CFD Analysis of 500 MWe Tangentially Fired Boiler Furnace

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ABSTRACT

The performance of coal fired boiler furnace are depends on the complete combustion of the coal and the minimal release of environmental pollutants. The techniques for analyzing air flow rate based on coal input, combustion, heat and mass transfer rate inside the furnace are required to optimize the coal fired furnace for different loading conditions. In this paper Computational fluid dynamics (CFD) simulation model was developed using FLUENT 6 to characterize the combustion performance of a typical boiler furnace. A PDF (Probability Density Function) table was constructed for the calculation of temperature, density and percentage of composition of different species using single mixture fraction approach. To simulate the combustion behavior a Lagrarangian based Discrete Phase model, Single step de volatilization model was used. The radiation heat transfer between coals and the fluid continuum and between the water wall and the continuum is accounted in the simulation model.

KEY WORDS: Coal, Combustion, CFD.

I. INTRODUCTION

The boiler furnaces are used to convert energy from chemical to thermal through combustion route and these energy are utilized into various form of thermal equipment like steam turbine. To achieve this objective, two fundamental processes are necessary: combustion of the fuel by mixing with oxygen and the transfer of the thermal energy from the resulting combustion gases to working fluids such as hot water and steam. A utility boiler and its accessories are briefly explained in Figure.1.

Generally the steam is generated from the boiler continuously by feeding water by consuming the heat the coal which is fed into the boiler furnace. As fuel is burned, it forms combustion products which serve as a heat transfer agent in the heating surfaces where it gives up its heat to the water and steam which are called working fluid. On passing the heating surfaces, the combustion products temperature reduced up to the atmospheric temperature and ejected from the boiler through a stack into the atmosphere. The superheated steam generated in a boiler is admitted into a steam turbine where its thermal energy is changed into mechanical work on turbine shaft. The turbine shaft is coupled to an electric generator in which the mechanical energy is transformed into electricity. The waste or dump steam is supplied from the turbine into a condenser, an apparatus in which the steam is cooled and condensed by means of cold water supplied from a natural(river, sea, pond) or artificial(cooling tower) source

Tangential Firing configuration: Furnaces in which fuel is fed into the furnace from the corners to make a fireball are termed tangential fired furnace. A simplified schematic detailed diagram is presented in Fig.2. In these furnace, the burners are fixed in the corners of the boiler furnace and air and coal injected tangentially with respect to the center of the furnace .At this point, the flames generated into a rotating "fireball" due to high turbulence and mixing. Four air zones are handled by the wind box: primary, fuel, over fire, and auxiliary. Primary air and coal are injected through nozzle and secondary air respectively (Chen Donglina, 2003). The over fire air portion is injected via ports either on top of the wind box or separate from the wind box. The auxiliary air is the primary source for complete combustion in addition to the other source. The air and fuel nozzles are assembled with in the wind box and its tilts uniformly during the combustion process. The tilting mechanism decide the location of position of fireball furnace based on different loading condition.by the accumulation of ash on the furnace walls is depends on the fireball locations only (Chungen Yin, 2003). It begins at the lower position of the furnace and travels upward. Low ash and heat is available in the furnace gases and less is transferred at the convective pass of the boiler. Due to this, the fireball is moved upward by manually tilting the burner assembly to compensate the heat loss. The fireball cycle return to original position once the ash deposits are removed, for example, after soot blowing incidents.

2. METHODS AND MATERIALS

Model and mesh generation: The model includes provisions for ten combustion elevations with alternately located fuel and air nozzles of different four corners. A pair of integrated over-fire air nozzles is also provided at all four corners. Geometrical details to represent the annular airflow around coal nozzles, variable tilt (in the vertical plane) and yaw (in the horizontal plane) for the fuel and air nozzles are all provided in the computational model. A model was built in GAMBIT and meshed with hexahedral elements as presented in Fig.3 to 4. Total number of nodes is around 1, 50,000 and the number of cells is also around 1, 50,000. Top view of fuel and air injection direction is presented in Fig.5. Coal and air nozzles along a corner are presented in Fig.6.

