ISSN 2250-3153

Analysis of Fuel Injection System in Blast Furnace with the Help of CFD Software Approach

Gourav Kumar Thakur[*], Kawal Lal Kurrey[**], Abhishek Bhushan[***], Sandeep kashyap[****]

[*] M.tech scholar ccet, Bhilai
[**] Assistant professor ccet, Bhilai
[***] Indian institute of technology, Roorkee
[****] Global College of engineering & management

Abstract- This paper described the combustion characteristics of pulverized coal injection (PCI) in the blow pipe tuyere assembly using injection patterns are simulated, to improving the practical performance of the blast furnace. In these study a three dimensional mathematical models has been developed based on computational fluid dynamics software gambit & fluent. The model was capable of handling steady state, three dimensional multi phase flow of pulverized coal injection. The model was applied to simulate the flow pattern of the pulverized coal inside the tuyere. The information including mean temperature distribution and combustion characteristics has been obtained in details.

Index Terms- Pulverized Coal Injection (PCI), Tuyere, Gambit & Fluent, Lance.

I. Introduction

The blast furnace is fundamentally a vertical shaft varying in height from 24 to 33 meters with a diameter at the hearth of about 8.5 m[4]. It is the most widely used iron making process. The total volume is more than 1400 cubic meters. The blast furnace has charging arrangements at the top and a means of running off the pig iron and slag at the bottom. Air is blown in near the bottom of the furnace, and this increases the speed of combustion and maintains the necessary higher temperature. Pulverized coal injection has assisted the steel industry to lower operating costs, extended oven life and lower green house emissions. 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 [7]. This applies to any process where a blast is delivered under pressure to make a fire hotter.

Fig.1 pulverized coal injection system [5]

Shan-Wen Du[1] solved the Navier–Stokes equation, the thermal-energy-balance equation with conjugated heat transfer, and the mass transfer equation at steady state to predicts the decrease in temperature of the eroded hearth of the blast furnace **Chen ching –wen[2]** Modified single lance injection into double lance injection for pulverized coal injection (PCI) system they developed a three-dimensional mathematical model on computational fluid dynamics software PHOENICS to simulate the fluid flow phenomena inside blast furnace tuyere **D.Maldonad[3]** validated three-dimensional numerical model of the blowpipe/tuyere/raceway for various plant-specific investigations of blast parameters such as oxygen enrichment, blast temperature and atomic oxygen-to-carbon ratio. 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. The conclusion was made that many of the research is already done in hearth portion. From this, the conclusion is made to study some other part of the blast furnace except hearth, then after getting deep into the blast furnace, a point was made that only a few researchers did study in the tuyere portion.

ISSN 2250-3153

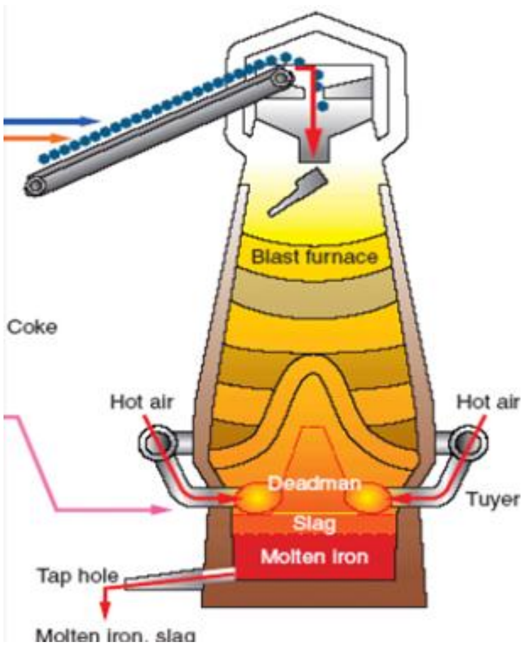

Fig. 2 schematic diagram of blast furnace [8]

II. SIMULATION PROCEDURE

The model geometry is based on a commercial blast furnace. The main dimensions of the model geometry are shown in Table (1). The lance, blowpipe and tuyere are in actual dimensions, the raceway is designed in the shape of a 'balloon', rather than a divergent 'tube', as used elsewhere[3]

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

Table 1 Design parameter

Boundary condition is taken for analysis of blast furnace Tuyere is shown in below [6]:

- Inlet velocity — lance inlet
- Pressure inlet --- tuyere inlet
- Mass flow rate --- tuyere
- Pressure outlet --- tuyere out

Using slandered IGES format to developed the model and analysis [4]:

- Grid check
- Choosing models :- k-epsilon model, steady flow, considering energy equation as well as radiation,
- Species selection: - transport and reaction: - By this proximate analysis is done in partial combustion species.

