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Experimental, CFD & Parametric Analysis of Super Heater in Bagasse Fired Water Tube Boiler

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***Abstract*— A CFD simulation was carried out for the super heater placed in the combustion chamber of Bagasse fired water tube Boiler. It has been employed to understand the thermal flow in the boiler to resolve the operational problem and search for optimal solution. The numerical analysis is carried out to enhance heat transfer characteristics and minimize thermal losses. Velocity, Pressure, Temperature, of steam as well as the temperature of tube wall was computed. The heat transfer coefficient was determined based on the measured steam temperature at the inlet & outlet of the super heater. The heat transfer coefficient computed using CFD analysis and compared with experimental results. A deviation of 1.93% in heat transfer coefficient is observed at 0.4320 kg/s, of steam mass flow rate, 573 inlet temperature, with 873 constant wall temperature. If total number of super heater pipes was decreased by 45 to 40 then Nusselt number increases by 10.02% indicating the increase in heat transfer. The results are useful for the maintenance engineer to make suitable prediction of the super heater tube life and make suitable action for the high temperature zone The results are useful for the maintenance engineer to make suitable prediction of the super heater tube life and make suitable action for the high temperature zone**

***Index Terms* -** Bagasse fired water tube boiler, Super heater, Thermal Measurements

I. INTRODUCTION

Boilers are generally used in sugar industry to generate steam and electricity. We can say that boilers are the heart of sugar industry. Therefore it is necessary to increase the performance of boiler. Computer simulation has been employed to understand the thermal-flow and combustion phenomena in the boiler to resolve operation problems and in search for optimal solutions.

Boiler failure happens due to the super heater tube failure. The reasons may be excessive heating, un uniform gas flow un uniform steam distribution , localized prolong heating, thermal stresses, thermal fatigue ,creep, erosion, expansion of materials, desired steam outlet temperature , velocity, pressure of steam & flue gases etc. The operation of the super heater for producing high-pressure, high-temperature steam may result in malfunctioning frequently due to ruptured super heater tubes.

II. CFD ANALYSIS

A. Introduction:

CFD analysis of super heater can be useful to gain insight to the gas flow distribution. Efforts are made to measure the velocity and pressure distribution of flue gases which will be useful to find the effect of the operating parameter on the tube erosion rate and velocity and pressure distribution inside the super heater of bagasse fired water tube boiler. CFD has evolved as important tool for modeling of coal fired boiler and it can useful to quantify the gas flow field and temperature distribution with the boiler super heater. Hence CFD model of super heater was developed to study the velocity, pressure and temperature distribution of the steam inside the super heater. Thus this study is focused on simulating isothermal turbulent flow within the boiler super heater.

B. Role of computational flow analysis in boiler tube failure

Power generation units have to be controlled properly to ensure continuous energy production. CFD modeling has been used to study boiler tube leakage problem by considering the super heater section. It explains the fundamental physical processes that determine the interactions among the input and output variables. This model can simulate various operating procedures similar to those actually used in power plant operation. Hence, simulation of the SH helps to understand its behavior. Computer simulation of the super heater provides the detail of the flow pattern over the tube, the colored plots of temperature of the flue gases which will be helpful to the maintenance engineer to know the process and knowing the critical areas and reasons of tube failure. Taking this view in consideration some objectives was set for the work on Bagasse fired water tube boiler.

Stepwise Approach for CFD Analysis is as given below, is followed to carry out numerical analysis.

- Create Geometry in HYPER-MESHING.
- Mesh Generation in HYPER-MESHING.
- Solver (Defining boundary • Condition).
- Post Processor.

