Design and Analysis of furnace Burner for Thermal Power plant using CFD

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Abstract—In thermal tangentially fired boiler, the flame stability mainly dependent on the central swirl strength which characterizes the mixing between the air and fuel. In this work, numerical investigation is performed on 600MW pulverized coal tangentially fired dry-bottom boiler and validated with experimental data. The main focus of the work is to study the effects of burner firing angle and mass flow rate of primary air on the flow characteristics inside the burner. The important feature of the model is a tangential fired geometry where four burners are kept at the corners of the burner for generating swirling vortex in the center tangentially, which decides the flame propagation effectiveness and time to sustain flame for longer time and combustion efficiency. Optimization is performed for different design parameters like burner velocity and firing angle with objective function of enhancement of mixing efficiency in the furnace. For the designer of optimization and simulation makes it possible to find the optimum design and operating parameters. The literature is reviewed to understand the base case as shown in Figure 1 is simulated using the burners angle & velocity as mentioned in Table 1 and the numerical results for the base parameters are compared with the experimental results.

Keywords— *Burner, flame, mixing, tangentially fired boiler, vortex.*

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1. Introduction

In this paper investigated that Thermal power plants are one of the most important process industries for engineering. Over the past few decades, the power sector has been facing a number of critical issues. However, the most fundamental challenge is meeting the growing power demand in sustainable and efficient ways. Power plant engineers not only look after operation and maintenance of the plant, but also look after a range of activities in that including research and development, starting from power generation, to environmental assessment of power plants. In thermal power plant, the chemical energy stored in fossil fuels such as coal, fuel oil, natural gas is converted successively into thermal energy, mechanical energy and finally electrical energy. In the Rankine cycle, high pressure and high temperature steam raised in a boiler is expanded through a steam turbine that drives an electric generator.

Pulverized coal tangentially fired furnaces are used extensively in power generation worldwide due to a number of their advantages, [1] like uniform heat flux to the furnace walls and NO_x emission lower than in other firing types. Further study of the furnaces is needed by both experiments and simulations. While full-scale measurements are restricted by considerably high expenses, numerical simulation provides a cost-effective and powerful engineering tool, complementing experimental investigations.

TABLE I: Geometrical and Flow Parameters of the Burner

Parameters	Values
XL	0.657m
YL	0.741m
Θ_a	45^0
Θ_b	36^0
Inlet Velocity	14.1 m/s

2. Numerical modeling

The developed comprehensive model extended available sub models by describing fully the 3D flow, combustion and heat transfer in existing geometry, with in details modelling of the interactions between turbulence and particles and by including chemical kinetics of the coals considered and real coal particle size distribution.

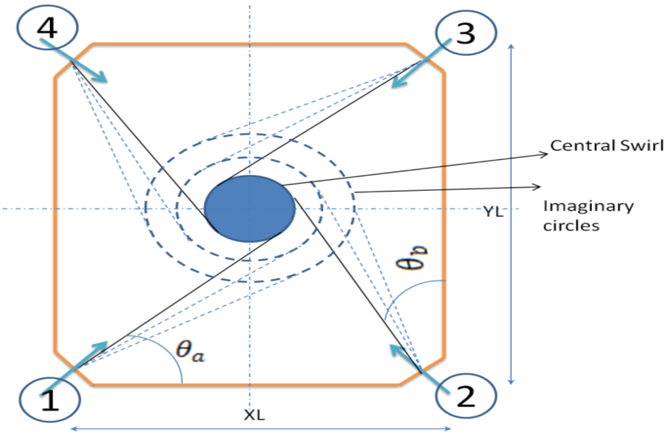


Fig.1- Schematic diagram of power plant burner

2.1. Numerical Model

Turbulence modeling is the construction and use of a model to predict the effects of turbulence. Averaging is often used to simplify the solution of the governing equations of turbulence, but models are needed to represent scales of the flow that are not resolved. [2]

Turbulence is that state of fluid motion which is characterized by apparently random and chaotic three-dimensional vorticity. When turbulence is present, it usually dominates all other flow phenomena and results in increased energy dissipation, mixing, heat transfer, and drag. If there is no three-dimensional vorticity, there is no real turbulence. The reasons for this will become clear later; but briefly, it is ability to generate new vorticity from old vorticity that is essential to turbulence. And only in a three-dimensional flow is the necessary stretching and turning of vorticity by the flow itself possible.

