Experimental Investigation to Improve Flame Intensity in 250MW Tangentially Firing Furnace

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Abstract—: The objective of this study is experimental investigation of 250 MW coal based thermal power plant to predict the performance of tangential fired (TF) boiler and to determine the flow patterns of the gas and coal particles, with an emphasis on increasing the flame stability in combustion zone at low load conditions at which thermal plants are forced to operates owing to number of practical limitations in this region. The effects of four parameters that are experimentally investigated are Coal air velocity through burner, Burner outlet temperature, Burner tilt & Furnace draft. The experimental results show considerable increase in flame stability at low load conditions while operating at Coal air velocity of 19.19 m/sec, Burner outlet temperature of 70°C, furnace draft of -10mmwc and burner tilt of +20°. The work has been validated with the help of CFD code Fluent. The results obtained from the present work are directly relevant to coal-fired Utilities for not only demonstrating the effectiveness of computational fluid dynamics (CFD) based tools in combating operational issues but also provides an alternative to conventional remediation strategies.

Keywords— Tangential firing furnace, CFD Fluent, Coal fire power plant, Coal combustion, Flame intensity

1.Introduction:

Efficient use of pulverised coal in boilers with tangential firing system is crucial to the power generation in most countries, which was the main motivation for undertaking this research. Due to number of practical limitations most of the coal based power plant in the region runs on part load conditions, which ultimately puts them in danger of tripping due to low flame intensity due to decreased rate of coal flow. Increasing flame stability at low load conditions is the prime objective of this research.

Tangentially fired boiler is the most commonly used industrial coal combustion system and thus gains much attention. With the development of comprehensive combustion models and their successful applications in industrial coal-fired boilers, as surveyed in the literature the complex phenomena in tangentially fired boilers, including gas–solid flow, combustion, heat transfer and NOx reduction, are widely studied using simulations. The gas temperature deviation is commonly considered to result from the after swirl in furnace exit. However, this aspect has not been well demonstrated because it is difficult to study the gas temperature deviation by experiments and theoretical ways. Along with the development of numerical techniques and their applications in coal combustion, it has become possible to investigate the gas temperature in a tangential coal-fired boiler. In some cases it replaces physical experiments with equivalent 'numerical' experiments.

The paper presents the experimental results of the Parli power station boiler equipped with tangential firing of the burners. The Computational Fluid Dynamics (CFD) approach is utilized for the creation of a three-dimensional model of the boiler furnace, including platen super-heater sections in the upper part of the furnace. Standard k–e model is employed for the description of turbulent flow. Coal combustion is modeled by the mixture fraction/probability density function approach for the reaction chemistry, with equilibrium assumption applied for description of the system chemistry. Radiative heat transfer is computed using P1 radiation model. The described case and other experiences with CFD prescribe the advantages Of combining numerical modelling and simulation over purely field data study, such as the ability to quickly analyse a variety of design options without modifying the object and the availability of significantly more data to interpret the results.

In the present study, parameters which were investigated include Coal air velocity through burner, Burner outlet temperature, Burner tilt & Furnace draft. The boiler geometry and operating conditions are described in the next section. This is followed by the description of the mathematical model. Then the results are presented and discussed following the validation of model with plant trials. Finally, the paper ends with a summary of the main conclusions and recommendations for future work and acknowledgment.

2. Literature review:

Ahmed F Ghoniem et al 2011 found that When operating under elevated pressure, the gas phase flow field and coal particle residence time may change significantly. The effect of pressure on the characteristics of mass and heat transfer, char and gas phase combustion kinetics and dynamics, etc, are also still relatively unknown. Research on the characteristics of oxy-combustion at elevated pressures is needed. S Belosevic et al 2006 presented selected results of numerical simulations of processes in utility boiler pulverized coal tangentially fired dry-bottom furnace. The simulations of the processes are based on a comprehensive 3D differential mathematical model, specially developed for the purpose. The model offers such a composition of sub models and modelling approaches so as to balance sub model sophistication with computational practicality. A 3D geometry, Eulerian– Lagrangian approach, k–e gas turbulence model, particles-to-turbulence interaction, diffusion model of particle dispersion, six-flux method for radiation modelling and pulverized coal particle combustion model based on the global particle kinetics and experimentally obtained coal kinetic parameters are the main features of the model. Zadiraka et al (1996) proposed a method to control the emissions of SOx and NOx content in the flue gases. If coal was to be used as the fuel, the new power plants need to be very clean, with higher efficiency and economical. Sensors and control techniques are being developed to permit the accurate measurement and control of the individual burner air and fuel flows as they are introduced to the time-temperature-turbulence combustion processing the furnace.

