

Simulation and Experimental Analysis of Tangential Over Fire Air System of an Industrial Boiler

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ABSTRACT

The tangential over fire air system is a unique firing technique used in modern boilers. The combustion technique has been successfully used for bagasse combustion in cogeneration plants. In these boilers the fuel particles are accelerated by the distributor air jets to enter the furnace chamber. As the particles enter the combustion chamber, they are further subjected to under grate air and tangential over fire air, which helps in rapid mixing of the fuel with air. The present study provides numerical and experimental investigations made on an industrial biomass fired furnace with tangential firing system. The effect of tangential over fire air system on combustion of bagasse across the tangential plane is well predicted and compared with good agreement with the measurements made at tangential plane.

Keywords: *Bagasse, Combustion, Tangential plane, Over fire.*

1. INTRODUCTION

Modern boilers with tangentially fired furnaces have fuel spreaders and air supply system tangentially from the furnace corners or near the corners [1]. The combustion of fuel inside the furnace depends on many parameters such as air flow rate, fuel and the inclination of the tangential air ducts. In these furnaces, jets of air coming from the ducts are directed tangentially to an imaginary circle at the centre of the furnace. Experimental measurements were used for validation. High temperature was observed near the furnace walls due to the effect of tangential over fire air system. Temperature measurements were made at tangential plane level. The furnace was modeled by using three dimensional computational fluid dynamics package FLUENT.

Computational Fluid Dynamics modelling has become a routine design tool to investigate the wide variety of flow and combustion related areas [2]. Certain investigations on bagasse-fired furnaces have been focused on the effect of overfire air system on boiler design [2]. Flue gas composition and flame intensities on two different suspension-fired bagasse boilers have been investigated at various operating conditions [3]. A major work in the field of computational modelling of bagasse-fired furnaces has been carried out and reported a good agreement between steady-state calculations and experiments on temperature and concentration of oxygen [4]. Several numerical studies and field tests that applied to the tangentially-fired boiler have been carried out. Flow pattern, mixing, temperature distribution are the main targets in their studies [5, 6]. A numerical investigation on the performance of a large-scale tangentially-fired boiler using pulverised-coal has been performed with respect to flow field and heat transfer [7].

A CFD model of a 375 MW tangentially-fired furnace has been developed and fuel feed rates, air flow rates, coal particle size distribution have been studied. Performance of two turbulence models, standard k- ϵ model and SST model, are compared. The effect of particle dispersion on predicted results is found to be insignificant [8].

Experimental investigations of a 250 MW coal based thermal power plant to predict the performance of tangential fired boiler has been carried out. The flow patterns of the fuel particles and gas has been studied, with an emphasis on increasing the flame stability in combustion zone at low load conditions [9].

Experimental and CFD simulation has been carried out to compare the flame shape to the actual flame in the boiler and showed a good agreement. The flow field and temperature distribution inside the tangentially fired boiler were analyzed under the operation conditions [10]. A computational fluid dynamics (CFD) modeling study was performed for the combustion of the brown coal in a large-scale tangentially-fired furnace (550 MW) under different operating conditions and performance has been studied [11].

In the present work, the furnace has tangential over fire air system. Only air enters from the tangential ducts. Bagasse is the fuel enters the furnace separately from the bagasse spreaders on the front wall. The flow of bagasse into the combustion chamber is aided by the jets of distributor air situated at the bottom of the bagasse spreader. The main source of air for combustion is the undergrate air coming from the bottom through the grate.

2. COMPUTATIONAL MODELING

The temperature distribution across the tangential pane of the furnace was measured by a k-type chromel-alumel thermocouple. Temperatures were recorded by a digital indicator. At a height of about four meters above the grate. Also temperatures are recorded at various points on the furnace. The depth of the furnace was 6985 mm and width 7595 mm. The measurements were made several times and the average values are recorded.

