CFD MODELLING OF A COMPLETE ELECTRIC ARC FURNACE ENERGY SOURCES

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Abstract: *This paper, concentrates on a three-dimensional (3D) computational fluid-dynamics (CFD) model for coal combustion and electrode radiation inside an electric-arc furnace (EAF). Simulation of the complete EAF model includes combustion reactions of coal particles and radiation from electrodes. Particle surface and gas phase reactions were used to predict injected coal particle combustion. The CFD model provided detail information for the coal particles combustion and radiation interactions phoneme inside the electric-arc furnace. Results showed that CFD simulation could efficiently be used to develop and investigate EAF in design phase.*

Keywords: ELECTRIC ARC FURNACE, CFD, COMBUSTION, RADIATION, HEAT TRANSFER

1. Introduction

Generally electric arc furnaces consume high levels of energy to run the steelmaking processes that uses the coal and the electricity as the main resources of the energy. In order to increase the efficiency of these types of huge processes expensive experimental investigations using trial-error methods are required. Recently developed computational resources can solve interpenetrating physical phenomenon such as the solid particles combustion and the evaporation as well as the turbulence and the radiation together. CFD is an advanced simulation tool with a capability to comprehensive model for the industrial applications such as EAF. In this study commercial CFD software ANSYS FLUENT 14.0 [1] is used to develop a simulation methodology on EAF. One of the important targets to create an extensive CFD model of EAF is to investigate the combustion phoneme of injected coal particles, electric arc radiation and slag surface temperature distribution in order to analyze and verify the accuracy of simulations. In addition, the CFD model provided detailed information on the spatial distribution of the jet velocity, combustion species distributions and heat output from the EAF walls.

A number of reference studies have been carried out on combustion for the EAF. CFD model on post combustion reactions in the EAF has been studied [2] by simulating the radiation heat transfer, post combustion reactions, and de-post combustion reaction which is reacted between CO_2 and carbon in the liquid metal or the electrodes. Also radiation heat transfer from the electric-arc has significant effect to melt the metal mixture in the EAF. Guo and Irons [3,4] simulated the EAF radiation using CFD in order to introduce the energy distribution of the radiation heat transfer. They studied the radiation energy distribution for the sidewall refractory, water-cooled side panels and the furnace roof. Based on Guo’s study some assumptions on heat transfer coefficients, radiation emissivity of the walls and the electric-arc surfaces were applied in the current model.

EAF are widely used to melt scrap metal in the steelmaking industry. Taking this into account, the studies on energy efficiency are of a great significance. Therefore, this study aims to develop a comprehensive three dimensional CFD model for the coal combustion and the radiation heat transfer process. In this model, the location or quantity of the injectors, the injection angle, chamber dimensions of the EAF, the oxygen or the coal contents and radiation rates of the electrodes etc. can vary to reach the targeted temperature on the melt surface. On that sense the model provides flexibility on design parameters. Such a flexible CFD model can provide optimization the combustion and the electrode radiation to decrease the energy consumption in an EAF.

2. Computational Simulation

In this study, an EAF produced by CVS Tecnologies for scrap melting process has been modeled. The EAF parameters are internal height 3505.25 mm, internal furnace radius 3600 mm, internal slag surface radius 3080 mm electrode radius 305 mm used to create the 3-D model for the computational domain. Boundary conditions which include inner surfaces of the furnace walls, upper and sidewalls of the chimney were given particularly in Figure1. All injectors located 1.07 m above from the slag surface and aiming 45^o downwards. In order to simplify the model, bottom surface of the computational domain was accepted as a slag surface instead of modeling the overall melt volume. Combustion products and the other unburned gasses leave the computational domain from the exhaust surface of the EAF. Bottom surfaces of three electrodes generate electric arc and the radiate energy with the constant heat flux.