III. RESEARCHER'S WORK

Raja Saripalli, Ref.et.al. [1] presented the detailed thermal flow and combustion in the boiler and showing possible reasons for super heater tube rupture. The exhaust gas temperature is consistent with the actual results from the infrared thermograph inspection. It helps industry to improve boilers efficiency, reduce emissions, avoid rupture of super heater tubes, and to understand the thermal flow transport in the boiler. Jayakumar Ref.et.al. [2] reported that heat transfer in a helical coil is higher than that in a corresponding straight pipe. It was observed that the variation of local Nusselt number along the length and circumference at the wall of a helical pipe. Movement of fluid particles in a helical pipe has been observed. Ingale Ref. et.al. [3] reported the boiler tube leakage problem in the super heater and tried to find the causes of tube leakages with the help of simulation. Ingale Ref. etal. reported the boiler tube leakage problem in the super heater and tried to find the causes of tube leakages with the help of simulation A 2 D Modelling of superheater is performed using CFD and temperature of flue gases over the coils using the actual boundary conditions has been studied.

Shajikumar Ref. et.al. [4] presented an investigation on tube temperature distribution in a water tube boiler, performs detailed efficiency testing and simulation of thermal flow inside an industrial Boiler. The temperature distribution in the boiler tube is affected by many variables such as mass flow rate of steam, steam temperature, feed water temperature and pressure. It is found that the increase of mass flow rate of steam through the boiler tube causes the decrease in temperature in the inner tube wall. This behavior occurs due to heat releasing from flue gas to steam is not proportional as the ability to absorb heat from flue gas for higher mass flow rate is faster. If mass flow rate of steam is increased, as a consequence of it, temperature of flue gas must be increased to make heat balance in equilibrium condition. The steam inlet temperature affects the thermal efficiency of a thermal power plant. The higher steam inlet temperature increases thermal efficiency. Higher operating temperature can also increase scale growth. Therefore it conducted simulation on the effect of steam inlet temperature to the temperature distribution in the boiler tubes.

Begum Ref. et.al. [5] reported that now a days boiler tube failures is main cause occurs in plant and that effects on total performance of the plant. The thermal heat transfer analysis was conducted by applying surface heat flux on the inner wall surface of the tube that will either supply heat or take away heat during the process. Parit Ref. et.al. [6] presented possible causes of super heater tube failure. It deals with the failure investigation of secondary super heater tube panel of SA213-T11 grade steel. The primary observations made with visual inspection and then metallurgical investigation carried out by microstructure analysis. The temperature distribution on the tube walls of the super heater is analyzed using computer aided engineering tools. From CFD results and metallurgical examination, localized overheating was seen in failed region of super heater tubes. Thermal analysis is carried out in Ansys Workbench. This analysis gives actual temperatures on tubes. Temperature distribution obtained after thermal analysis is the resultant temperature distribution to which tubes are exposed.

Khanorkar Ref. et.al. [7] presented CFD analysis of the vertical tube .A vertical copper tube having constant cross section area used for representing the medium through which natural convection of water takes place. In this work the study and analysis of natural convection flow of water through vertical pipe is done and study the effect of the physical parameters of tube like diameter, length and heat flux on the outlet flow parameters like velocity and temperature. Constant heat flux is boundary conditions provided on the entire tube surface. In this study he found that outlet temperature and outlet velocity that going to be increased as tube length was increased but as diameter of pipe increased outlet temperature also increased but velocity decreased. CFD results and experimental results were compared which validate the software results. Saripally and Ting Wang Ref. et.al. [8] conducted a simulation of thermal flow in an industrial boiler using a CFD package. The CFD analysis provided fluid velocity, pressure, temperature, and species concentration throughout the solution domain. During the analysis, the geometry of the system and boundary conditions such as inlet velocity and flow rate was changed to view their effect on thermal flow patterns or species concentration distribution in boiler and showing possible reasons for super heater tube rupture. The exhaust gas temperature is consistent with the actual results from the infrared thermograph inspection.

