Numerical analysis of flow through a super heater for enhancement in heat transfer characteristics.

[1]Prashant Kumkale, [2]Dr.C.R.Sonawane

[1]PG Student, [2]Associate Professor

[1,2]Mechanical Engineering Department,

[1,2]Pimpri Chinchwad College of Engineering, Pune, India

***Abstract*—Boiler is a metal container in which a liquid is heated till it changes to vapor or high temperature liquid. Heat supplied in boilers by means of radiation, convection and conduction. There are mainly two type's boiler fire tube boilers and water tube boilers, here analyzed water tube boiler. It is very essential to study and optimize the heat transferring mechanism as well as their characteristics to study and control the various thermal losses. In this paper internal flow analysis of a super heater is done to study heat transfer characteristics of super heater of a boiler using a CFD (ANSYS-FLUENT) package. The CFD analysis provided fluid velocity, pressure, temperature, wall fluxes and especially we have concentrate on pressure drop from inlet to outlet of the super heater of a boiler. The Computational Fluid Dynamics (CFD) approach utilized here to solve many boiler problems such as pressure drop, heat losses and parametric study of super heater analysis helped to study the possibilities of enhancement in heat transfer characteristics.**

***Index Terms*—CFD, Wall fluxes. Introduction**

The boiler is the main device of power plant which generates steam by efficient burning of available fuels used to generation of power. The super heater can be treated as the heart of any boiler system, the main duty of which is to supply desired amount of steam regularly at rated temperature and pressure. Super heater is mainly a heat exchanger in which heat is transferred from furnace gas to the steam. Due to improper heat transfer between steam and furnace gas leads to problems of heating. Reduced performance, repetitive failures in boiler components are common problems related to any type of boiler system. Super heater tube failure is very common issue in boilers. In this investigation, we have done CFD analysis of super heater flow to study thermal parameter, to investigate the enhancement in heat transfer characteristics.

Temperature distribution in a water tube boiler performs detailed efficiency testing and simulation of thermal flow inside an industrial boiler. The analysis of the temperature distribution for every location inside the domain is conducted by setting constant temperature, and varying parameters such as mass flow rate of steam, steam inlet temperature and scale thickness. The commercial CFD software employed a control volume based technique to convert the governing equations which were solved numerically using the implicit method. 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. If we increase the mass flow rate of steam through the boiler tube causes the decrease in temperature in the inner tube wall [5]. Computer simulation has been employed to understand the thermal flow in the boiler to resolve the operational problem and search for optimal solution. The thermal flow behavior inside the boiler was studied to make the enhancement in heat transfer characteristics and minimize the thermal losses. The study performs a detailed simulation of combustion and thermal flow behavior inside the industrial boiler.

Actual Working Conditions

Fig.1 Actual photograph of Steam drums of a super heater

Fig.2 Actual photograph Super heater tubes of a boiler

The existing super heater of a boiler is made up of by Walchandnagar Industries Ltd. and assembled by Hi-Tech Engineering Corporations for the Shrinath Mhaskoba Sakhar karkhana Ltd. Patethan Tal: Daund ,Dist:Pune.This plant has capacity of 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 as shown in the figure 1. and there is separator in the drum so that water and steam is separated, below 300 ° steam is reheat and the only above 300 ° 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 number of tubes , that's why we have consider single tube for the analysis.

Table 1 Actual working Parameter

Working Fluid Parameter	**Value**
Inlet Mass flow Rate(single)	0.4320 Kg/s
Inlet Temperature	573 K
Outlet Pressure	40 Kg/cm^2
Constant Wall Temperature	873 K
Specific heat of steam(C_p)	2916.19 J/Kg-K
Thermal conductivity of steam(K)	0.05194 W/m-k
Density of Steam(ρ)	18.46 Kg/m3
Dynamic Viscosity of Steam (μ)	1.985e-5
Total length of Super heater pipe	28.07 m
Inner diameter of a super heater pipe	0.041 m
Number of Super heater Pipe from the steam drum	45
Total heating Surface Area of Super heater	160 m^2

III Computational Details

To investigation the turbulent flow in the super heater pipe of a boiler, K-ϵ model is employed in this study. In the present study ,the finite volume modeling was conducted by the simulation Fluent 14.0.Pressure and velocity field are linked by semi implicit method for pressure linked equations SIMPLE algorithm.