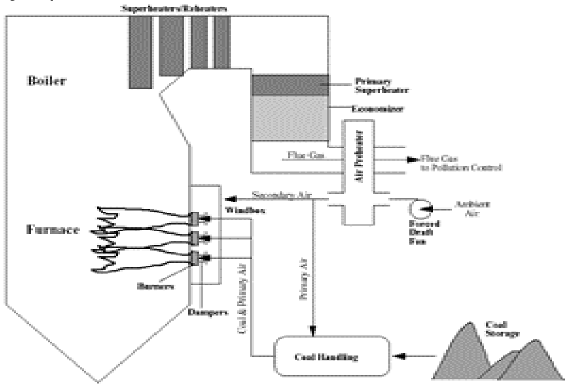

Figure.1. General Schematic of a Boiler

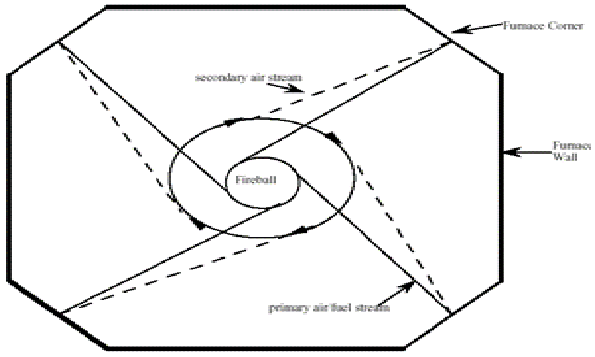

Figure.2. Tangentially Firing Configuration

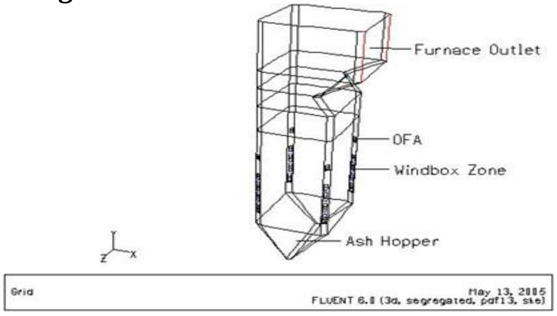

Figure.3. Model of Furnace

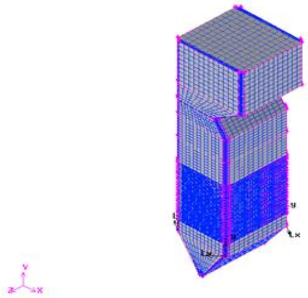

Figure.4. Isometric view of the computational Domain

Fluid properties and boundary conditions: To model the presence of coal in the continuous flow domain, either Eulerian-Eulerian based multiphase model or Lagrangian-Eularian based DPM model can be chosen (Hao Liu, 2005).

The computational domain is assumed to be compressible multiphase fluid with varying physical properties. In species transport for individual species are solved and are based on finite reaction rate formulation. For coal combustion which is usually turbulent and the chemistry is usually infinite fast. Under this valid assumption, non-premixed combustion option can be chosen (Hao, 2004; Jianren Fan, 2000). In non-premixed combustion, fuel and oxidizer enter the reaction zone in different streams Species reactions are derived from the pre PDF and tabulated for look-up in FLUENT. Interaction of turbulence and chemistry is accounted for with a probability density function (PDF) (Marc Cremer, 2002). To account for radiation heat transfer from combusting particles to the fluid continuum P1 radiation model was chosen (Zhou, 2002).

The inflow, Coal mass flow rate and outflow conditions are applied in the furnace model as given in Table.1.

Table.1. Coal Properties and Boundary Conditions

Inflow Boundary conditions for furnace				
Location of Coal Particles	X-Velocity (m/s)	Z-Velocity (m/s)	Note: As no tilt is provided Y Direction Velocity is considered as zero velocity	
corner1	18.73	20.8		
corner2	15.65	-23.21		
corner3	-15.65	23.21		
corner4	-18.73	-20.8		
Mass flow rate of coal injected from one nozzle				
Details			Value	Unit
Total coal flow rate			373	T/h
Mass flow rate from each coal nozzle			373/7= 3.7	kg/s
Outflow Boundary conditions for furnace				
Pressure		- 10 mm of water column		[9,10]
Coal properties				
Proximate Analysis		**Ultimate Analysis**		
Moisture	20.50%		Carbon	39.35%
Volatile Matter	23%		Hydrogen	2.33%
Fixed Carbon	26.50%		Sulphur	0.30%
Ash	30%		Nitrogen	0.79%
			oxygen	6.735

3. RESULTS AND DISCUSSION

The temperature contours, velocity contours, were studied. The temperature at furnace outlet usually will be of the range between 1373 K to 1473 K. Since a high temperature at furnace outlet will affect the downstream metallic components. The temperature at furnace outlet was found to be 1358 K. The peak temperature is found to be 1728 K.

At the middle a very high temperature is observed and at the near wall region the temperature seems to be of lesser magnitude. Temperatures at the mid plane and furnace outlet are shown in Fig.5, Fig.6, and Fig.7. Fire ball formation is also observed from Fig.8. In Fig.7, even though the temperature scale showing higher value 1666 K, those planes correspond to relatively low temperature because char burnout will takes place there which provides high temperature in a narrow region. Fire ball formation is also observed from Fig.8.