The furnace was modeled by three dimensional FLUENT package. The segregated implicit solver was used for solving the transport equations. The turbulence was modeled by standard $k - \epsilon$ model. Radiation is modeled by using P1 model. Single-mixture fraction approach was used for combustion and combustible particles were assumed for bagasse particles. The turbulence kinetic energy k and its rate of dissipation ϵ are obtained from the following transport equations.

$$\rho \frac{Dk}{Dt} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\mu_k} \right) \frac{\partial k}{\partial x_i} \right] + G_k + G_b - \rho \epsilon - Y_M \quad (1)$$

and

$$\rho \frac{D\epsilon}{Dt} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\mu_\epsilon} \right) \frac{\partial \epsilon}{\partial x_i} \right] + C_{1\epsilon} \frac{\epsilon}{k} (G_k + C_{3\epsilon} G_b) - C_{2\epsilon} \rho \frac{\epsilon^2}{k} \quad (2)$$

Where G_k is the generation of turbulent kinetic energy due to the mean velocity gradients. G_b is the generation of turbulent kinetic energy due to buoyancy, Y_M represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate. $C_{1\epsilon}$, $C_{2\epsilon}$, and $C_{3\epsilon}$ are constants. σ_k and σ_ϵ are the turbulent Prandtl numbers for k and ϵ , respectively.

2.1 Flow model

The particle phase is modeled using Lagrangean method to include the effect of mass, momentum and energy that characterize the change in particle properties along particle trajectory as it moves through the gas continuum.

$$\frac{dm_p}{dt} = -R_p \quad (3)$$

The variable m_p is the mass of the particle and R_p is rate of change of mass due to phenomena such as droplet vaporization, particle devolatilization.

P-1 is chosen for radiation model. The radiation flux q_r was obtained by

$$q_r = - \frac{1}{3(\alpha + \sigma_s) - C\sigma_s} \nabla G \quad (4)$$

Where α is the absorption coefficient, σ_s is the scattering coefficient, C is the linear anisotropic phase coefficient, and G is the incident radiation.

The rate of devolatilization of the particle may be represented approximately as a first order reaction with an Arrhenius rate constant.

$$\frac{dm_v}{dt} = -m_v k_{pyr} \tag{5}$$

Where m_v is the mass of the volatile, K_{pyr} is the rate constant.

The char burning rate is given by

$$\frac{dm_c}{dt} = -i \left(\frac{M_c}{M_{O_2}} \right) A_p k_c (\rho_{O_2}(s))^n \tag{6}$$

Where i is the stoichiometric ratio of moles of carbon per mole of oxygen, A_p is the external particle surface area, k_c is the kinetic rate constant, $\rho_{O_2}(s)$ is the oxygen partial density at the surface of the particle, and n is the order of the reaction.

The grate was modeled as a packed bed using porous zone and the SIMPLE algorithm is used to solve the equations.

The parameters used for the measurement are Velocity, temperature, moisture. Under grate air velocity, distributor air velocity, Tangential over fire air velocity, bagasse input, temperature of the wall (340° C) were considered as input boundary conditions for the model.

3. RESULTS & DISCUSSION

Distribution of temperature at tangential plane is shown in Figure 1. The temperature is on higher side near the walls. Temperatures measured at various points at the tangential plane. Maximum temperature of about 1050°C was measured at the rear end of the furnace. The measurements made at side walls had approximately 1000°C. The effect of tangential firing will be carried up to the neck of the furnace where the temperature reaches the maximum value. The simulation prediction of carbon dioxide at the tangential plane is as shown in Figure 2. The middle region in both the Figure 1 and 2 shows lesser temperature and carbon dioxide is due to piling of bagasse at the centre of the furnace. Since fuel is fed continuously from the spreaders, piling will occur at the centre.

The temperature near all the water walls were on higher side. This is due to the effect of tangential over fire air systems. Smaller particles of the fuel will burn in suspension in the vortex formed by tangential firing system.

