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CFD Analysis of Injection of Heavy Fuel Oil and Plastic Particles into a Blast Furnace Raceway – Estimation of Droplet Size Distribution

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CFD methods have been used to simulate the injection of plastics into the blast furnace raceway at blast furnace A at voestalpine Stahl GmbH, Linz (Austria). Various auxiliary reducing agents like oil, tar, pulverized coal, natural gas, coke oven gas and waste plastics are applied for injection into the blast furnace to decrease the coke rate. For a better understanding of the effects of combined injection an extended model is being developed based on the CFD model for plastic particle injection reported earlier. The new model makes use of the capability to predict the raceway shape based on a new porous media approach avoiding the high computational effort of a full eulerian multiphase formulation and incorporates also a simplified reaction mechanism for calculation of the high temperature conversion of the injected materials. In addition to that code to handle the injection of multicomponent droplets like heavy fuel oil and tar has been incorporated. An important parameter to give valid estimates of the oil spray length is the droplet size distribution of the fuel oil. Unfortunately for the injection lance geometry used at the modelled blast furnace no suitable correlations to predict the spray parameters like droplet size and droplet speed have been found. Since direct measurements of the size distribution at raceway conditions are not possible a lab scale model based on similarity scaling rules (Reynolds analogy) has been developed. Optical measurements using particle image velocimetry (PIV), laser doppler anemometry (LDA) and a high speed camera have been carried out. Based on this experimental data a correlation for the spray parameters has been implemented into the CFD model. Furthermore measurements of other high temperature material properties have been carried out, e. g. for the thermal conductivity of the coke bed. Using these improved boundary and inlet conditions as well as improved physical properties the quality of the CFD simulation results and the predictions could be further improved.

1. Introduction

Basing on a CFD model for plastic particle injection published by the authors (Jordan et al, 2008) an extended simulation model is developed. The new model makes use of the

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capability to predict the raceway shape using a new porous media approach. This allows to avoid the high computational effort of a full eulerian multiphase formulation and incorporates a simplified reaction mechanism for calculation of the high temperature conversion of various injected reduction agents. Furthermore the ability to handle the simultaneous injection of multicomponent droplets like heavy fuel oil and tar has been incorporated.

2. CFD Geometry and Boundary Conditions

1.1 2.1 Geometry and operational data of the blast furnace

The largest blast furnaces (BF "A") of voestalpine Stahl GmbH in Linz, Austria is considered in this work (voestalpine Stahl, 2007). The blast furnace has a hearth diameter of 12 m, a working volume of 3125 m³, in total 32 tuyéres are installed. BF "A" has a hot metal capacity of approximately 7800 - 8800 t per day. For cost effective operation, combined injections of various reducing agents are possible. At the site heavy fuel oil, tar and plastic pellets are commonly used (Andahazy et al, 2006). The plastic pellets are fed into the furnace using a pressurized air transport system; heavy fuel oil injection utilizes coaxial two-phase nozzle lances that are supplied with 170°C steam. The average blast temperature is 1,220 °C, the hot blast amount (including additional oxygen) is about 320,000 Nm³/h, the blast furnace is operated at a hot blast pressure of approximately 4.2 bar (gauge pressure). The geometry section implemented for this work is shown in Figure 1. The detailed geometry includes not only the blast furnace walls, tuyéres and the hot blast pipes, but also the injection lances for the alternative reduction agents.

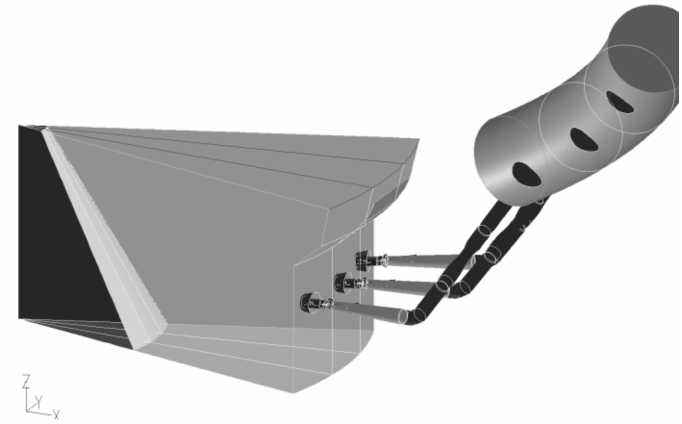

Figure 1: Detailed blast furnace geometry – simulated section in the lower part of the furnace featuring three of 32 tuyéres and also includes the hot blast pipes.