M Habermehi et al 2012 investigated the effect of burner on flame stabilization. Starting from an existing burner design for a bench scale burner, a new burner concept based on aerodynamic stabilization of an oxy-fuel swirl flame was developed. For this development process, CFD was intensively used as a design tool. Adapted models for homogeneous and heterogeneous reactions were integrated into the CFD code to take the different conditions for oxy-fuel combustion into account. As a result a burner able to operate in air and oxy-fuel conditions was developed and its functionality was demonstrated in experiments. By these experiments, it was proven that applying the measures for oxy-coal swirl flame stabilization an oxy-coal flame can be stabilized aero-dynamically at an oxygen concentration down to 18 vol.-% for wet and dry recirculation. In UK boilers the video camera probes are mounted on the rear wall to observe the oil gun flames during the start up for safety purpose. When the boiler is on load the large flames are close to the rear wall and there will be dust and ash deposits near the rear wall. This causes variation in the colour of the fire ball which is utilised to observe the combustion conditions. A video monitoring system was developed to monitor the combustion activities. A Euclidean distance classifier was used for identifying the combustion conditions along with the CO emissions. Principal Value Decomposition (PVD) and Euclidean classifier were used for classification of flame images based on their combustion status by Abdul Rahman et al (2006).

Donglin Chen et al concluded that the deflected angle of a torsion-spring incorporated damper and the air-jet at BWD exit is approximately a linear function of air velocity inside burner nozzle and simultaneously affected by the damper's length, installation distance and the spring's mechanical constant. With a proper combination of the spring's mechanical constant k, the damper's length l and installation distances, satisfied deflecting characteristics for the jet of BWD can be obtained. Flame Doctor, a burner flame monitoring system was developed by Timothy et al (2004) to reduce NOx emissions and to improve the overall performance. The signals from an optical flame scanner diagnose the operation of the burners. Continuous monitoring by flame doctor makes it possible to analyze the flame colour thereby optimizing the overall performance of the furnace load changes, fuel quality variations, and equipment modifications. This article describes the status of an ongoing EPRI Beta Test Program and the results from combustion tuning service work which offers specific challenges encountered during Flame Doctor Installation and start up. Demonstrated performance improvements include reductions of 20% in NOx, 70% in CO, and 70% in LOI. These improvements are sustainable and translate directly into significant cost savings in the expenditure of the power plants.

The thermal characteristics of propane air diffusion flames using high temperature combustion air are presented in this work by Ashwani Gupta et al (2000). Global flame characteristics are presented using several different gaseous fuels. A specially designed regenerative combustion test furnace facility, built by Nippon Furnace Kogyo, Japan, has been used to preheat the combustion air to elevated temperatures. Stable flames were obtained at remarkably low equivalence ratios, which would not be possible with normal temperature air. The global flame features showed flame color to change from yellow to blue, bluish-green and green over the range of conditions examined using propane as the fuel. In some cases hybrid color flame was also observed. Under certain conditions flameless or colourless oxidation of the fuel has also been observed for some fuels. Some fuels provide purple colour flame under similar operational conditions. Information on the flame spectral emission characteristics, spatial distribution of OH, CH and C2 species and emission of pollutants has been obtained. Low levels of NOx along with negligible amounts of CO and HC were obtained with high temperature combustion air. Experimental results have been complemented with numerical simulations. The thermal and chemical behavior of high temperature combustion flames depends on the fuel property, preheat temperature and oxygen. The challenges and opportunities with high temperature-air combustion technology are also described.