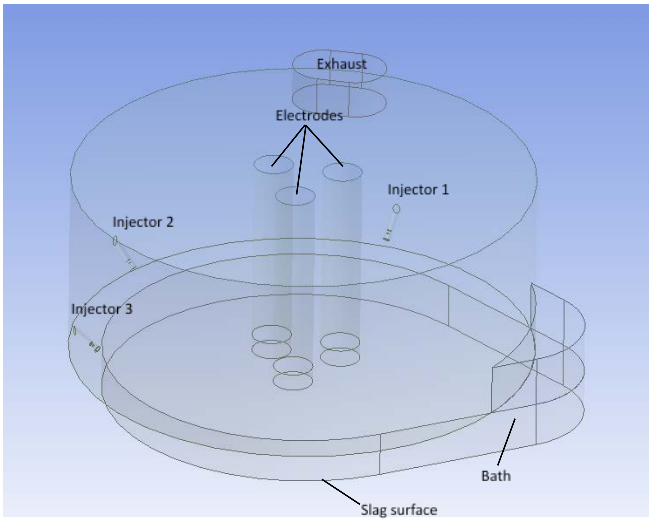

Fig. 1 *3-D CAD model of the EAF*

The skewness is an important parameter to understand the grid structure quality therefore great attention has been given to the skewness. Triangle prism mesh structures were used to create small computational domains in the model. The boundary layer mesh and weight factors are also used to create some critical zones for the computational accuracy. The sufficient grid refinement at the slag surface, arc generated surfaces of the electrodes and the injectors are necessary to capture the surface interactions and provide computational stability. The mesh structure of the EAF model, mesh inflation at the slag surface and dense grids at the injectors can be seen in Figure 2.

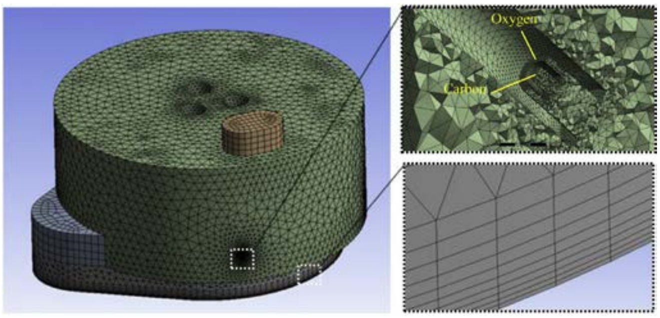

Fig. 2 *EAF mesh structure*

The model of EAF includes turbulent flows, combustion reactions, radiation, conduction and convection heat transfer. The realizable k-ε model was applied in the model to solve the turbulence which shows a good agreement with experimental observations of the gas flows with the coal particles combustion according to literature [5]. Previous studies on the liquid fuels and the coal combustion modeling [6,7,8] were showed that discrete phase model which has applied in current study, is a useful method to simulate the particle trajectory. The particle diameter distribution of the coal was modeled using Rosin-Rammer method with spread parameter of 4.52 and 10 groups. The minimum, the maximum and the mean particle diameters were chosen as respectively 70e-06 m, 200e-06 m and 134e-06 m. Discrete random walk model was enabled for stochastic tracking of coal particles. P1 radiation model has been chosen in order to solve the radiation originated from the electrodes and combustion reactions in the current model.

In the CFD code, the coal is simply classified as a single species due to the quantities of the fixed carbon and volatile matter [1]. Several classifications for the coal can be found in the FLUENT depending on property of the coal density, the specific heat and component fractions etc. In this study the volatile matter (VM) break up was assumed as a single hypothetic hydrocarbon component consist of Carbon (C), Hydrogen (H), and Oxygen (O). After injecting the coal particles into the computational volume, volatile matters in the coal particles are initially converted to a pseudo gas phase species with using the constant rate de-volatilization model [9].

Three-step volumetric reactions with six species including the volatiles matter combustion were applied to the model. These gas phase reactions deals with the local chemical equilibrium are calculated by Arrhenius type chemical kinetics. Three-step gas phase and surface reactions were listed in table 1 including Arrhenius Reaction Rate and Activation Energy.