1.2 2.1 Material Properties

CFD simulations require suitable boundary conditions, which can be extracted from the original process modeled (see Section 2.1). Furthermore material properties of the present fluid and solid phases are required as input for the CFD code. Figure 2 gives an overview of the data on the plastic particles used for this calculation and the appropriate source. Similar property data are also to be provided on the coke bed and the heavy fuel oil.

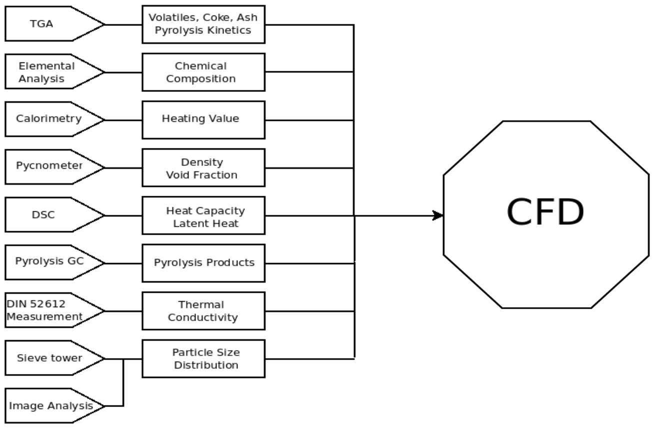

Figure 2: Source of the material data of the plastic particle.

The gas phase inside the blast furnace has been considered as an ideal gas. Temperature dependant gas thermal conductivity, heat capacity and molecular viscosity are assumed to follow an ideal gas mixing law of the components (O_2, N_2, CO, CO_2, H_2, H_2O, C_{solid}, fuel-oil), species data taken from NIST (2007) or VDI (2002). A short summary of the data for the alternative reduction agents, plastic particles and heavy fuel oil, used to model the co-injection process can be found in (Jordan et al, 2008a). Both, the plastic particles as well as the heavy fuel oil droplets are simulated using a lagrangian tracking method called discrete particle model (DPM). The reaction kinetics and the fuel analysis of the plastic particles have been obtained using TGA and laser ablation experiments (Lackner et al, 2007) to account for the high temperature during the conversion process in the blast furnace raceway (Löffler et al, 2001). A compact reaction mechanism consisting of 15 semi-global gas phase and surface reactions has been set up (Harasek et al, 2007). Turbulence interaction and radiative heat transfer have also been considered using standard models available in the CFD code (ANSYS/Fluent, 2001-2008). The radiation model required several extensions implemented as user defined code: A custom WSGG (weighted sum of grey gases) approach accounts not only for water vapour and carbon dioxide but also for the presence of large amounts hydrogen and carbon monoxide. In addition to that it takes care of the optical properties of the dense coke bed. To ensure proper boundary conditions for the particle and droplet reactions within the raceways also the surrounding coke bed has to be characterized. Important parameters for the solid coke are the thermal conductivity and the specific heat capacity. Since these material properties are strongly temperature dependent and also vary with particle shape and size as well as with the composition, direct analysis of the material charged to the considered blast furnace is required. The measurement procedures for the temperature dependent heat capacity using a drop calorimeter (Ohmura et al, 2003) and the thermal conductivity according to Magee and Bransburg (1995) have been discussed in Jordan (2010). The mechanical behavior of the coke bed within the blast furnace (porosity and fluid dynamic resistance) has been treated using a simplified raceway model, which considers the void fraction to be a linear function of the velocity (Jordan et al, 2010). The linear relationship is bounded by the minimal fluidization velocity and the terminal sinking velocity of an average coke particle of the bed.