3. Experimental setup:

The furnace geometry of the simulated boiler can be seen in Fig. 1 for which the dimensions are given in Table 1. As evident from Table 1, the tangentially fired furnace is 52 m high,15.240 m wide and 11.506 m deep and with an installed capacity of 250 MW. The boiler considered for the modeling studies is a subcritical one comprising of concentric firing system with tangential firing burners. Twenty four burners are arranged in an array of six burners positioned at different levels on four corners of the furnace walls. The specifications of the furnace geometry and original drawing are given in Table 1 and Fig. 1.

Table 1

Specifications of furnace geometry.

Sr no	Parameters	Value (m)
1	Furnace width	11.506
2	Furnace length	15.240
3	Furnace height	52

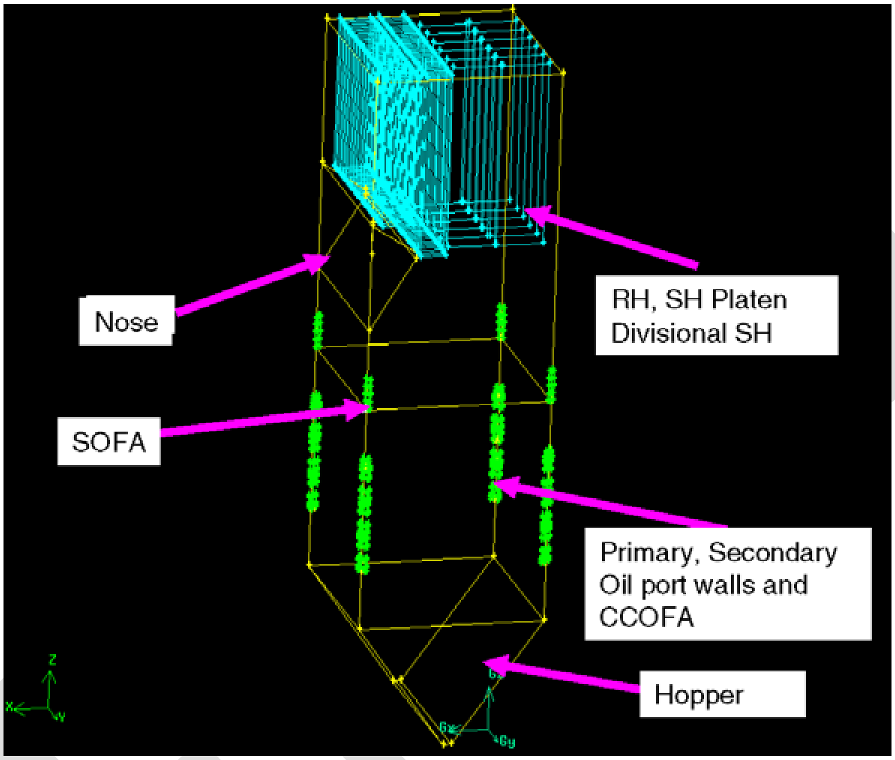

Fig. 1. Furnace geometry

4. Model description:

The three-dimensional geometry was created using GAMBIT – a FLUENT pre-processor. An isotropic view of the geometry and grid system is shown in Fig. 1. The meshed-geometry contained 402,852 nodes with hexahedral cells in one zone and the remaining zones with quadrilateral cells. In our study, the results are observed to be grid independent as three different sizes indicated no significant change in the flow patterns or trajectories.The furnace geometry has been constructed using the specifications provided by the utility. Fig 1 also presents information on super-heater and re-heater sections of the boiler. The burner arrangement, orientation, windbox elevation designations,details relevant to SOFA/CCOFA, burner tip, fuel air tip and auxiliary air nozzle tip are shown in Fig. 2. The figure is mainly used to construct the correct geometry of furnace to represent the orientation of nose, hopper and furnace wall sections as per the desighn of furnace.As indicated in Fig 2 it is used for constructing the various burner ports in four corners (1–4) along with Separated Overfire Air Register (SOFA) at different levels A–D from the bottom of the furnace as well as Close Coupled Overfire Air Compartment (CCOFA) ports at levels A and B with specified tilt angles from the plant operators. Following these SOFA/CCOFA ports, additionally Fig. 2 also refers to auxiliary air ports at A–A, B–C, D–E, F–F, Coal elevation ports at A–F and oil elevation ports at A–B, C–D,E–F which helped to represent the whole furnace ports in the geometry as per the specifications.