Rahmanand Sukahar Ref. et.al. [9] presented the application of finite element method (FEM) to analyze the tube temperature distribution in a water tube boiler. Two-dimensional (2-D) finite element models were developed and axi-symmetric triangular elements for the tube cross section area were employed. The results showed that the temperature distribution at the tube wall decreases with increased mass flow rate of steam and increased scale thickness.

IV. Experimental Setup

The existing boiler is bagasse fired boiler and made by Walchandnagar Industries Ltd. and assembled by Hi-Tech Engineering Corporations for the Shrinath Mhaskoba Sakhar Karkhana Ltd. Patethan Tal: Daund, Dist: Pune (M.S). This boiler plant has capacity 70 Tons/hour. In this plant there are two types of superheating coils primary and secondary coils , heated water and steam from the heating pipe is enter in the steam drum and there is separator in the drum so that water and steam is separated, below 300^0C steam is reheat and the only above 300^0C steam flows in the super heater pipe that steam temperature again increase by due to heating of flue gas in the boiler drum .There are total 45 number of same super heating tubes present at the separator drum arrangement.and 70 Tons/hour steam is flow through the super heater tubes. Same steam flow rate get divided in 45 numbers of tubes, hence here consider single tube for the analysis.

As the Boiler is provided well equipped control room to measure and control different operating parameters like steam pressure, temperature, steam flow rate ,furnace Temperature, feed water flow rate ,Economizer inlet & outlet Temperature ,Drum level ,flue gas temperature at inlet and outlet of air preheater , feed water temperature of boiler.

Fig. 1: Experimental model

A. Mesh conversions study

A 3D geometrical model is created in professional geometric modeller CATIAV5 in STL, and imported in CFD tool ANSYS Fluent. There are 10 numbers of turns to the super heater of a pipe, geometry divide in 19 parts. We are simulating only flow inside the super heater pipe. The pre-processor software Ansys. is used to generate the grids. Fig. 4.5 shows typical surface grids. Automatic meshing is done for super heater pipe geometry so that results obtained are accurate so fine meshing is done and meshed geometry is shown in fig 4.5. Following assumptions are made while carrying the current numerical study.

- The fluid is assumed to be incompressible with constant thermal physical properties and the flow is assumed to be steady, irrotational, turbulent, and three dimensional.

The working fluid is steam.

- A constant temperature is prescribed on the super heater tube wall.
- No-slip velocity conditions are applied at all walls.
- A uniform mass flow rate and temperature are set at the inlet of superheater.
- A pressure outlet condition is assumed at the outlet.
- A turbulence intensity level of 1% is assumed for the flow.

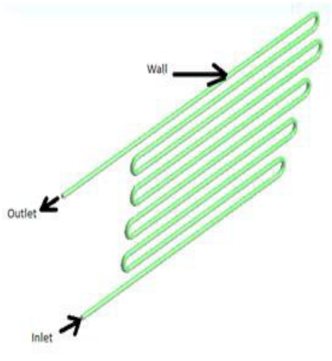

Fig. 2: Numerical Model in this study (Secondary Superheater)

B. Boundary Conditions

The heat transfer in the super heater is important for boiler design, the heat transfer enhancement in the boiler is the major concern of this project. A temperature is prescribed on wall. no-slip conditions are applied at all walls. A uniform mass flow rate and temperature are set at the inlet and pressure outlet condition is chosen at the outlet. The fluid is assumed to be incompressible with constant thermal physical properties and the flow is assumed to be three dimensional, turbulent, steady and irrotational, the working fluid is steam.

In this study, because of high Reynolds number and the complex computational model, the standard wall functions of the K-ϵ model are employed in the study. The convergence criterion for continuity, momentum, k, energy equation is 1e-6.

