Computational Analysis of Blast Furnace Pulverized Coal Injection For Iron Making

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Abstract*: The combustion characteristics of pulverized coal injection (PCI) in the blow pipe tuyere assembly using different injection patterns are simulated, to improving the practical performance of the blast furnace. The model was capable of handling steady state, three dimensional multi phase flow of pulverized coal injection using k-epsilon model. The model was applied to simulate the flow pattern of the pulverized coal inside the tuyere lance design for the pci system. The model is validated against the measurements under different conditions. The model provides a cost-effective tool for understanding and optimizing the in-furnace flow-thermo-chemical characteristics of the PCI operation in full-scale blast furnaces.*

Keywords: tureye, CFD, lance, PCI, gambit, fluent

Introduction: In iron making industries there is lot of research in all area of blast furnace but when we talk about the fuel injection system there is a very less improvement in this field. But the rise of price of coal it is very important to improve cost effective fuel injection system. in this paper with the help of CFD software simulate the different injection pattern for improve the efficiency of blast furnace injection system.

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Fig. 1- Pulverized coal injection system [8]

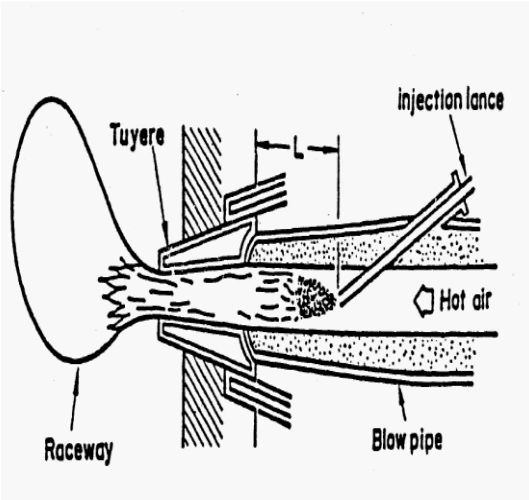

Fig. 2- Schematic diagram of the process

A tuyere is a tube, nozzle or pipe through which air is blown into a furnace or hearth Air or oxygen is injected into a hearth under pressure from bellows or a blast engine or other devices. This causes the fire to be hotter in front of the blast than it would otherwise have been, enabling metals to be smelted or melted or made hot enough to be worked in a forge. This applies to any process where a blast is delivered under pressure to make a fire hotter.

***Design parameters**:* The methodology combines 3-D CFD model, which is used to predict the hot face temperature for a given inner profile, 1-D heat transfer model, which is used to predict fine tune the inner profile [3]. Tuyere part is very important in the blast furnace because a high velocity, high temperature air blast is coming from the tuyere which is an aid for the molten of the iron. It is a vital component portion in the blast furnace process, through this portion smelting process happens, and the desired product i.e. molten iron is making.

Tuyere length	3.59 cm
Inner dia. Of tuyere or outlet of the blowpipe	12.46cm
Outer diameter of tuyere	10.5cm
Lance inlet angle	7deg.
Inner dia. Of lance	.95cm
Outer dia. Of lance	1.89cm
Lance length	15.3cm

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Table 1- Design Parameters

Tuyere inlet pressure	**461300 pa**
Air blast velocity in tuyere	**128m/sec**
Blast temperature	**1300k**
PCI flow rate	**.5kg/sec**
Air velocity	**107.8m/sec**
Temperature of primary air	**473k**
Wall temperature	**1423k**
Internal emissivity	**.5**

Table No.-2 Boundary condition

Design procedure: To analyze the combustion process inside the tuyere in one lance system with some inclination software packages like computational fluid dynamics software gambit and fluent used [11]. And the results of these injection patterns, through some profiles of temperature distribution, pressure profiles, velocity distribution etc.