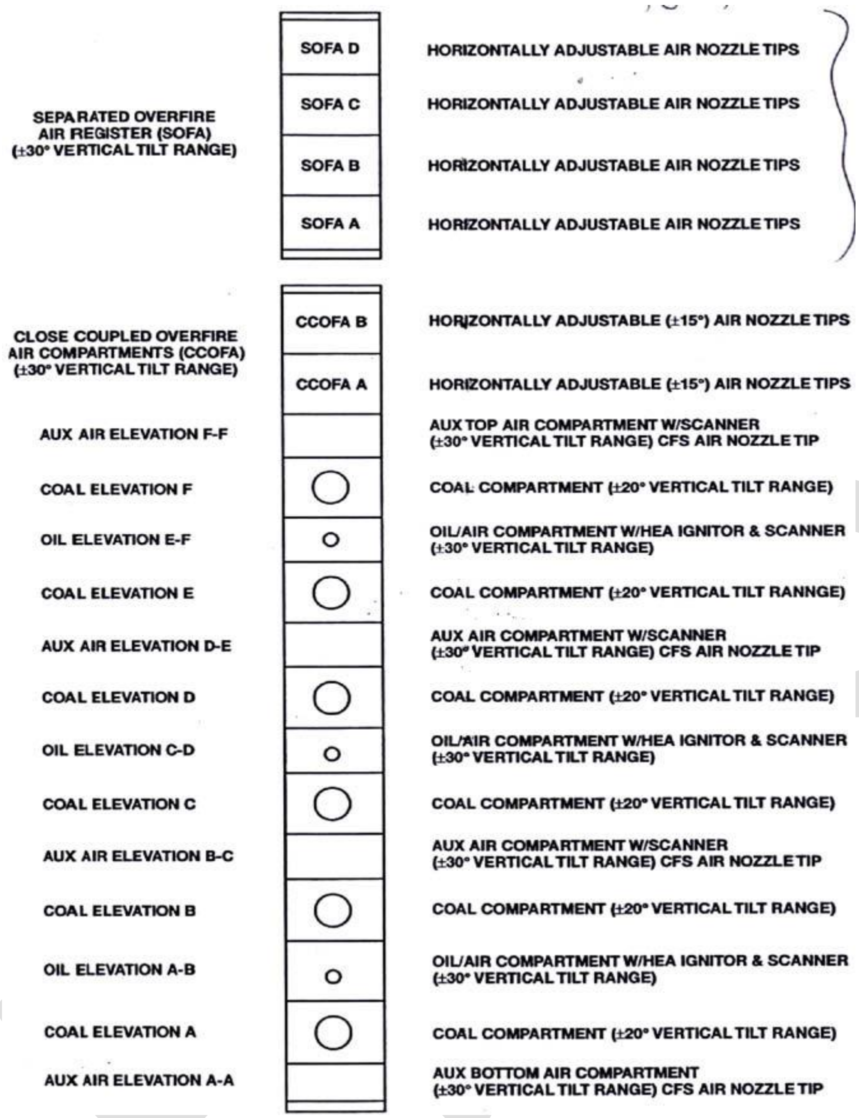

Fig. 2. Burner specifications; Windbox elevation designations.

5. Experimental Results and discussion

The computational model has been applied to the furnace of 250 MW boiler fired bituminous coal. The input data for simulations (including boiler operational conditions) have been selected in accordance with data related to the experimental tests done for the boiler considered.