3. Considerations on Heavy Fuel Oil Injections

The evaporation and the conversion rates of the liquid injections (heavy fuel oil, tar) strongly depend on the droplet size which can be achieved by the atomizer (injection lance). Another important parameter is the initial velocity of the droplets.

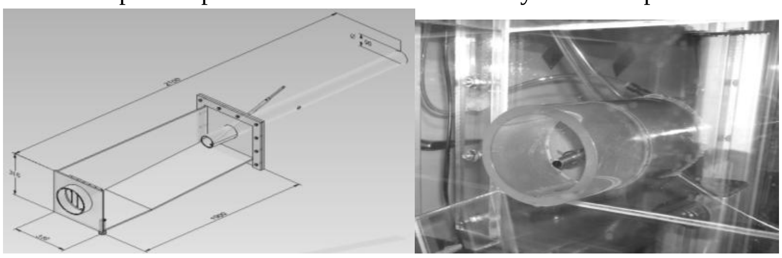

Figure 3: Overview – lab scale test rig for PIV measurements

To improve the model parameters for the heavy fuel oil spray and evaporation, a lab scale test rig of one tuyére section was constructed (Figure 3). PIV (Particle Image Velocimetry) measurements and high speed camera techniques will be used to estimate the mean droplet diameter of the liquid spray and initial velocity in the downscaled model. Characteristic dimensionless numbers (especially the Reynolds number and the Ohnesorge number) are used to calculate the corresponding parameters in the full scale blast furnace at operating conditions.

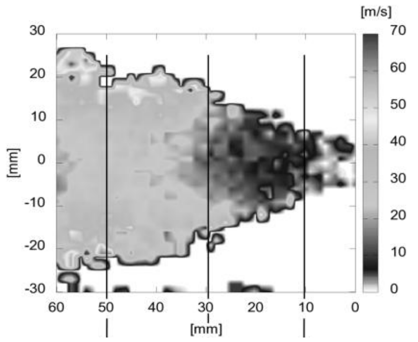

Figure 4: Example - PIV velocity profile of a droplet spray in the high velocity gas jet.

An example of the resulting velocity plots is shown in Figure 4. Scaling from the lab test rig to the real process was done for characteristic parameters like the average droplet size and velocity at constant distance from the nozzle position, which can be directly applied as boundary conditions in the CFD model. The scaling law has been set up using a power law approach.

4. Preliminary results of the CFD simulations

Figure 5 shows the discrete particle (DPM) tracks of the simultaneous injection of plastic particles (injection lance pointing upwards from the lower right side; light-grey) and heavy fuel oil (lance pointing downwards from the upper right side; dark). It can be seen, that the smaller fuel oil droplets evaporate after only a short distance, the much bigger (6-8 mm) plastic particles shrink during the travel time but may reach the raceway boundary. The impacted plastic particles react until they are completely decomposed. Other results from the CFD model are the pressure, velocity and species distribution within the modeled region, these can be used for design and process developments.

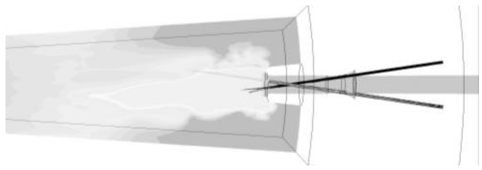

Figure 5: Simultaneous injection of particles (injection point lower right side, pointing upward left – slow reaction) and heavy fuel oil (upper right side – rapid evaporation). Shape of the raceway at injection level in the background.

5. Conclusions and further work

A CFD model for simulating the plastic pellet injection into a blast furnace raceway was successfully implemented. Using this model the conversion of plastic particles at high temperatures and high heat flux rates could be investigated. Particle data obtained from ultimate and optical analysis combined with thermo-analytical data were used to adjust a discrete phase model. Moreover a new modeling approach to calculate the raceway shape was implemented. The results agree well with published simulation data using other models and with the practical experience of the blast furnace operators. The modeling allows for providing additional insight into the conversion process. With further simulations using the detailed blast furnace geometry the effect of different injection amounts will be studied in more detail. Also important problems like if the impacted plastic particles on the raceway boundary have any effect on the pressure drop and/or flow distribution, or if coke particles remaining from the pellets are entrained into the bed could be addressed.

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