There are several subcategories for the linear eddy-viscosity models, depending on the number of (transport) equations solved for to compute the eddy viscosity coefficient.

1. Algebraic models
2. One equation models
3. Two equation models

2.2.1 Algebraic turbulence models

Algebraic turbulence models or zero-equation turbulence models are models that do not require the solution of any additional equations, and are calculated directly from the flow variables. As a consequence, zero equation models may not be able to properly account for history effects on the turbulence, such as convection and diffusion of turbulent energy. These models are often too simple for use in general situations, but can be quite useful for simpler flow geometries or in start-up situations. The two most well-known zero equation models are the

- Baldwin-Lomax model and the
- Cebeci-Smith model

Other even simpler models, such a models written as

$$\mu_t = f(y^+)$$

are sometimes used in particular situations (e.g. boundary layers or jets).

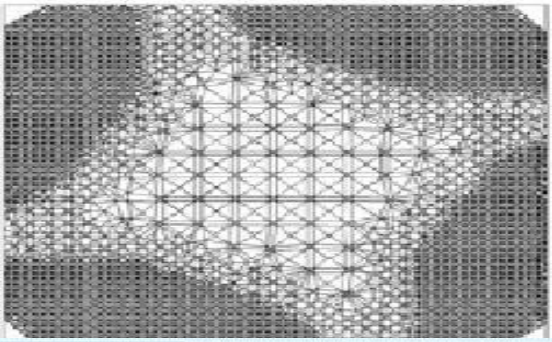
2.2. 2 One equation turbulence models

One equation turbulence models solve one turbulent transport equation, usually the turbulent kinetic energy. The original one-equation model is Prandtl's one-equation model. Other common one-equation models are:

- Baldwin-Barth model
- Spalart-Allmaras model
- Rahman-Agarwal-Siikonen model

3. Preprocessing

In Grid generation mainly there are two types of Grid. For four corners burner situated furnace with grid generation are shown in Fig. 2



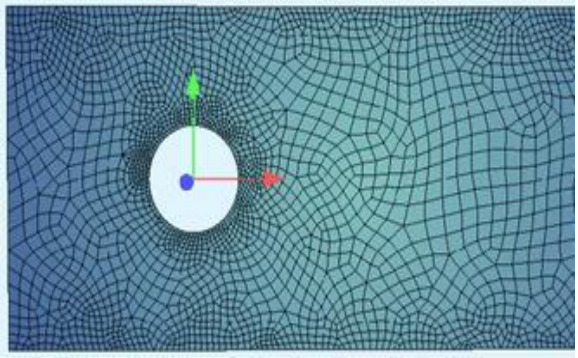


Fig.2-Grid generated in four corner burner furnace
Fig.3-An unstructured grid

3.1. Numerical Model

It is characterized by irregular connectivity. Storage requirements for an unstructured mesh can be substantially larger

Good for complex geometry

The domain is divided into polygons, triangles are often used. See Fig.3 for a triangulation of the unit square. Software to generate this type of discretization normally require the user to input an initial, very coarse, triangulation. Perhaps only containing points on the boundary of the domain. Techniques for automatic refinement is then used. In the data structure, each triangle has pointers to its neighbors, but there is no information on coordinate directions.

3.2. Structured grid

It is characterized by regular connectivity. It restricts the element choices to quadrilaterals in 2D or hexahedra in 3D.

A structured grid is something which is indexed along coordinate directions. We think of a grid as a mapping $x(\xi, \eta, \zeta)$, $y(\xi, \eta, \zeta)$, $z(\xi, \eta, \zeta)$ from the unit cube $0 \le \xi \le 1$, $0 \le \eta \le 1$, $0 \le \zeta \le 1$ to the physical space. See Fig. 4 for finite difference approximations, we want the grids to be smooth transformations, by transforming to the Pde to the unit cube, and solve it there. The transformed problem will contain derivatives of the grid as coefficients. This is in analogy with the smooth local coordinate maps of differential geometry. It is possible to define finite volume or finite difference approximations which do not require smoothness of the grid, but these approximations are in general more complicated, and computationally expensive.