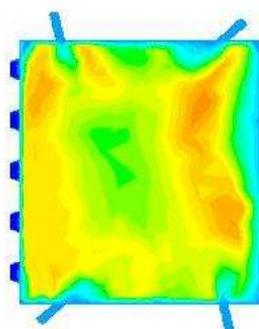
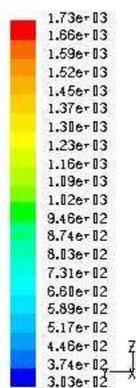


Fig.1 Temperatures at tangential plane

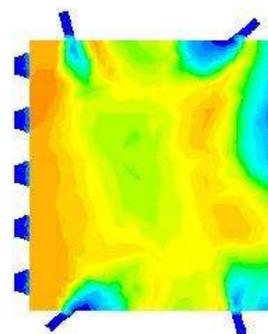
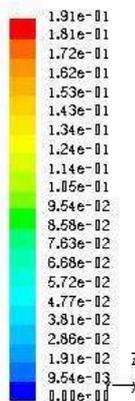


Fig. 2 Distribution of carbon dioxide at tangential plane

The prediction of the mass fraction of H₂O at the tangential plane is shown in Figure 3. Since the moisture level of bagasse is high as nearly 50%, at the entry, demosturisation of fuel particles starts immediately from the spreaders. The mass fraction has been reduced from 4.66X10⁻¹ at the entry to around 2.94X10⁻¹ at the centre of the furnace. At the rear end of the furnace the mass fraction reduces to 1.72X10⁻¹. This is due to the combustion of the fuel particles at the rear end of the furnace. Also the mass fraction of H₂O reduces at the water walls.

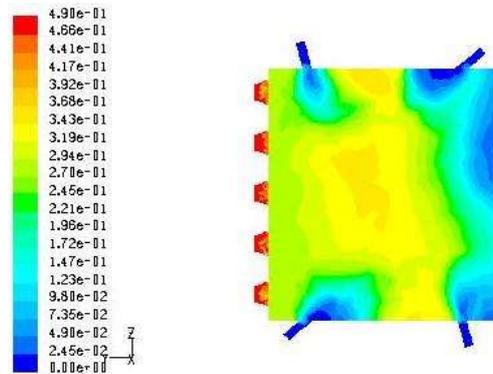


Fig.3 Mass fraction of H₂O at tangential plane

The advantage of the tangential over fire air system in reducing the nitric oxide concentration is shown in Figure 4. The mass fraction of N₂ has been reduced from 7.51×10^{-1} at the entry to 1.58×10^{-1} . This flow will be extended up to the neck of the furnace where it reaches the maximum temperature. The higher temperature is due to the intense imaginary vortex and results in complete combustion of the particles. The concentration of N₂ is high at the entry of the tangential ports and at the rear side of the furnace, where the influence of the tangential air system is not much. This zone at the rear end of the furnace is predicted with higher N₂ concentration.

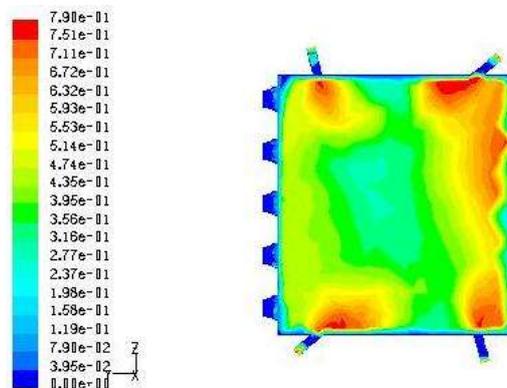


Fig. 4 Mass fraction of N₂ at tangential plane

5. CONCLUSION

The results of the present works indicate that much of the combustion activity occurs over the rear half of the test furnace. Combustion of bagasse will be delayed due to its high moisture level. Tangential over fire air system results in rapid mixing of fuel and combustion air at tangential plane. Tangential air flow results in recirculation zone by forming an imaginary circle of flame inside the furnace to increase more heat transfer to the furnace walls.

The inclination of the front two ducts results in lesser temperature near the front wall and also significant influences on the flow path of the fuel particles. Also the bagasse and air flow rates through spreaders are found to have some influence on the ignition delay and the location on the furnace grate where the large particles come to rest. The tangential over-fire air system provides cooling for the furnace walls and aid in combustion. It provides turbulence which thoroughly mixes volatile gases thus assuring complete combustion.

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