Table 1: *Gas phase and heterogeneous particle surface reactions.*

Gas Phase reactions			
No	**Reaction**	**A**	**Ea (j/kgmol)**
1	$mv_{vol} + 1.706O_2 \rightarrow CO_2 + 1.543H_2O$	2.119e+11	2.027e+08
2	$H_2 + 0,5O_2 \rightarrow H_2O$	1e+15	1e+08
3	$CO + 0,5O_2 \rightarrow CO_2$		

Heterogeneous Particle surface reactions				
No	**Reaction**	**A**	**Ea (j/kgmol)**	**Diffusion rate constant**
4	$C<s> + 0,5O_2 \rightarrow CO$	0.002	7.9e+07	5e-12
5	$C<s> + CO_2 \rightarrow 2CO$			
6	$C<s> + H_2O \rightarrow H_2 + CO$			

3. Results and discussion

Figure 3 (a) shows the velocity profiles on a plane intersecting the center of the injector 1. Velocity data plotted in the figure 3 (b) is obtained from a straight line (demonstrated in the figure 3(a) with a dash line) from the slag surface to the injector. Values range from a maximum from 349 m/s to zero for the O2 stream and outer flow. The speed of the jet decreases as it expands and mixes with the coal particles and gases. Swirls and high temperature combustion effects expand the velocity gradients to the larger volumes. Jet reaches the melt surface about 75 m/s.

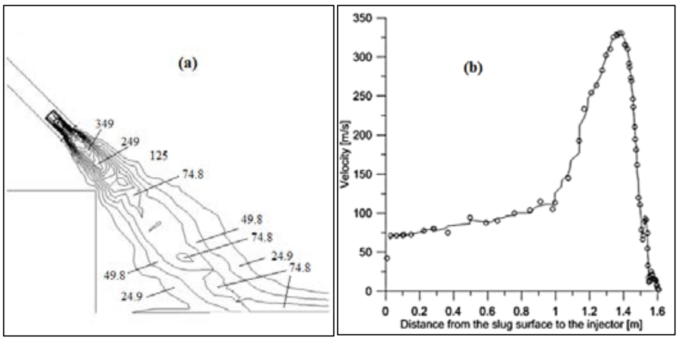

Fig. 3 *Velocity (m/s) magnitude for a plane intersecting the injector 1; (a) Velocity distribution profile and (b) Velocity data graph.*

The temperature profiles inside the EAF are presented for a plane intersecting from the center of the injectors. The combustion temperature profiles of injector 1, 2 and 3 are shown in Figure 4. The temperature at the jet flow after injector 1 and 3 is distributed between 2270 and 3200 K. Injector 2 which is located between two injectors, the maximum combustion temperature at the jet flow is investigated as 3000 K. The minimum temperature values are obtained at the near furnace walls as 692 K because of the heat transfer effects from the cooled furnace walls. The maximum combustion temperatures at the injector exits are continuously decreased to around 2200 K on the slag surface.

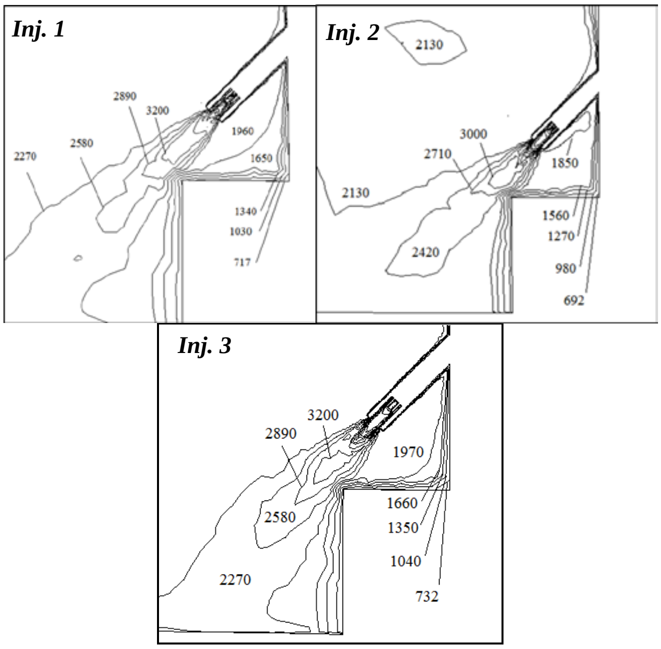

Fig. 4 *Temperature (K) profile for a plane intersecting the injector 1,2 and 3*

The radiation temperature distribution which is identified on the bottom surface of the electrode can be seen in Figure 5. The radiation temperature is between 2050 K and 1860 K inside the furnace chamber.