Governing Equations

Continuity equation

$$\frac{D\rho}{Dt} + \rho\nabla . V = 0 \qquad (1)$$

Momentum Equations

X Component:

$$\rho\frac{Du}{Dt} = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \qquad (2.1)$$

Y Component:

$$\rho\frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f_y \qquad (2.2)$$

Z Component:

$$\rho\frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \qquad (2.3)$$

Energy Equation:

$$\rho\frac{D}{Dt}(e + \frac{V^2}{2}) = \rho\dot{q} + \frac{\partial}{\partial x}(k\frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(k\frac{\partial T}{\partial y}) + \frac{\partial}{\partial z}(k\frac{\partial T}{\partial z}) - \frac{\partial}{\partial x}(up) - \frac{\partial}{\partial y}(vp) - \frac{\partial}{\partial z}(wp) + \frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{yx})}{\partial y} + \frac{\partial(u\tau_{zx})}{\partial z} + \frac{\partial(v\tau_{xy})}{\partial x} + \frac{\partial(v\tau_{yy})}{\partial y} + \frac{\partial(v\tau_{zy})}{\partial z} + \frac{\partial(w\tau_{xz})}{\partial x} + \frac{\partial(w\tau_{yz})}{\partial y} + \frac{\partial(w\tau_{zz})}{\partial z} + \rho f.V \qquad (3)$$

Turbulent kinetic energy k equation:

$$\frac{\partial}{\partial x_j}(\rho u_j k) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + \Gamma - \rho\varepsilon \qquad (4)$$

Γ indicated production rate.

Rate of energy dissipation equation:

$$\frac{\partial}{\partial x_j}(\rho u_j \varepsilon) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + c_1\Gamma\varepsilon - c_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}} \qquad (5)$$

where Γ represents the production rate of k and is calculated by

$$\Gamma = -\overline{u_i u_j}(\partial u_i/\partial x_j) = \frac{\mu_t}{\rho}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j} \qquad (6)$$

$$\mu_t = \rho C_m\frac{k^2}{\varepsilon} \qquad (7)$$

Boundary conditions

The numerical simulations in this study have been performed based on some assumptions which were also the assumptions of other researchers while studying the super heater flow analysis. Following are some of the assumptions on which the current study is based.

- The fluid is assumed to be incompressible with constant thermal physical properties and the flow is assumed to be three dimensional, turbulent, steady and non-rotating. 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.
- A pressure outlet condition is assumed at the outlet.
- A turbulence intensity level of 1% is assumed for the flow.

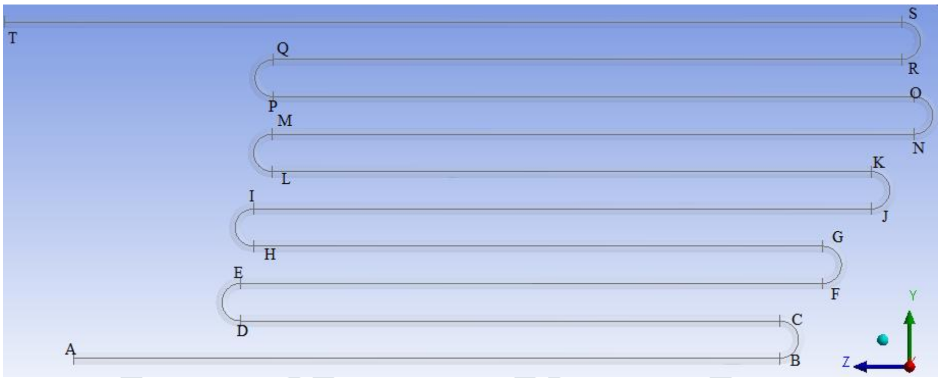


Fig.3 Numerical Model in this study

Here we divide geometry in 19 parts to study the various thermal parameters in the different parts of the super heater pipe as shown in the figure, the fluid flow from inlet to the outlet. Here we drawn the line inside the super heater geometry at the center and measure the temperature and pressure at the various parts in the super heater pipe , measure the pressure, temperature and drawn the curves for the section ST .