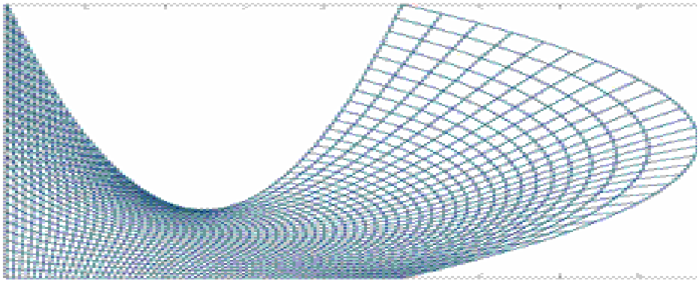


Fig.4-Structured grid

4. Effect of parameters on the performance of tangentially fired furnace

The Burner design and analysis is performed for the different parameter with the following objective function

- To investigate the vortex strength of tangentially fired boiler, sustains the flame propagation for efficient combustion
- To investigate the effect of the following important parameters on vortex formation
- Burner Angle (Base Case 43^0 , 39^0)
- Inlet Velocity (Base Case V=14 m/sec) [4]

4.1. Numerical Investigation of burner

In the cold surrounding spreads faster than a cold jet in the same surrounding.For any downstream axial distance, the maximum velocity is at the centre and minimum at the periphery such that a parabolic profile is developed as shown in Fig.5

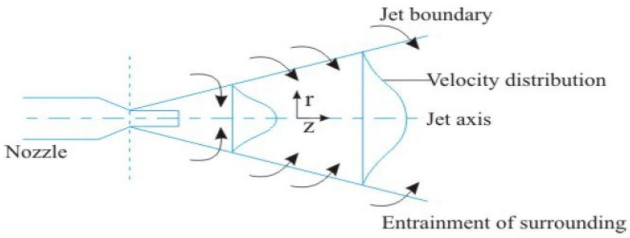


Fig.5-Jet dynamics from the burner as nozzle

Table 2: Burner velocity arrangement configurations

Cases Sr. No.	Parameter-Velocity (m/s) Range
1	10
2	12
3	14 (Base)
4	16

4.1.1 Burner Velocity (V=10 m/sec)

The burner velocity is decreased from the base case i.e. from 14m/sec to 10 m/sec for understanding the effect of Burner velocity on the turbulence dynamics in the Burner. The contours of velocity and turbulence as well as static and dynamic pressure are shown in the Fig. 6&7.

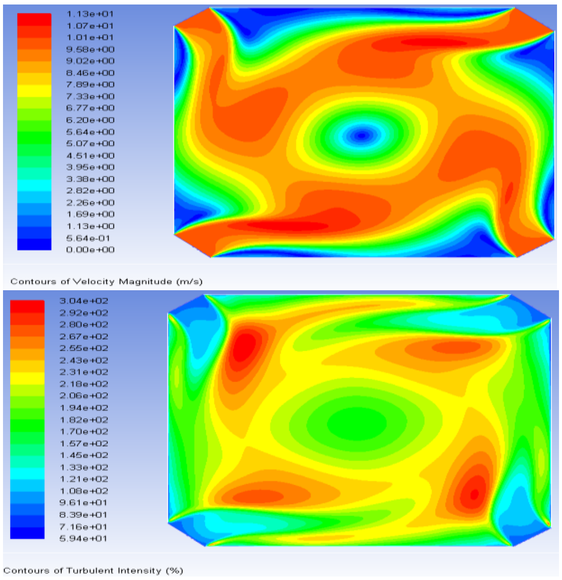


Fig.6-Contours of velocity magnitude and turbulence intensity for Burner Velocity 10 m/sec.