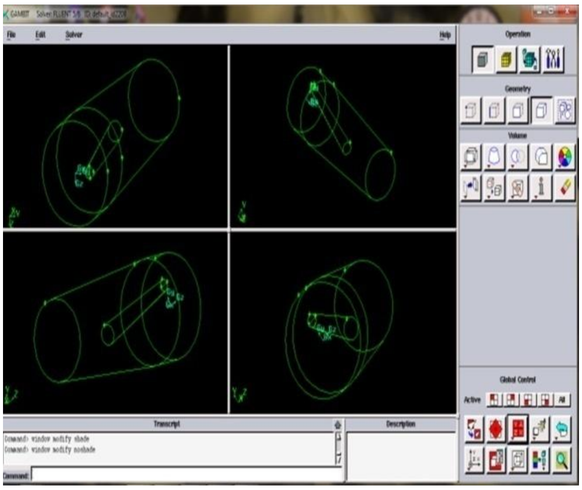

Fig. 3- Wire frame model of tuyere

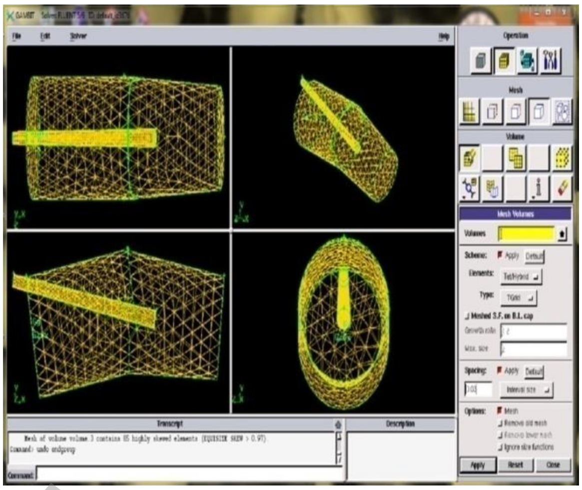

fig. 4- Grid generation of tuyere

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Nomenclature [9]:

A_p — particle projected area, m2
C_1, C_2 — turbulent model constants
C_D — drag coefficient
C_p — particle heat capacity, J kg_1 k_1
D — external diffusion coefficient of oxygen in Gibb model,m^2 s^{-1}
f_D — drag force from a particle, N
H — enthalpy, J kg^{-1}
[i — molar fraction of reactant species i
k — turbulent kinetic energy, m^2 s^{-2}
m — mass transfer rate from a particle, kg s^{-1}
n_p — particle number per unit volume, m_3
q — Heat transfer from a particle, W
Re — Reynolds number
T — temperature, K
T_c — activation energy in Gibb/Field model, K
T_s — constant in Gibb model, 6240 K
U — mean (true) velocity of gas, m $s\_^{-1}$
u, *v*, *w* — gas velocity components, m s^{-1}
v_i — stoichiometric coefficient of species i.
W_i — reaction rate of species i (per unit volume), kg m^{-3} s^{-1}
Y_i — mass fraction of species i

Greek letters

α — Volume/internal surface area ratio in Gibb model

α_1, α_2	volatile yield
ε	Turbulent dissipation rate, $m^2\ s^{-3}$
ε_p	Particle emissivity
k	thermal conductivity, $Wm^{-1}\ k^{-1}$
σ_k, σ	turbulence model constant
σ_B	Stefan–Boltzmann constant, $5.67x\ 10^{-8}Wm^{-2}\ k^{-4}$
ϕ	mechanism factor in Gibb model
ρ	density, $kg\ m^{-3}$
γ	volume porosity (γ = 1 for cavity)
μ	dynamic viscosity, Pa s
μ_t	turbulent viscosity, Pa s
Γ_i	molecular diffusivity of species i, $kgm^{-1}\ s^{-1}$

Subscripts

g	gas
p	particle

Mathamatical model

Governing equations for the gas and particle phases [9]

Phase Mass
$$\nabla.(\rho U) = \sum_{n_p} m$$

Momentum
$$\nabla.(\rho UU) - \nabla.(\mu + \mu_t)((\nabla U + (\nabla U)^T) = -\nabla\left(P + \frac{2}{3}\rho K\right) + \sum_{n_p} f_D$$

Energy
$$\nabla.\left(\rho UH - \left(\frac{\gamma}{C_p} + \frac{\mu_t}{\sigma_H}\right)\nabla H\right) = \sum_{n_p} q$$

Gas species I
$$\nabla.(\sigma UY_i - \left(\tau_i + \frac{\mu_t}{\sigma Y_i} - \left(_i + \frac{\mu_p}{\sigma_{Y_i}}\right)\nabla Y_i\right) = W_i$$

Turbulent kinetic
$$\nabla.\left(\rho Uk - \left(\mu + \frac{\mu_t}{\sigma_k}\right)\nabla k\right) = (P_k - \sigma\varepsilon)$$

Turbulent dissipation Rate
$$\nabla.\left(\rho U\varepsilon - \left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\nabla\varepsilon\right) = \frac{\varepsilon}{K}(C_1 P_k - C_2\sigma\varepsilon)$$