IV Result and Discussion

Pressure drop from inlet to outlet

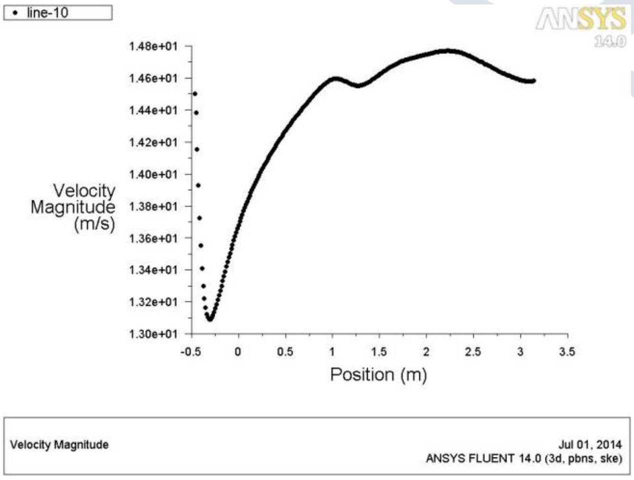
$\Delta P = f\,\frac{\rho v^2}{2D}(x_2\text{-}x_1)$ (8)

$(x_2\text{-}x_1)$ = Length of pipe

Friction Factor

$f = (0.790 \ln \text{Re} - 1.64)^{-2}$ (9)

For $3000 \leq \text{Re} \leq 5*10^6$



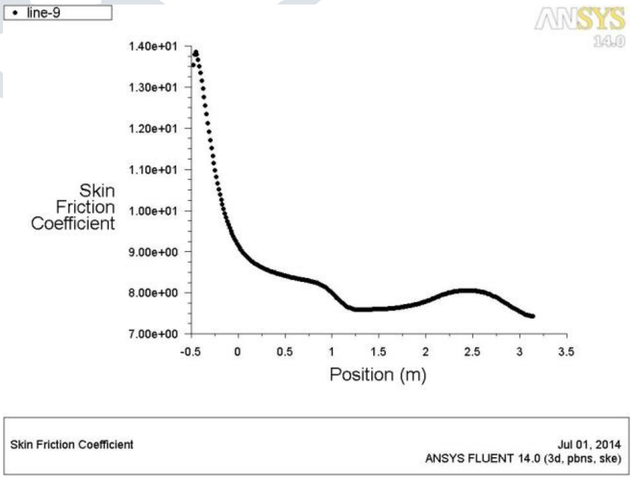
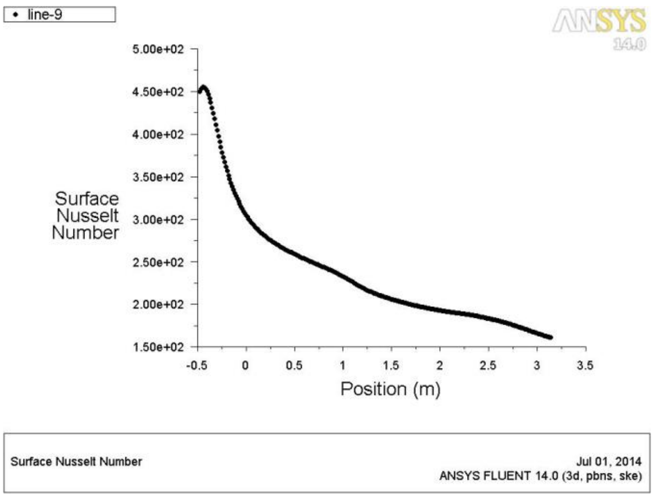


Fig.5 Velocity plot for Super heater Section ST **Fig.6 Skin friction coefficient plot for Super heater Section ST**