5.1 Coal air velocity:

Experimentation results are as shown in the Table 2.experimentation is performed on the furnace by keeping the load below technical minimum.Coal air velocity is measured in coal pipes as shown in the Fig 3.results obtained show that we are getting maximum flame intensity at 19.19 m/sec.

Fig 3: Velocity measurement in coal pipe.

Table 2

Pipe no	Velocity (m/sec)	Load (MW)	Flame intensity (Lumens)
Corner-1	16.46	160	384
Corner-2	16.46	160	672
Corner-3	19.19	160	960
Corner-4	17.50	160	384

5.2 Burner tilt:

The position of the burner is as shown in the fig 2.All the dampers are connected with a single link so whenever we are giving command to burner for tilting all the four corners are simultaneously operated. Experimentation results show that while operating below technical minimum load at +20° of burner tilt we are getting maximum flame intensity as shown in the table 3.

Table 3

Burner tilt (Degree)	Load (MW)	Flame intensity (Lumens)
-30	160	264
-25	160	345
-20	160	194
-15	160	225
-10	160	361
-5	160	159

0	160	357
5	160	441
10	160	451
15	160	657
20	160	684
25	160	397
30	160	279

5.3 Furnace Draft:

Furnace draft is the pressure inside furnace. It must be kept below atmospheric in order to maintain fire ball and flue gases flow to second pass. We have operated in between -5 mmwc to -10 mmwc of furnace pressure and at technical minimum load as shown in the table 4.Experimentation results show that when we operate the furnace at -10 mmwc pressure we get maximum flame intensity.

Table 4

Pressure (mmwc)	Load (MW)	Flame intensity (Lumens)
-5	160	259
-6	160	364
-7	160	471
-8	160	521
-9	160	754
-10	160	789

5.4 Burner outlet temperature:

Burner outlet temperature is same that of coal mill outlet temperature in coal based thermal power plant. As shown in table 5 experimentation results show that when we vary the burner outlet temperature in range of 65°C to 85°C we obtain maximum flame intensity while operating at 70°C of burner outlet temperature while we keep load on the boiler below technical minimum.

Table 5

Temperature °C	Load (MW)	Flame intensity (Lumens)
65	160	495
70	160	859
75	160	426
80	160	528
85	160	624

6. Results validation:

A three dimensional model has been developed for the simulation of flow, temperature and concentration fields in the coal based tangentially fired furnace. The model takes into account the turbulence chemistry interactions. The simulation was performed using the ANSYS FLUENT considering non premixed combustion as fuel and oxidizer enter in a distinct stream. The convergence for this simulation was decided based on the following factors. The drop in residuals for the governing equations was the primary while the mass flow conservation between the inlet and the outlet was another. Also, the Pressure and Temperature at the outlet was monitored to reach steady values.

ANSYS Fluent is a Finite Volume based Reynolds Averaged Navier-Stokes (RANS) solver. It has the capability to solve both structured and un-structured meshes. Also, the advanced features like combustion modeling, radiation modeling, multi-phase modeling as well as specie transport modeling are available. ANSYS Fluent supports the various file formats for efficient multi-disciplinary functions. For the low speed flows, the Pressure based solver provides the SIMPLE, SIMPLEC and PISO algorithm for the Pressure-Velocity coupling while the Density based solver for the high speed compressible flows provides accurate results.ICEM CFD provide the option to generate block-structured or un-structured meshes for the geometry. The mesh quality as well flow filed aligned meshes can be generated from the block-structured mesh though addition time and expertise required. In order to resolve the boundary layers, the 'o' grid options can be utilized to generate the mesh layers near the wall. In the Un-structured mesh generation, prism layers provide the ability to capture the near-wall flow physics. The unstructured mesh typically contains tetra-hedra elements in 3-Dimensional domain while triangle elements in 2-Dimensional domain.