For a particle in the Particle phase Mass
$$\frac{dm_p}{dt} = -m$$

Momentum
$$m_p\frac{dm_p}{dt} = -f_D$$
$$-f_D = \frac{1}{8}\pi d_p^2 \rho C_D \left|U - U_p\right|(U - U_p)$$

Energy
$$m_p C_p \frac{dt_p}{dt} = -q$$
$$-q = \pi d_p\, \lambda NU\left(T_g - T_p\right) + \sum\frac{dm_p}{dt}H_{reac} + A_p\, \varepsilon_p(\pi l - \sigma_{BT_p^4}\ )$$

Where $\mu_t = C_\mu \sigma\frac{k^2}{\varepsilon}; P_K = (\mu + \mu_t)\nabla U.(\nabla U)^T); C_D = \max\left(\frac{24\left(1+0.15Re^{0.687}\right)}{Re},\ 0.44\right); i = O_{2;} CO_2\ ; CO; VM, H_2, H_2O$

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Simulation procedure : In the present model, one single computational domain covers the lance, blowpipe, tuyere, raceway and coke bed, so that the effects of operational conditions and coke bed properties on coal combustion could be directly evaluated in real time. The blowpipe- tuyere-raceway region is treated as a cavity [13].

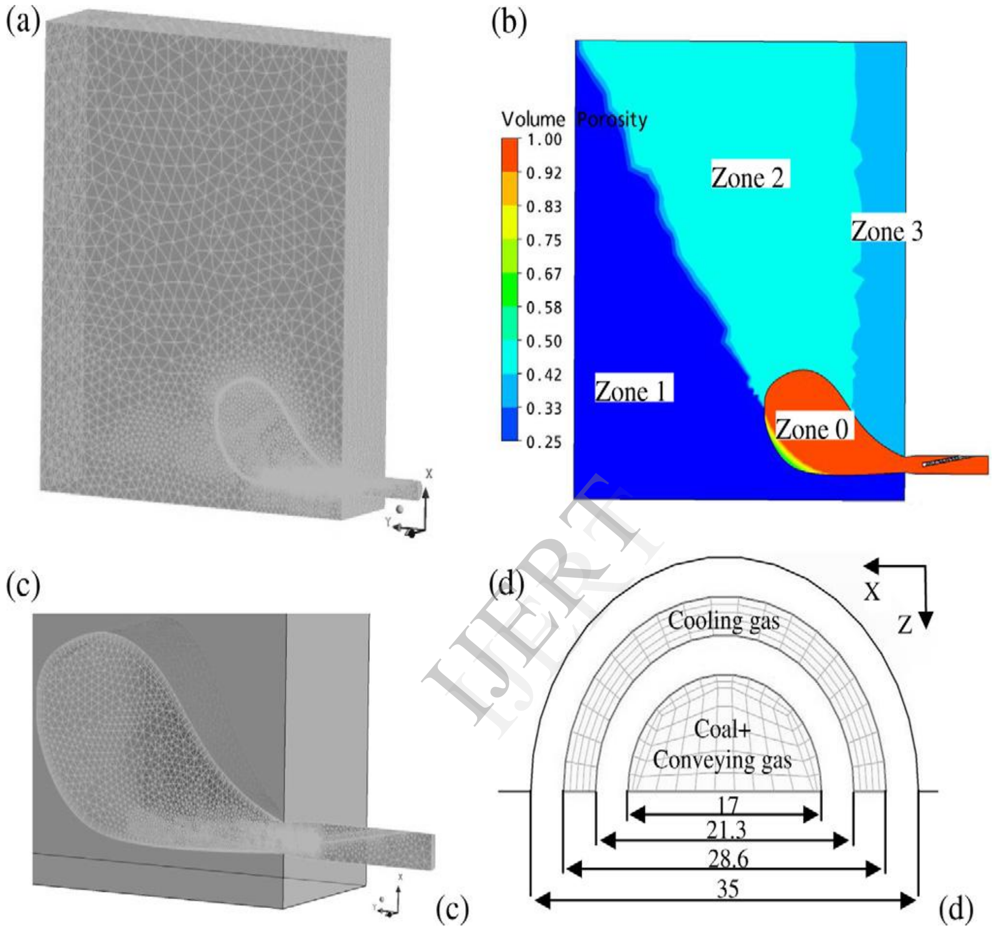

Fig. – 5 Geometry of the model: (a), the whole model; (b), porosity distribution; (c), blowpipe and raceway; and (d), lance tip. The detailed dimensions are [9].