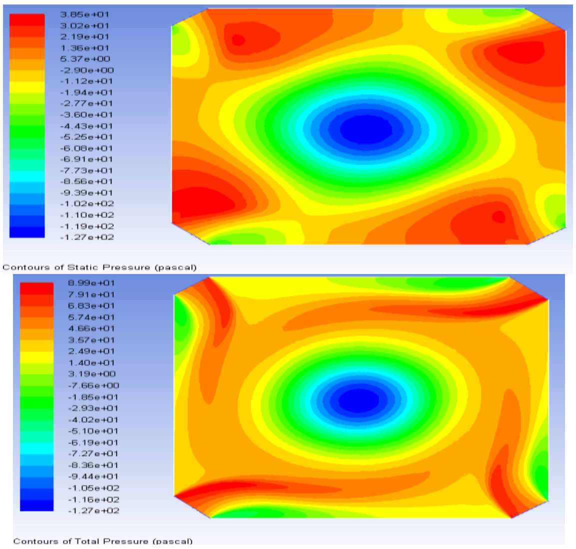


Fig.7-Contours showing static and total pressure for Burner Velocity 10 m/sec.

4.1.2 Burner Velocity (V=12 m/sec)

The burner velocity is further increased from the previous cases to 12 m/sec by less than the base case velocity. [6]The contours of velocity and turbulence as well as static and dynamic pressure are shown in the Fig. 8 & 9

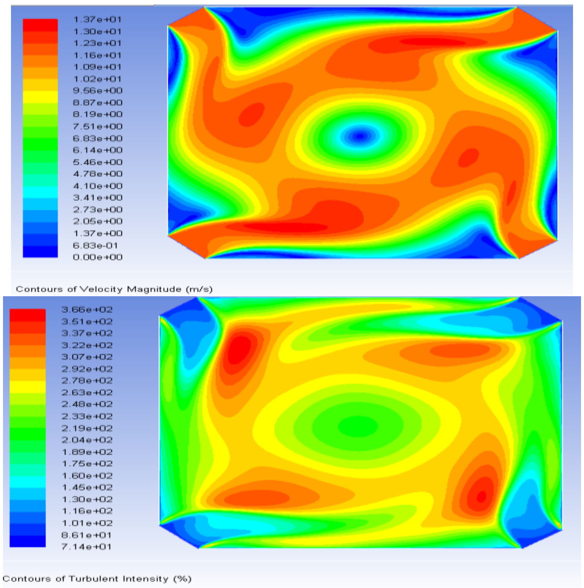


Fig.8-Contours of velocity magnitude and turbulence intensity for Burner Velocity 12 m/sec.

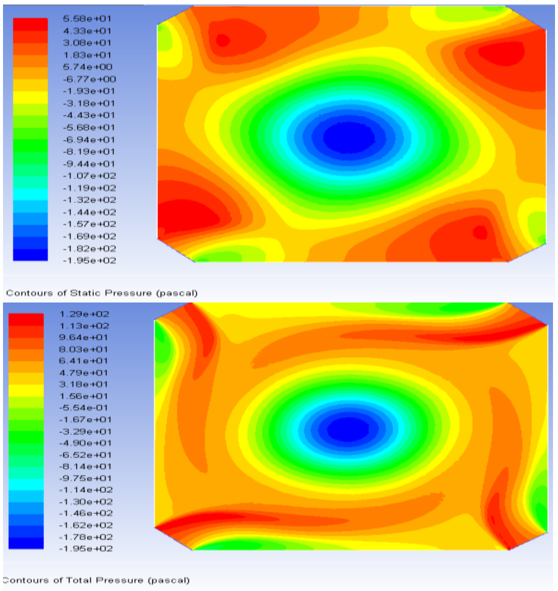


Figure 9. Contours showing static and total pressure for Burner Velocity 12 m/sec

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4.1.3 Burner Velocity (V=14 m/sec)

The base case for the burner is simulated for the given velocity i.e. 14m/sec and effect is checked with other design variables.