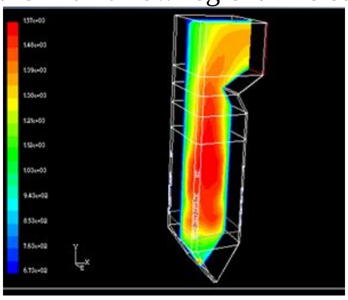

Figure.5. Temperature contour at mid plane

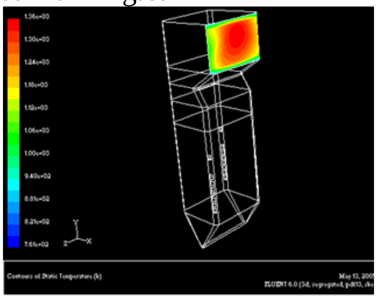

Figure.6. Temperature contour at Furnace outlet

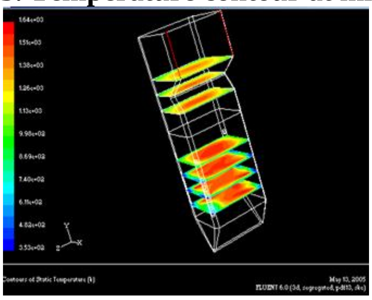

Figure.7. Temperature contour at various cross sections

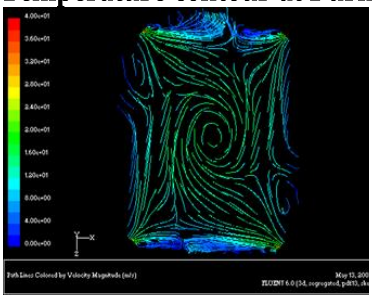

Figure.8. Path lines showing Fireball formation

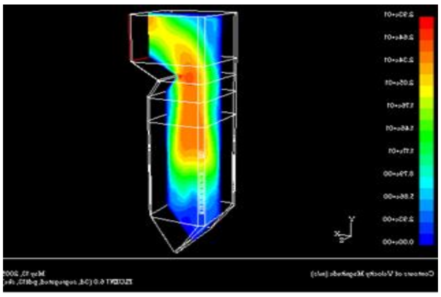

Figure.9. Velocity contour at middle plane

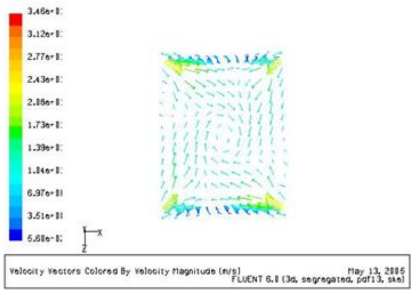

Figure.10. Velocity vector plot of Coal 'D' elevation

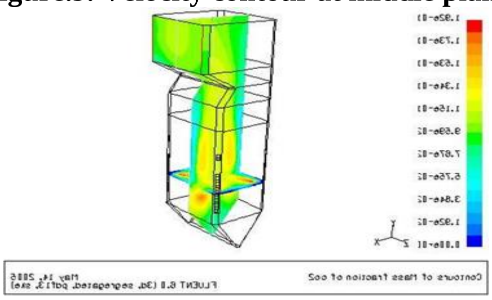

Figure.11. Contour plot of CO_2

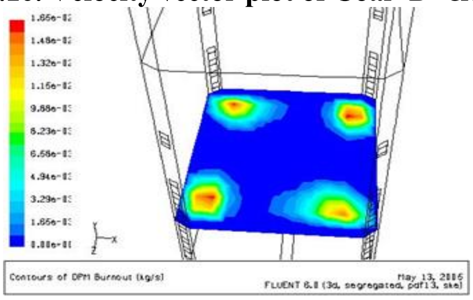

Figure.12. Contour plot of char burnout

The velocity contour presented in Fig.9, the flue gas velocity was higher in nose and arch portion of the furnace and at the center reasonably higher value is observed. Fig.10, represents a velocity at a plane correspond to burner elevation. In Fig.11 and Fig.12, CO_2 mass fraction contour and char burnout characteristics.

4. CONCLUSION

A CFD model was developed using FLUENT for the prediction of combustion behavior of a 500 MW_e tangentially fired furnace. The temperature and velocity profiles were studied. Temperature at furnace outlet is in close agreement with design value. The model analyses the data obtained from plant under the partial load operation and the procedure of analysis is similar for full load operation except that a few additional nozzles come into play.

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