- Flow is assumed to be steady
- Water Vapour is considered as the fluid for computations
- Flow considered as Turbulent (K-ϵ model)
- Inlet steam mass flow rate of magnitude 19.44 Kg/s for 45 pipes
- Steam inlet temperature of fluid in 573 K
- Outlet considered as pressure outlet of magnitude 40 kg/cm^2
- Steam density 18.46 kg/m3 at 43 kg/cm^2 pressure and 573 0 K temperature
- Dynamic viscosity of fluid 1.985e-5 kg/m-s
- Pipe wall temperature is 873 0 K

C. Various contours for super heater

Various contours of velocity, pressure, temperature are plotted for super heater .

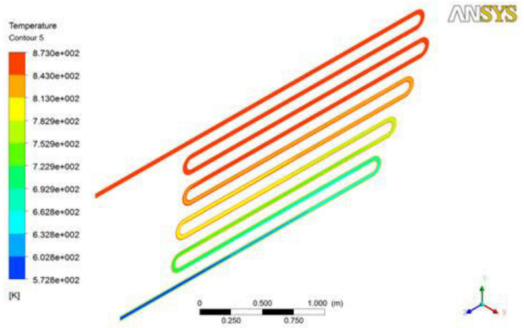

Fig.3. Contour of temperature along the interior of super heater

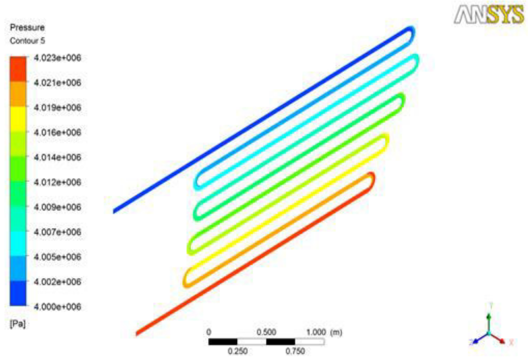

Fig.4. Contour of pressure along the interior of the super heater

Here various contours are plotted for a super heater to study and understand the thermal flow in the pipe to resolve the operational problems. Temperature is increases along the length of super heater as shown in figure 3.This fluctuation of temperature within the superheater causes erosion at high temperature and boiler tube leakage emerges from high temperature zone. As the super heater is nothing but the heat exchanger it increases the temperature of the steam flowing inside the tube and hence the temperature of steam increases from inlet to outlet because super heater wall is heated by flue gas around 600^0 C.

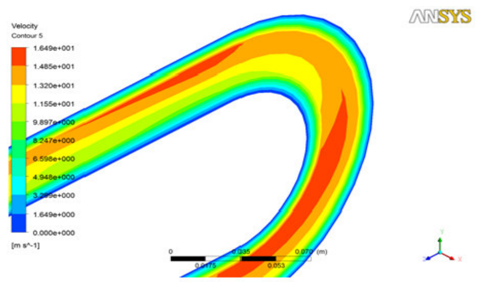

Fig.5. Contour of velocity along the bending interior of super heater

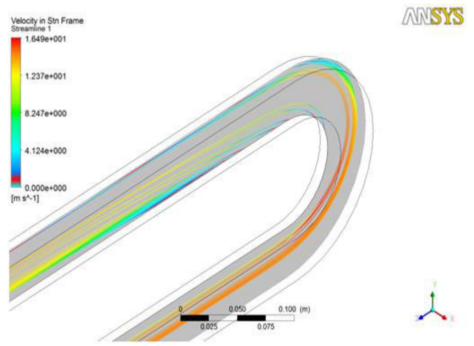

Fig.6. Contour of velocity streamline along the bending interior of super heater.

Figure 4.shows that pressure is decreases along the length of super heater, maximum pressure occurs at inlet and minimum pressure at outlet. The pressure drop in various bent geometries. The pressure drop is more significant due to flow separation at the inner wall in elbows as compared to bends.