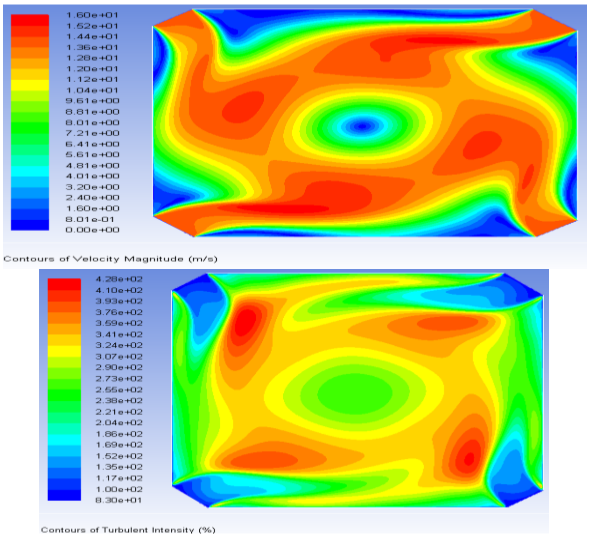


Fig.10-Contours of velocity magnitude and turbulence intensity for Burner Velocity 14 m/sec.

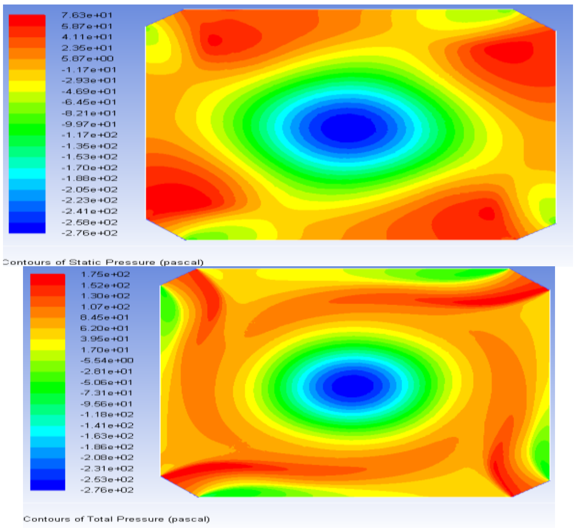


Fig.11-Contours showing static and total pressure for Burner Velocity 14 m/sec

4.1.4 Burner Velocity (V=16 m/sec)

The burner velocity is increased form 14m/sec to 16 m/sec by increasing the mass flow rate of the pulverized mixture for understanding the behaviors of internal burner flow dynamics. The velocity and turbulence contour along with pressure contours are shown in the Fig. 12 & 13 respectively.

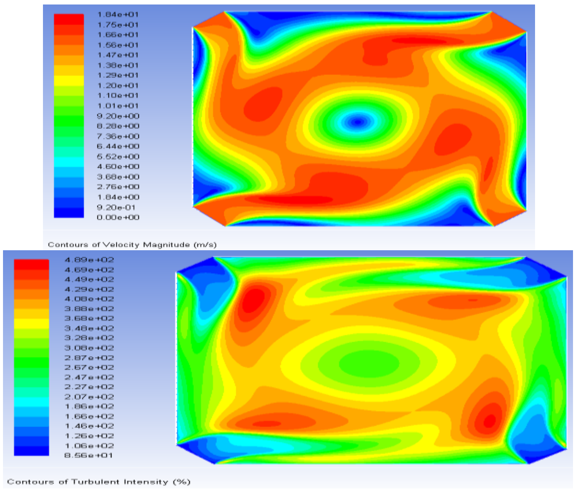


Fig.12-Contours of velocity magnitude and turbulence intensity for Burner Velocity 16 m/sec.

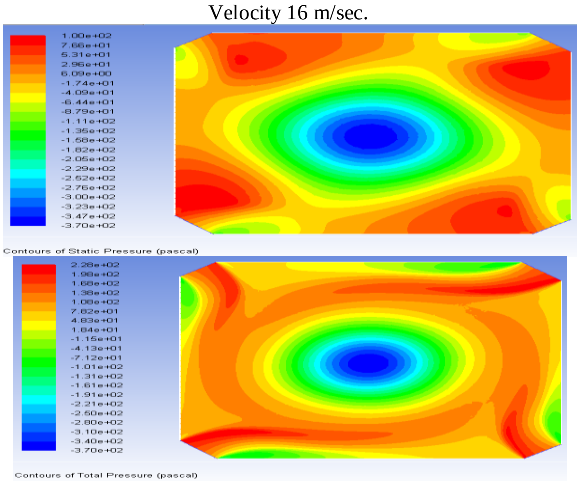


Fig.13-Contours showing static and total pressure for Burner Velocity 16 m/sec.