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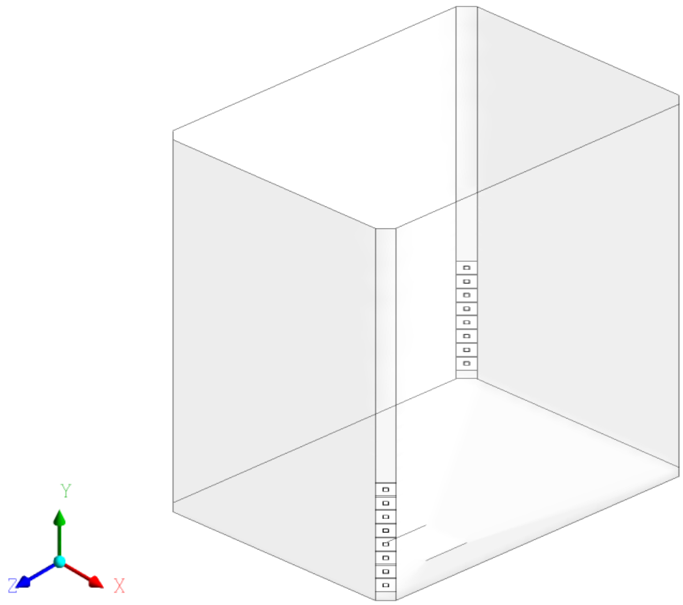
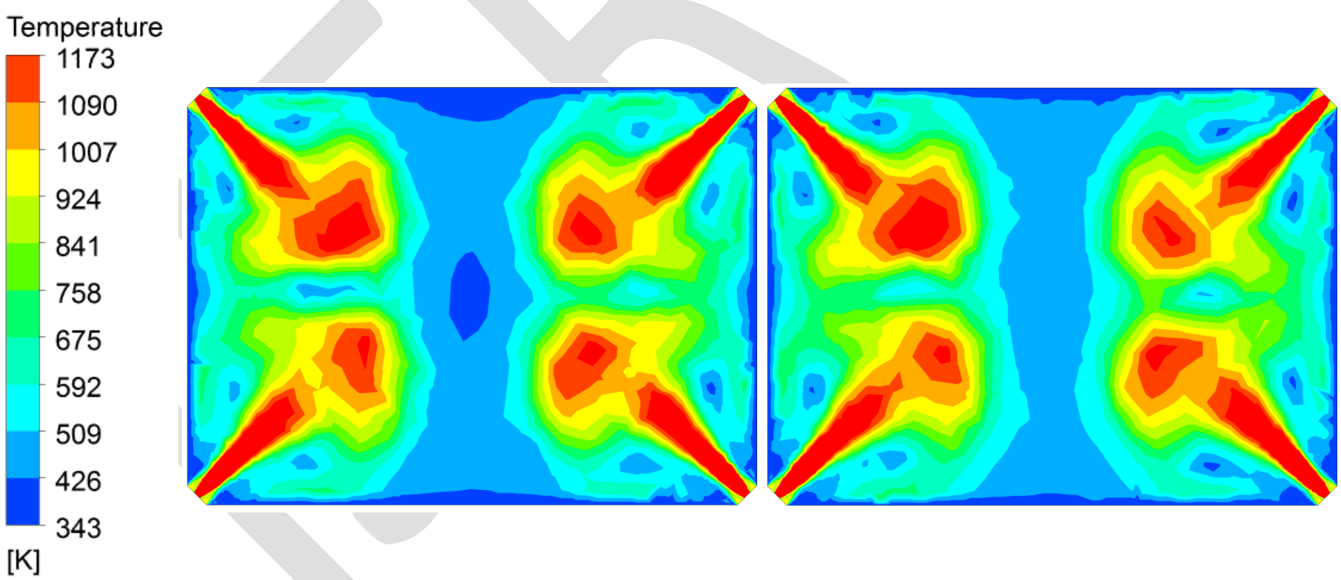


Fig 4 Furnace geometry made in ICEM

As shown in the Fig 4 furnace geometry is made in ICEM code. and for simulation purpose Fluent code is used.Pulverized coal tangentially firing furnace post processing is done by taking sections in Y plane section planes had been defined at the mid of each burner inlet. The temperature contour plots at these planes had been provided in fig 6.