The coke bed is treated as a porous media. The model includes the following physical and chemical processes [4]:

1. Turbulent gas-particle flow using k-epsilon model.
2. Coal combustion (devolatilization, volatile combustion, and char reactions).
3. Coke combustion and gasification.
4. Heat transfers in the considered gas-particle-coke bed. On the other hand.

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Raceway is defined as the boundary where the coke volume fraction is equal to the initial porosity near the tuyere. All the result should be simulate in raceway area and refine with number of iterations.

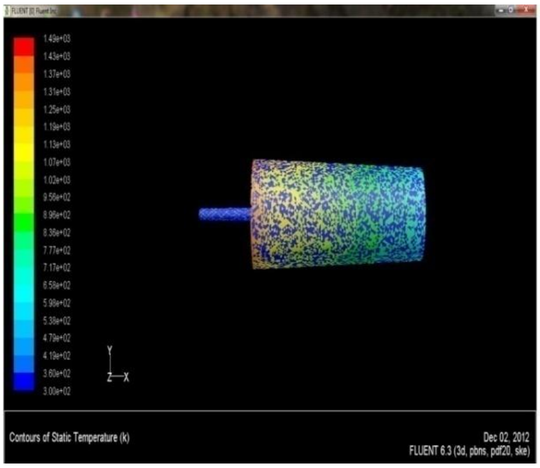

Fig. 6- Temperature profile in lance

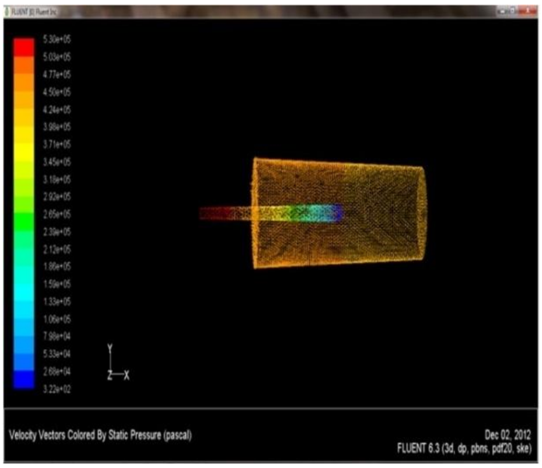

Fig. 7- velocity profile in lance

In this simulation process the specific algorithm solve the fluid and mass flow equations [11]. These screen shots show the result in profile form the different color shows the temperature and velocity profile compare with scale factor.

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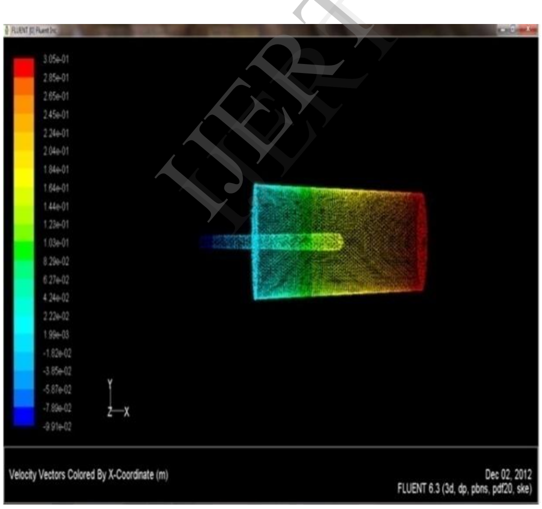

Fig. 8- Scale factor of velocity profile

***Results**:* The profiles which shown above describes the internal processes which are happened inside the tuyere in the one lance system having some inclination angle. In this, one assumption is taken. The assumption is that, the outlet of the blow pipe is the inlet of the tuyere part. So, what ever be the properties at the outlet of the blow pipe is using as the inlet of the tuyere part like temperature 1300k, velocity 107.8 m/sec, pressure etc.