4.2 Numerical Investigation of burner angle

Burner angle decides the direction of flow and the mid-circle diameter, but changing the burner angle is restricted by the size of the furnace, therefore one higher angle set and one lower angle set is selected which is feasible for the current furnace size for understanding the effect of burner angle on the vortex strength.[7]

Table 3: Burner angle arrangement configurations

Parameter-Angle(m/sec) Range	1	2
1 (Base)	43	39(51)
2	33	29(61)
3	39	35(55)
4	46	42(48)

The results are to be compared with the base case i.e. $\Theta_1=43^0$ and $\Theta_2=51^0$. The velocity and pressure contours are shown in the Fig. 14&15 respectively

4.2.1 Burner Angle (43^0, 39^0) is BASE CASE

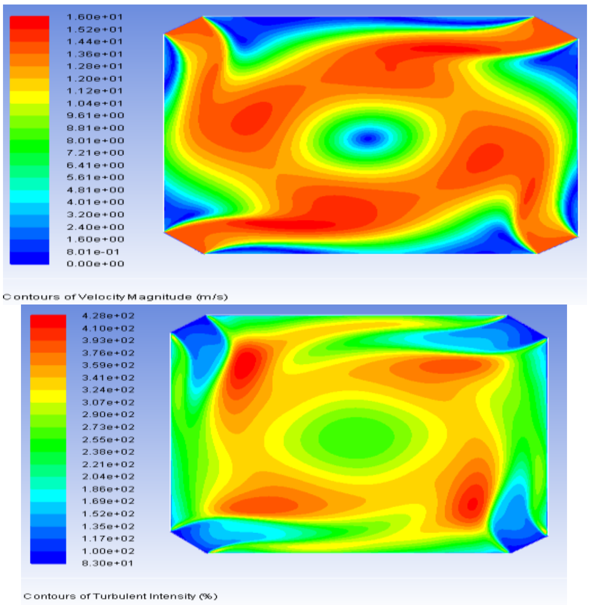


Fig.14- Contours of velocity magnitude and turbulence intensity for Burner angles (43^0, 39^0)

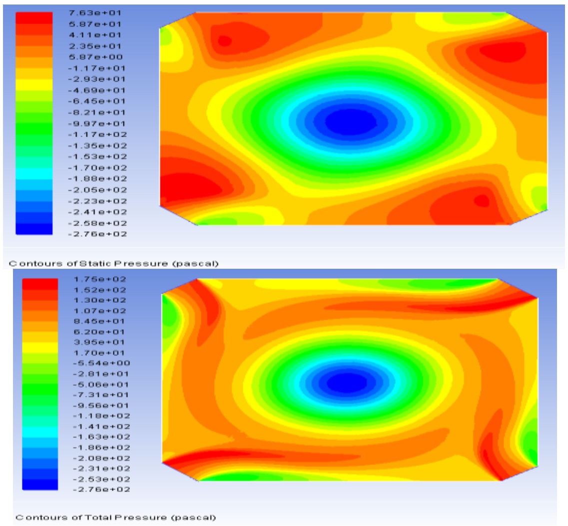


Fig.15-Contours showing static and total pressure for Burner angles (43^0, 39^0)

4.2.2 Burner Angle (33^0, 29^0)

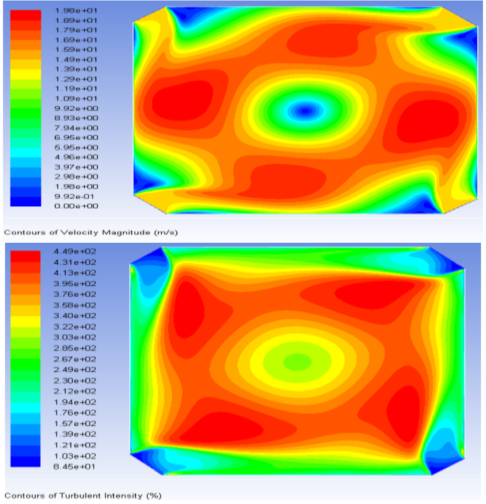


Figure 16. Contours of velocity magnitude and turbulence intensity for Burner angles (33^0, 29^0)