NOMENCLATURE [11]

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, $m^2\ s^{-2}$
$\dot{m}$	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 [11]

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

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

Turbulent dissipation Rate $$\nabla.\left(\rho U\varepsilon-\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\nabla\varepsilon\right)=\frac{\varepsilon}{K}(C_1P_k-C_2\sigma\varepsilon)$$

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 $$m_pC_p\frac{dt_p}{dt}=-q$$

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

Where
$\mu_t=C_\mu\sigma\frac{k^2}{\varepsilon}$; $P_K=(\mu+\mu_t)\nabla U.(\nabla U)^T)$; $C_D=\max\left(\frac{24\left(1+0.15Re^{0.687}\right)}{Re},\ 0.44\right)$; $i=O_2; CO_2; CO; VM, H_2, H_2O)$

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. The coke bed is treated as a porous media. The model includes the following physical and chemical processes: [15]

1. Turbulent gas-particle flow.
2. Coal combustion (devolatilization, volatile combustion, and char reactions).
3. Coke combustion and gasification.

Assumptions are made in this model for simplicity:

- coal and coke particles are spherical;
- there is no break-up or coalescence of particles;
- Liquid flow in the raceway-coke bed region is not considered.

CFD APPROACH TO SLOVE PROBLEM

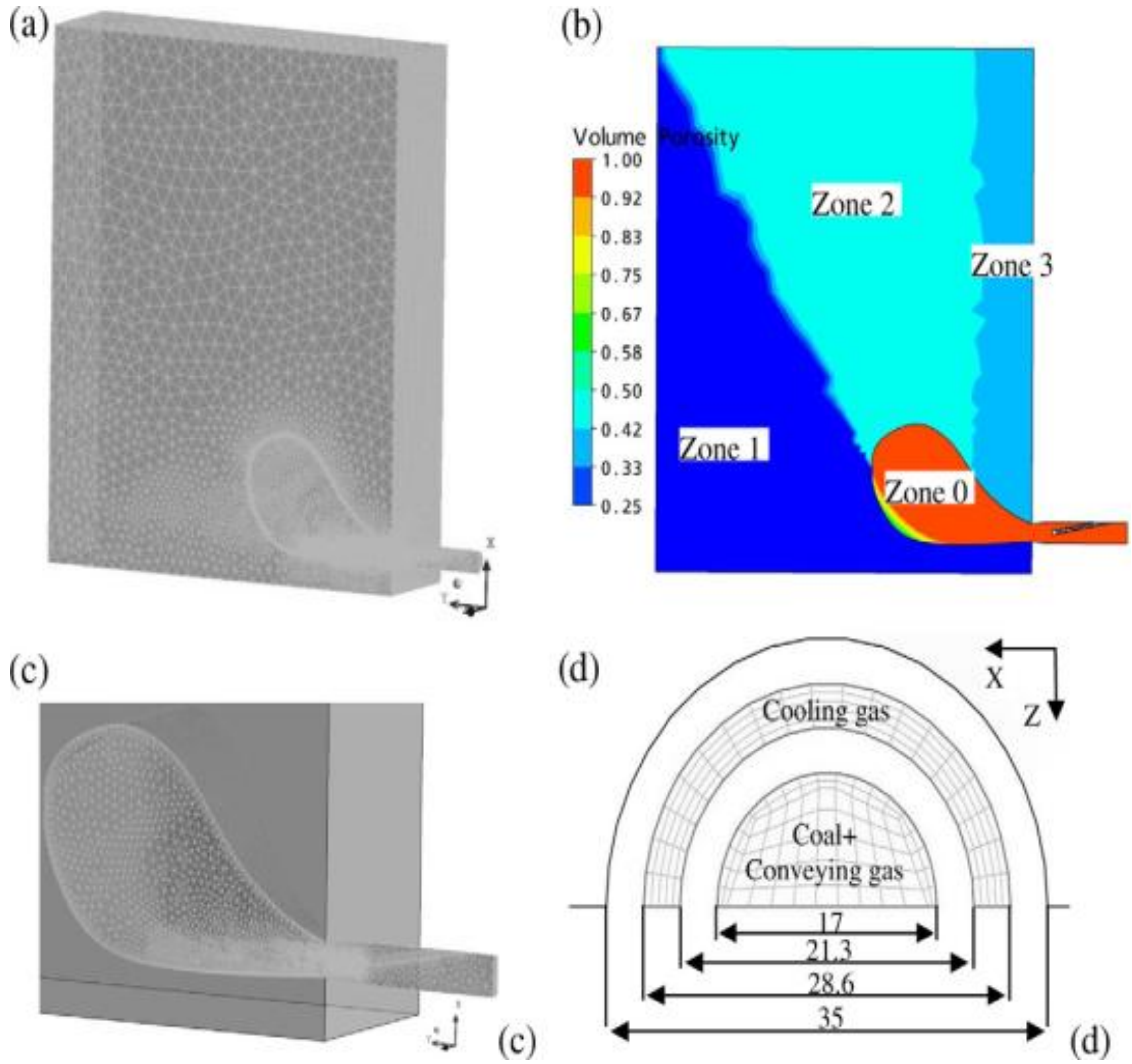

Fig. – 3 Geometry of the model: (a), the whole Model; (b), porosity distribution; (c), blowpipe and raceway; and (d), lance tip. The detailed dimensions are [11].

III. RESULT

After the simulation process some graphs show the results between temperature, velocity and mass friction 3d view of mean mass fraction and mean density