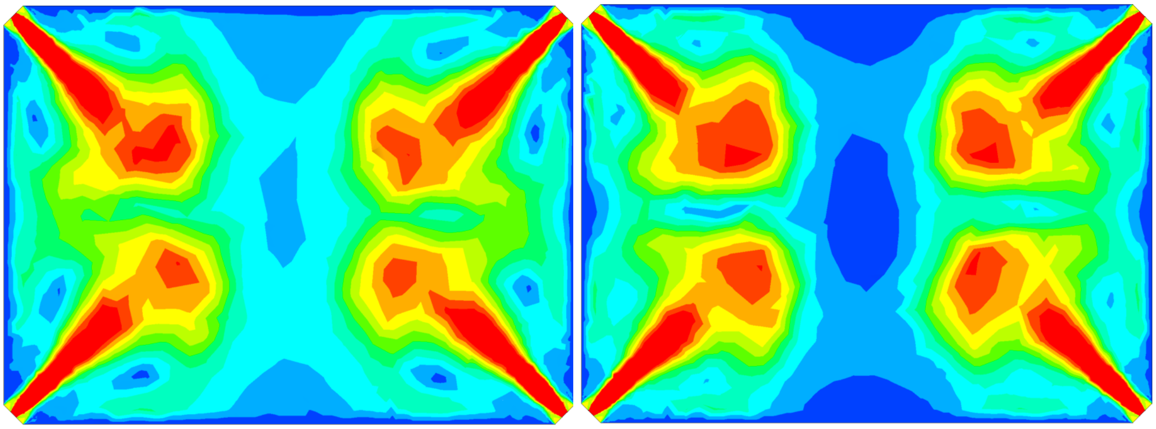


Fig 6: Temperature contours at different Y sections

The turbulence created by the jet effect at the coal and air inlet ensures flow distribution for most part of the furnace however there are certain zones with minimal flow distribution. Based on readings obtained from simulations for flame intensity vs. Coal air velocity a data table has been made which compares the readings of experimental data with that of data obtained from simulation. It can be seen in Table 6 that percentage error lies between 3.52-11.60 %.

Table 6

Sr No	Velocity m/sec (Experimental)	Velocity m/sec (Software)	Error	% Error
1	12.2	11	1.2	9.83
2	14	12.8	1.2	9.375
3	12.9	12.4	0.5	4.03
4	10.5	10.1	0.4	3.80
5	8.5	8.8	0.3	3.52
6	6.8	7.2	0.4	5.88
7	4.8	5.2	0.4	8.33
8	4	4.4	0.5	12.5

9	2.2	2	0.2	9.09
10	1.8	1.6	0.2	11.11
11	0.9	1	0.1	11.11
12	3	3.2	0.4	6.6
13	4.2	3.9	0.3	7.14
14	6.2	5.5	0.7	11.29
15	7	7.8	0.8	11.42
16	10	9.8	0.2	8
17	11.5	10.5	1	8.92
18	12.2	11	1.2	9.83
19	12	13.5	1.5	12.5
20	9	10	1	11.11
21	11.2	12.5	1.3	11.60
22	11.8	11	0.8	6.77

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CONCLUSION

If the thermal power plant of 250 MW is operated at recommended parameters it will give following monetary benefits.

1. Plant Availability factor in the observed period of 3 months is 96.29% .Remaining unavailability is solely due to plant tripping due to flame intensity failure. If the said parameters are maintained at low load conditions flame intensity will be high resulting in lower rate of plant tripping thereby increase in plant availability factor up to 100%.

2. Oil consumption while plant light up can be saved. It is observed that for every tripping it takes close to 20 KL of Light diesel Oil (LDO) which amounts to 1080000 Rs.If recommended parameters are maintained at technical minimum load it will decrease the chances of trappings' because of flame intensity failure.

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