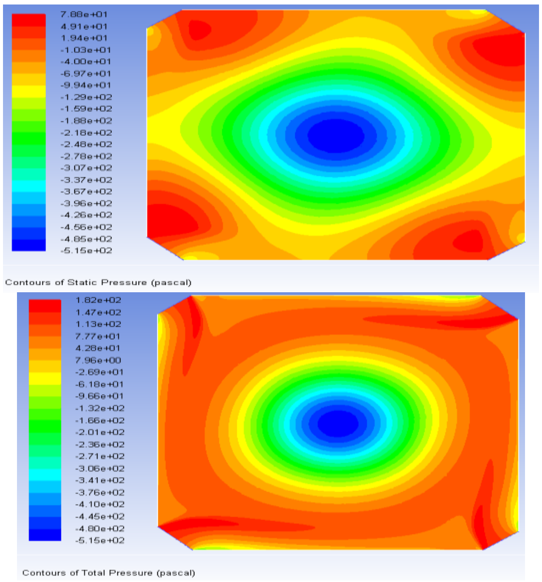


Fig.17-Contours showing static and total pressure for Burner angles (33^0, 29^0)

4.2.3 Burner Angle (39^0, 35^0)

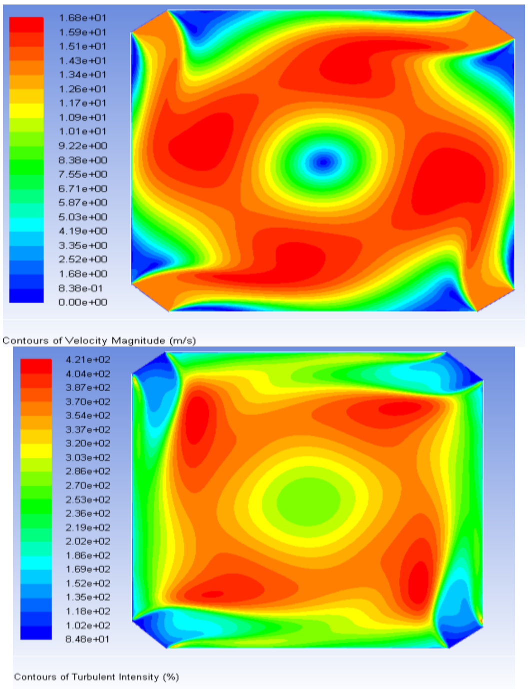


Fig.18.-Contours of velocity magnitude and turbulence intensity for Burner angles (39^0, 35^0)

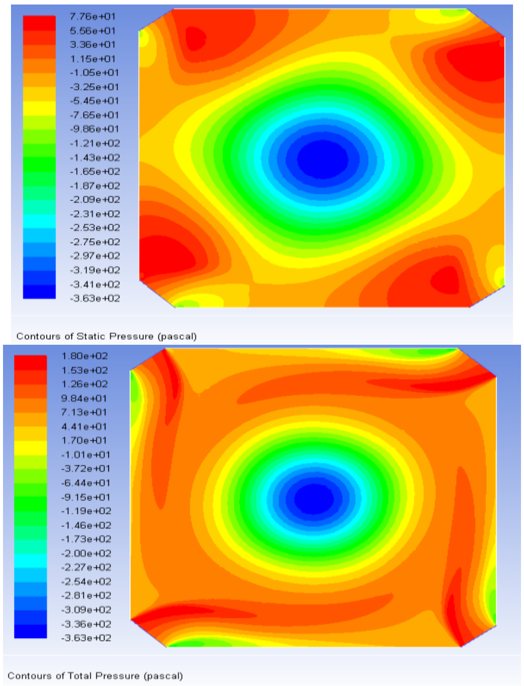


Fig.19- Contours showing static and total pressure for Burner angles (39^0, 35^0)

5. Results and discussion

The furnace burner is designed and analysis is performed for different key parameters like burner velocity, burner angle. The analysis of the above parameters is combined for the best combination of parameters with the objective function to maximize mixing efficiency in the burner which ultimately produces efficient combustion and reduces the losses in the mixing stage. The efficient combination of parameters produces cost saving design for better performance of overall plant.