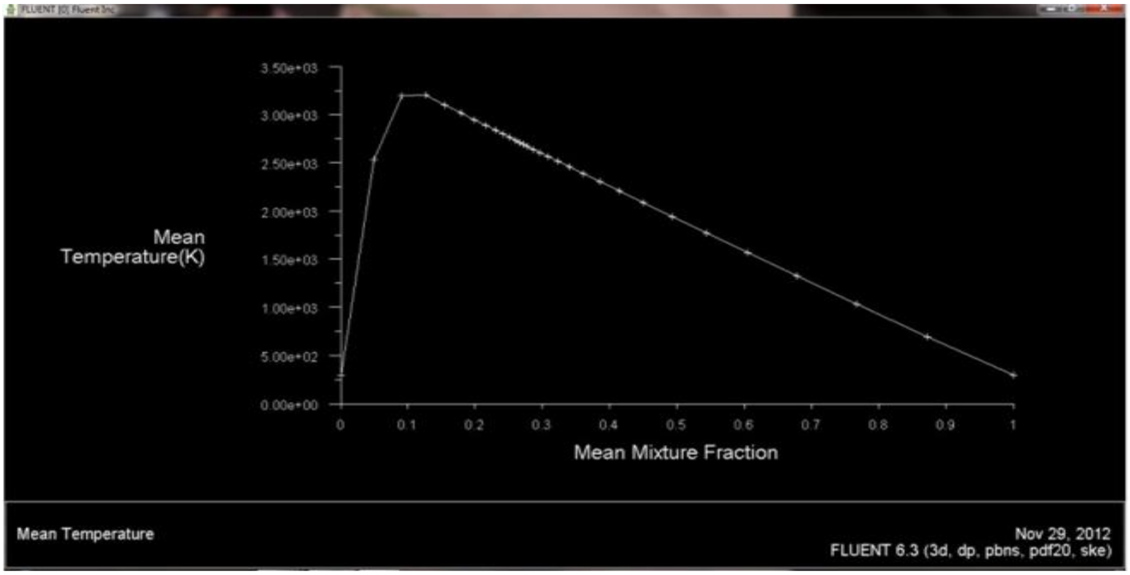

Fig.4 relation between Mean temperature and Mean Mixture Fraction

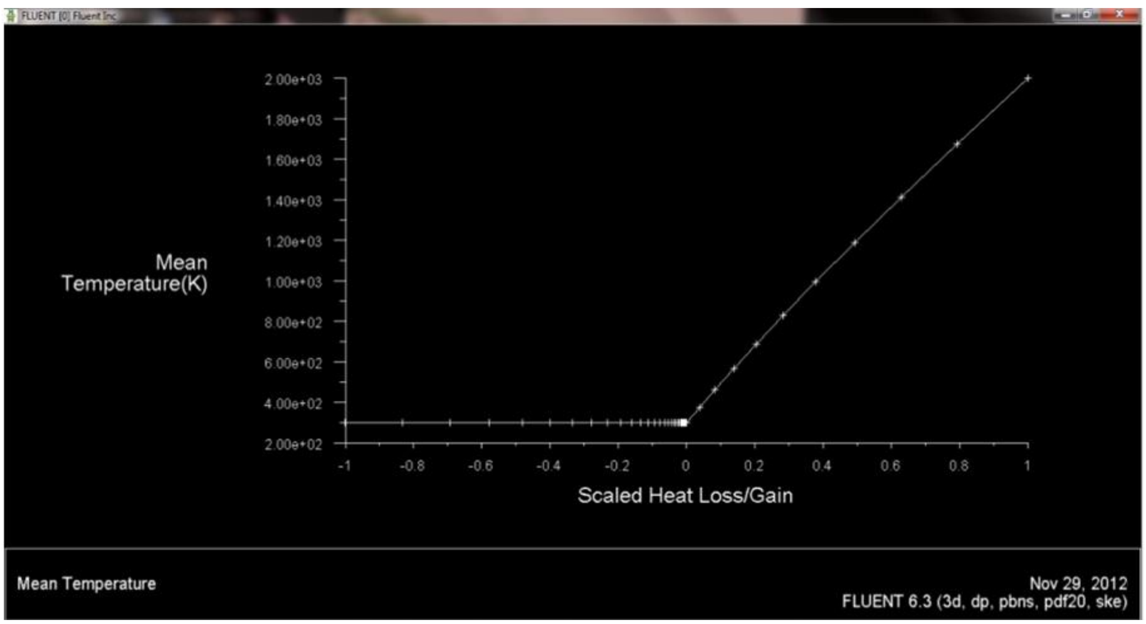

Fig. 5 relations between heat loss/gain and Mean Temperature

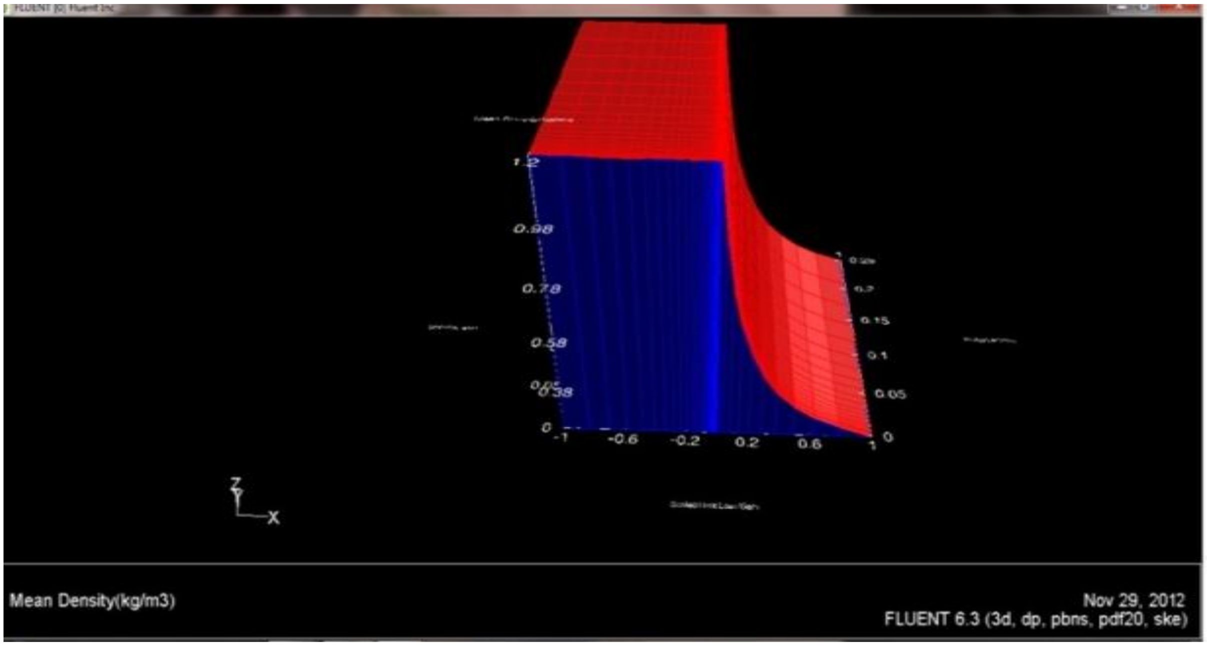

Fig. 6, 3D view of mean mass fraction and mean density

After the simulation the result are in graphical form which show the results in different are of furnace in different boundary conditions. The simulation procedure is based on algorithm which is predefined in this CFD software.