From the figure 5 and figure 6 it is observed that the velocity fluctuation takes place at the U-bending section. The sudden increment and decrement of the velocity takes place at the bending part of the super heater. Maximum velocity observed at the bending of a super heater. A boundary layer is formed as the fluid enters the pipe where the viscous forces are confined while the core is inviscid, like in a straight pipe. The secondary flow generated by the curvature is therefore moving the slower fluid from the boundary layer inwards and the faster fluid at the outwards. The inflow condition greatly affects the initial development of the flow with non-uniformity in wall shear stress, i.e. the shear is largest at the inner wall before the maximum moves to the outer wall, appearing at two times larger distance for the first inlet condition than for the second one.

C. Result comparisons :

Experimental & CFD results are approaching to each other with deviations shown below.

TABLE I.

RESULT COMPARISONS

Parameter	CFD	Experimental	Deviations in Result %
Pressure drop	22194.5 Pa	24163.39 Pa	8.87
Temperature outlet	868 K	773 K	10.94
Total surface heat flux	92847.008 W/m^2	89200 W/m^2	3.92
Heat transfer coefficient	158.75 W/m^{2}K	155.67 W/m^{2}K	1.93

V. PARAMETRIC STUDY

In this work main aim is to enhance the heat transfer characteristics of the super heater of a boiler so that changing mass flow rate, diameter of superheater ,inlet temperature in the existing super heater pipe to study the various results to obtain enhancement in the heat transfer characteristics. The following parameters are utilised for the parametric study.

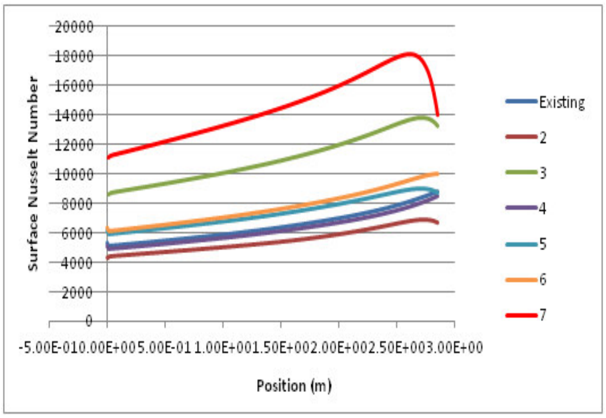

Fig.7 Nusselt number comparisons along the wall of super heater.

From the figures 7 it is found that if the mass flow rate of steam increases then Nusselt number increases. If the total number of tubes of super heater decreases then mass flow rate and Nusselt number increase. If the diameter of superheater tube increases then Nusselt number also increases.

TABLE II
PARAMETRIC STUDY

Conditions	Dia. (m)	MFR (kg/s)	No. of tubes	Tin(K)
Existing super heater	0.041	0.04320	45	573
Mass flow rate increase	0.041	0.5	45	573
Diameter of super heater tube increase	0.45	0.4320	45	573
Mass flow rate decrease	0.041	0.4012	45	573
Total number of super heater tube decrease	0.041	0.4861	40	573
Inlet Temperature decrease	0.041	0.4320	45	523
Diameter of super heater tube decrease	0.038	0.4320	45	573

VI. CONCLUSION

Experimental & CFD results are approaching to each other with deviations of less than 10%.

For existing super heater the heat transfer decreases along the length of a super heater pipe, and temperature range, surface Nusselt number is also same at all sections of a super heater pipe. Thus the super heater length can be reduced to avoid thermal losses as well as financial losses.

The total number of super heater pipes is decreased by 5 then steam mass flow rate increases in the super heater tube so that average Nusselt number increases by 10.02%.

The heat transfer increases and temperature decreases which assists to save the superheater from overheating. Turbulent kinetic energy at bending interior is increased by 19.06%, pressure drop is increased by 26.86 %.

The mass flow rate is increased by 12.6% then Pressure drop increases by only 2.52%.Average Nusselt number decreases by 3.89% and turbulent kinetic energy at bending interior is increases by 27.95%.

Surface Nusselt number decreases along the length of superheater at the last section. Velocity is more at bending section of superheater and pressure decreases at the same point.

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