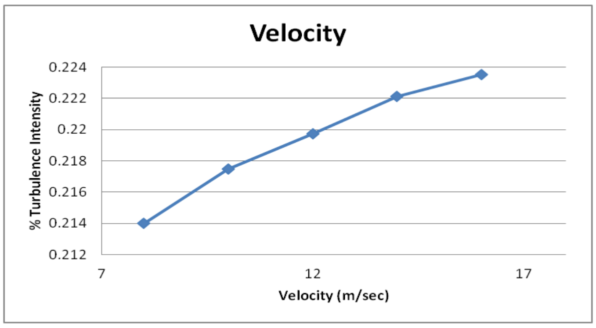
5.1 Effect of Burner Velocity

The turbulence intensity is checked for all the design variables for the velocity i.e. 10, 12, 14, and 16 m/sec. Out of which the results are compared with the Base case results i.e. 14m/sec.

Table 4: Turbulence intensity (%) for different velocity

Velocity (m/sec)	Avg. Turbulence Intensity	Max (Circle region)	Total	%
10	2.07	215.54	991	0.217
12	2.52	562	1206	0.219
14	2.96	315	1418	0.222
16	3.42	365	1633	0.223

As the velocity increases of the flue gases, the momentum is increases which also increasing the pressure loss inside the furnace geometry but the increment in pressure is from 185 Pa to 200 Pa which is < 15% but the increase in the turbulence intensity in the middle core is from 315% to 365% i.e. >20%.[8]. Therefore the higher velocity is selected as the optimum parameter for enhancing the flame stability but beyond this range there is no appreciable change in the turbulence. Optimum Velocity =16 m/sec is selected.



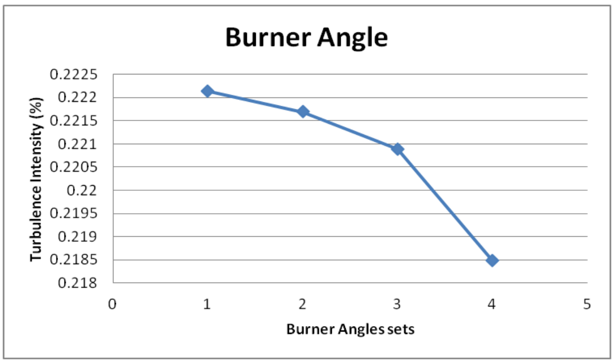
5.2 Effect of Burner Angle

The turbulence intensity is checked for all the design variables for the Burner Angle i.e. (43, 39), (33, 29) (39, 35) and (46,42). Out of which the results are compared with the Base case results i.e. (43, 39).

Table 5: Turbulence intensity (%) for different burner angles

SET	Burner Angle	Avg Turb Intensity	Max (Circle region	Total	%
1	43_39	2.96	315	1418	0.222144
2	33_29	3.46	366.9	1655	0.221692
3	39_35	3.12	330	1494	0.220884
4	46_42	2.92	305	1396	0.218481

Increase or decrease in burner angle from the existing set up does not help in increasing in vortex strength as the change in burner angle is restricted due to the size of the furnace; the optimum vortex strength is achieved at set 1 i.e. existing set up which is kept fixed.



6. Conclusion

Based on the tangentially fired furnaces in power plant industry, it has been found that four corner burners situated widely used with pulverized coal fuel studied for maximum flame stability by considering the turbulence intensity.

The base design is studied for different design parameters with objective function of increasing the turbulence intensity which directly enhances the flame stability for proper mixing of fuel and air which leads to better combustion efficiency. The effect of different parameters are studied on the vortex strength formed at the middle of circle for tangentially fired boilers. The information presented here would beneficial for presenting in this area of research.

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