IV. CONCLUSION

Because the melting point of iron is 1539oc, for this we need higher temperature at the end. This is possible only when the higher temperature air blast is passed over the iron ore.

The pci is coming from the lance system and while it comes out of the lance a high temperature air blast is passed through it so, the pci coming from the lance gets combusted and generating a high temperature at the end of the tuyere. Here, a less angle of 7deg. is using because higher the angle, higher will be the erosion of the wall because if the length of the lance is more and more angle is there, so, a high velocity will injected on the wall. So, that the erosion of the wall takes place, that is the reason of short length and low angle of the lance.

A three dimensional integrated model of coal/coke combustion is developed and then applied to the lance-blowpipe-tuyere-raceway coke bed region in a BF. Compare with other result which is based on mathematics modeling these result are better is getting from software approach. The present model is thus useful in predicting the optimum particle size distribution and injection velocity for any given operating and physical conditions of the PCI.

REFERENCES

[1] Numerical prediction and practical improvement of pulverized coal combustion blast Furnace-Shan-Wen Du a, Wei-Hsin Chen, dec 2005

[2] Numerical analysis for the multi-phase flow of pulverized coal injection inside blast furnace tuyere- -Ching-Wen Chen, JAN 2005, vol. 29, no9, pp. 871-884

[3] Shen YS, Maldonado D, Guo BY, Yu AB, Austin P, Zulli P. Computational fluid dynamics Study of pulverized coal combustion in blast furnace raceway. Ind Eng Chem Res 2009; 48:10314–23.

[4] CFD Modeling for High Rate Pulverized Coal Injection (PCI) to Blast Furnaces- www. Steel.org.

[5] Details of manufacturing blast of blast furnace component- http://www.evotech.in.

[6] Mathematical modeling of combustion in blast furnace raceways, including injection of pulverized coal, Iron making Steelmaking -A.S. Jamaluddin, T.F. Wall, J.S. Truelove 13 (1986)

[7] O. Kerkkonen: "Tuyere Drilling Coke Sample Data from Rautaruukki's Blast Furnaces No. 1 and 2", AIS Tech 2004, VOl I, Nashville, Tennessee, USA, 469-482

[8] B.J. Monaghan, R. Nightingale, V. Daly and E. Fitzpatrick: "Determination of thermal Histories of coke in blast furnace through X-ray analysis", Iron making and Steelmaking, 35 (2008), 38-42

[9] S. Dong, N. Paterson, S.G. Kazarian, D.R. Dugwell and R. Kandiyoti: "Characterization Of Tuyere-Level Core-Drill Coke Samples from Blast Furnace Operation", Energy & Fuels, 21 (2007), 3446-3454

[10] S. Gornostayev and J. Härkki:"Spinal Crystals in Tuyere Coke", Metallurgical and Materials Transactions B, 36B (2005), 303-305

[11] GIBB, J., (1985), "Combustion of Residual Char Remaining after Devolatilization", Lecture, Mechanical Engineering Dept, Imperial College, London.

[12] Three-dimensional modeling of in-furnace coal/coke combustion in a blast furnace Y.S. Shen a, B.Y. Guo a, A.B. Yu, P.R. Austin b, P. Zulli b Elsevier Fuel 90 (2011) 728–738

[13] R. Codina and J. Blasco, "Stabilized finite element method for the transient Navier-Stokes equations based on a pressure gradient projection", Comp. Meth. Appl. Mech. Eng., 182, 277-300 (2000).

[14] F. Ilinca, D. Pelletier and F. Arnoux-Guisse, "An adaptive finite element scheme for turbulent free shear flows", Int. J. Compute. Fluid Dyn., 8, 171-188 (1997).

[15] H.-G. Nowak, "Zur kapazitiv-korrelativen Durchflussmessung pneumatisch geförderter Staubkohle," PhD master's thesis RWTH Aachen, 1997

AUTHORS

First Author – Gourav Kumar Thakur, M.tech scholar ccet Bhilai, Email id: gauravthakur7575@gmail.com
Second Author – Kawal lal Kurrey, Assistant professor ccet Bhilai
Third Author – Abhishek Bhushan, Indian institute of technology roorkee
Fourth Author – Sandeep Kashyap, Global College of engineering & management