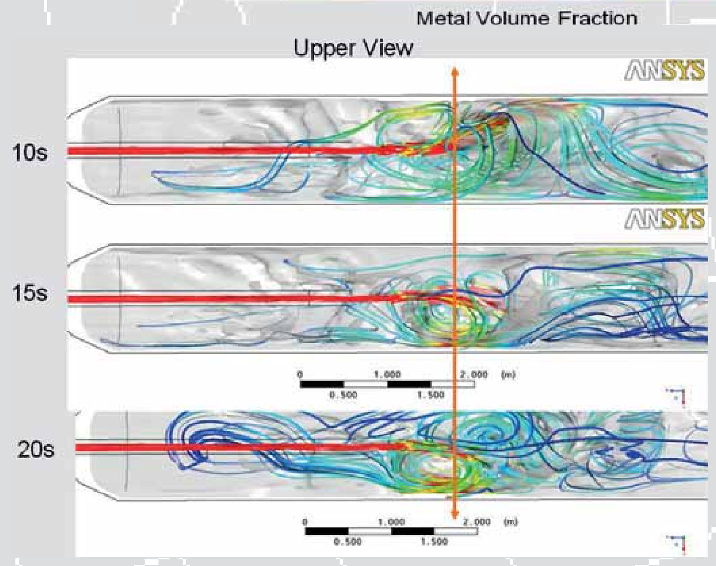
Few results are shown in this paper. First, it can be seen the good agreement between the jet numerical and analytical solution. The entrained air concentration is shown in the following picture (left) for the three time level, following by an upper view of the impinging jet, where it can be seen that the re-circulating region oscillates from one side of the channel to the other.

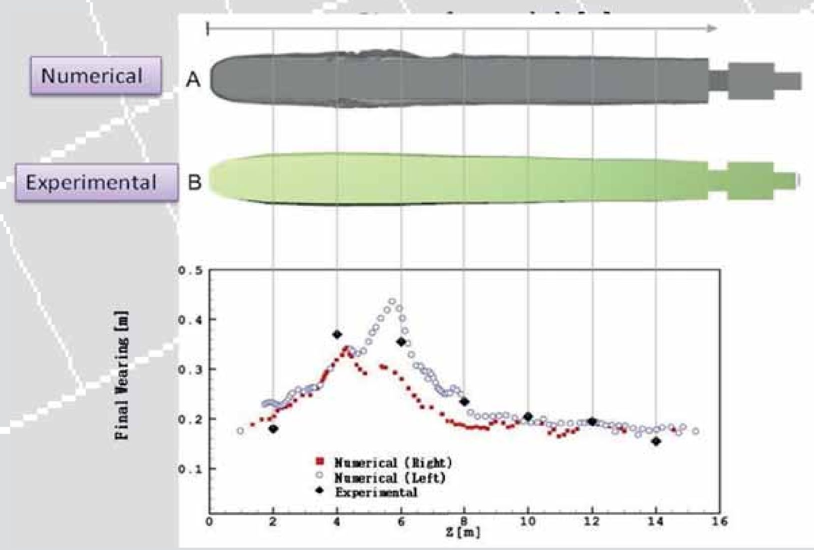
Finally, in the remaining pictures in the right side from top to bottom, one sees the lining material wear rate and the profile of the kinetic turbulent energy, what suggest some correlation between them and the final wearing of the channel compared with the experimental observations.











Conclusions

This work presented a numerical modelling of the multiphase flow in the main trough blast furnace, solving the true transient for 35 seconds. It was possible to show the behaviour of the wearing compared with the turbulent kinetic energy patterns and to propose an equation for correlating those parameters. Of course, this is a tentative of correlation, and a deeper analysis based on more physical cases need to be done. It can be said that a first step for better understanding the multiphase flow in the main trough of blast furnaces was done. Based on this model, one can improve the understanding of such complex flows..