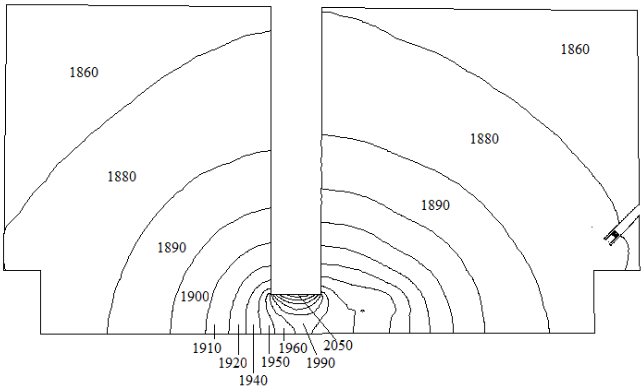

Fig. 4. *Radiation temperature (K) profile for a plane intersecting one of the electrode.*

Temperature distribution on the slag surface were introduced in Figure 6. According figure the slag surface static temperature variation is between 1860 K and 1970 K and the temperature of the slag surface mostly accumulated around 1880 K which is enough to maintain melt temperature at around 1800 K [10].

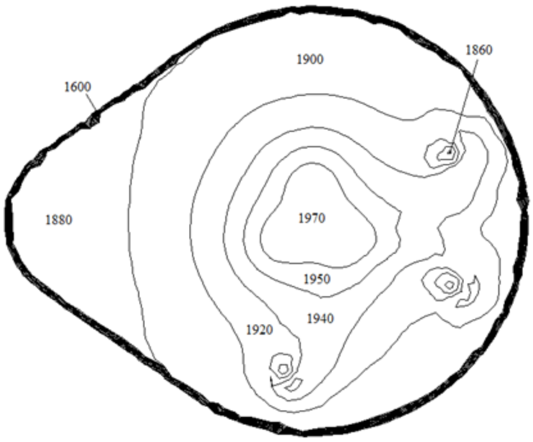

Fig. 5. *Temperature (K) distribution profile on the slag surface*

Figure 6 shows CO and CO_2 mass fraction distribution around the injector 1. Formation of CO from combustion reactions is lower than the slag surface diffusion as indicated in Fig. 9

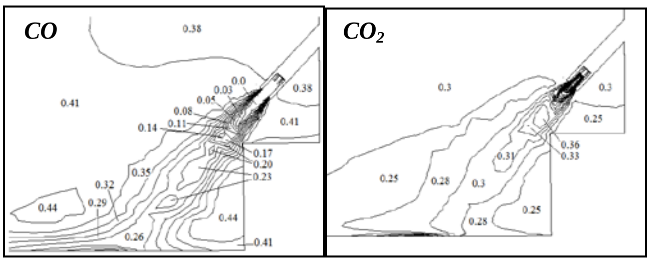

Fig. 6. *CO (left) and CO_2 (right) mass fraction in combustion field on a plane intersection the injector 1*

4. Conclusion

In this study thermal effects of carbon combustion and electrode based radiation are modeled for a commercial EAF using state of art simulation technique of CFD. Core temperature occurred with combustion in jet area and the temperature distribution on the slag surface is analyzed in detail with the model. The variation of the CO and CO_2 which are occurred by the carbon combustion reactions are given visually. The effect of the radiation temperature inside the EAF and on the slag surface is visually examined. The total and average temperature distribution on the slag surface is in satisfactory agreement with the real conditions.

The developed model can help us to increase the EAF efficiency by testing at the design level of the EAF. It was determined that the model is fast, reliable, low cost and able to give detailed results. This model gives us an alternative method for high cost experimental methods and the methods of zero dimensional calculations which have less consistency.

Acknowledgements

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