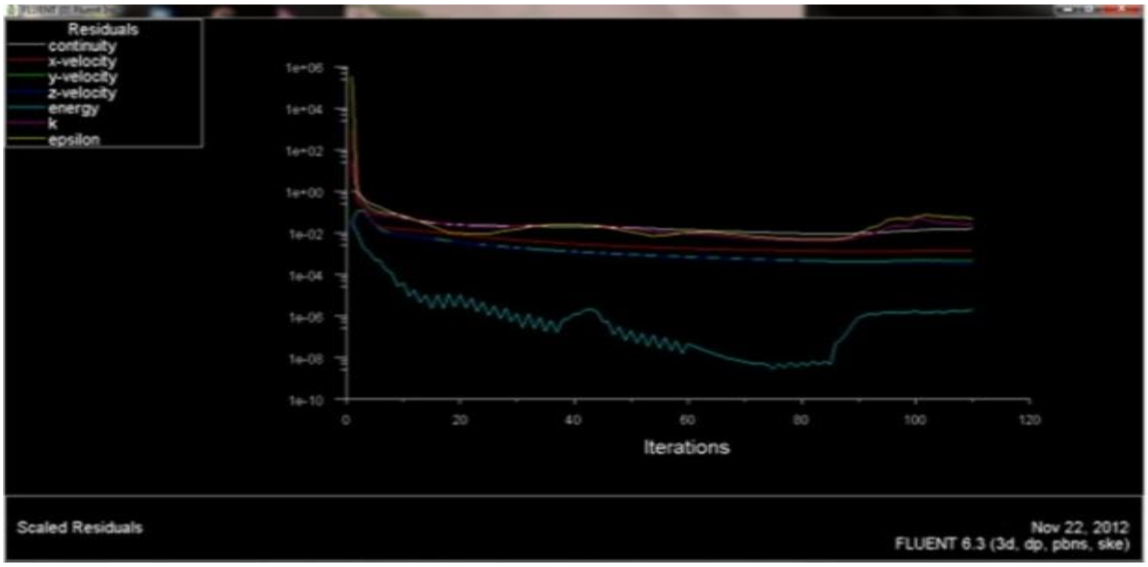

Fig. 9- result on the basis of 120 iterations

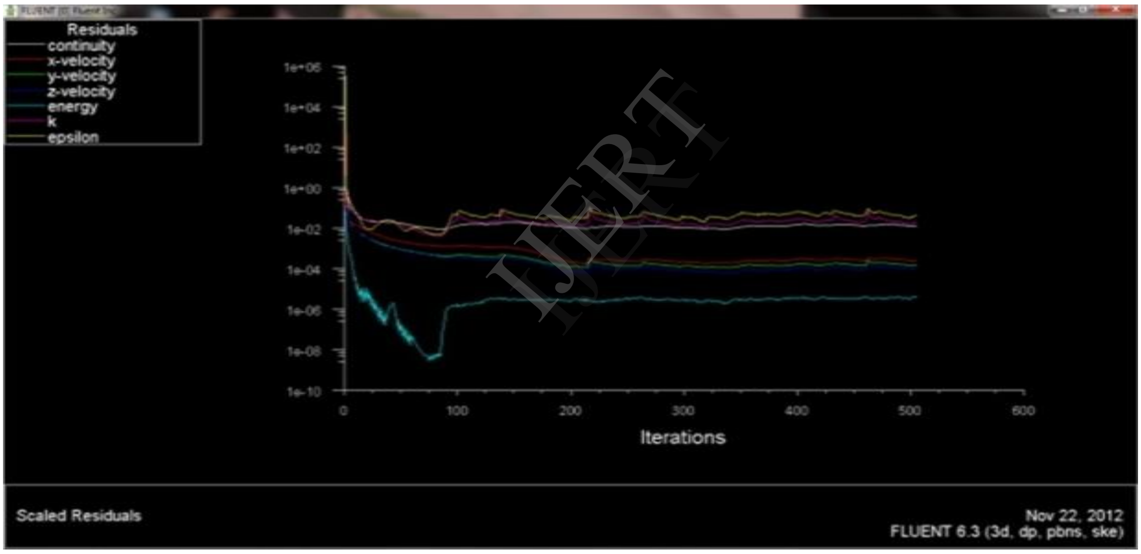

Fig. 10- refined result after 500 iterations

The first profile describes about the temperature i.e. the inlet temperature in the tuyere is t 1300k and in the lance system it is 299k in inlet because the pci is coming from there. So, the final temperature will coming as 1500k, near to the end of the tuyere. Similarly, 107.8 m/sec is inlet velocity of the air coming from the blowpipe and the result is coming as 484.64 m/sec. similarly, all the properties are changing from inlet to the outlet. The reason behind this is that because of higher temperature in the inlet of the tuyere, the convection and radiation is coming into the picture.

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