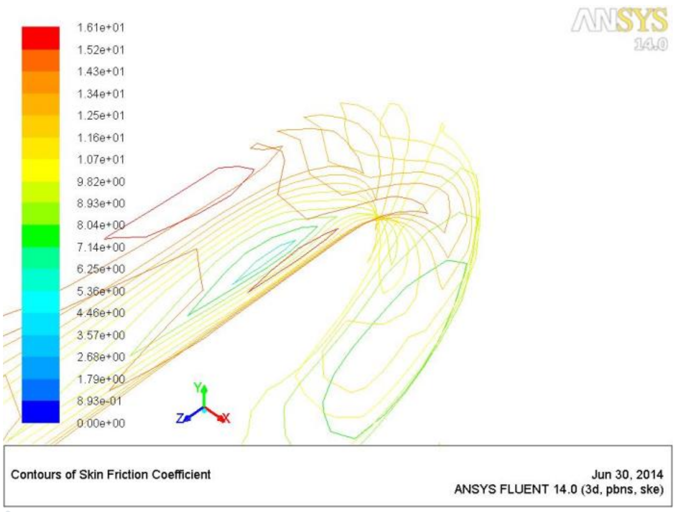
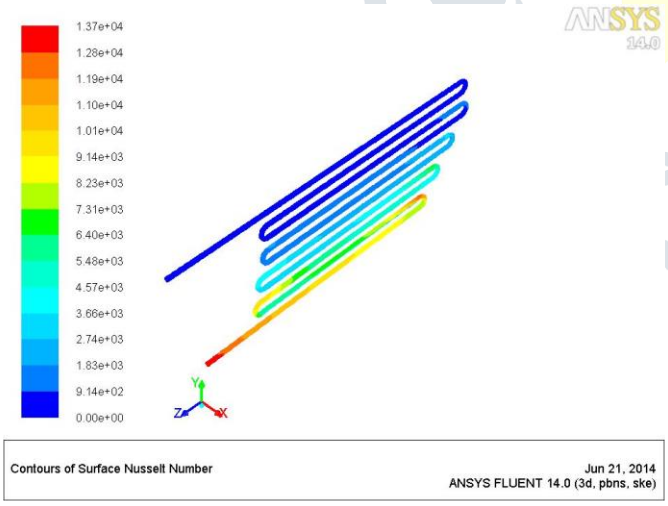


Fig.5 Nusselt Number plot for Super heater Section S

Fig.6 contours of Skin friction coefficient for Super heater Section ST

The velocity is plotted at the centre line of the super heater section ST from this graph it is observed that the velocity is increased along the length of the super heater then slightly decreased. Velocity is high at bending section of super heater pipe. Skin friction coefficient is plotted along the super heater wall at the section ST from this graph it is observed that skin friction coefficient decreases along the length at the last section ST. Surface nusselt number is plotted along the super heater wall at the section ST from this graph it is observed that skin friction coefficient decreases along the length of super heater at the last section ST. Temperature near the U-tube bend found more than the another part of the super heater. 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 ° Celsius. From the contour it is observed that turbulent kinetic energy is same at inlet and outlet of the super heater pipe, but high turbulence occurs at U-turn bending of the super heater pipe.



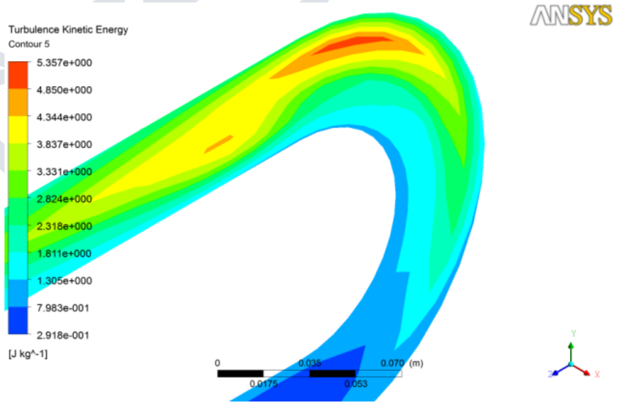


Fig.7 Contour for nusselt number for Super heater Section ST Fig.8 contour for Turbulent Kinetic Energy at bend section

Result comparisons:

Table 2 Result Comparison

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	158.75W/m^2K	155.67W/m^2K	1.93 %

The comparison between Experimental results and CFD results are shown in table it is found that results are close to each other.

V Parametric Study

In this paper our aim is to enhance the heat transfer characteristics of the super heater of a boiler so that we try to change some parameter in the existing super heater pipe to study the various results for enhancement in the heat transfer characteristics.

Actual Parametric Conditions

Table 3 Parametric study

Conditions /Parameter	Diameter (m)	Mass flow rate (kg/S)	No. of tubes Consider	Temperature Inlet (K)
1 Existing Super heater	0.041	0.4320	45	573
2 Mass flow rate increases	0.041	0.5	45	573
3 Diameter of Super heater tube increase	0.045	0.4320	45	573
4 Mass flow rate decrease	0.041	0.4012	45	573
5 Total number of super heater tubes decreases	0.041	0.4861	40	573
6 Inlet Temperature decreases	0.041	0.4320	45	523
7 Diameter of Super heater tube decrease	0.038	0.4320	45	573

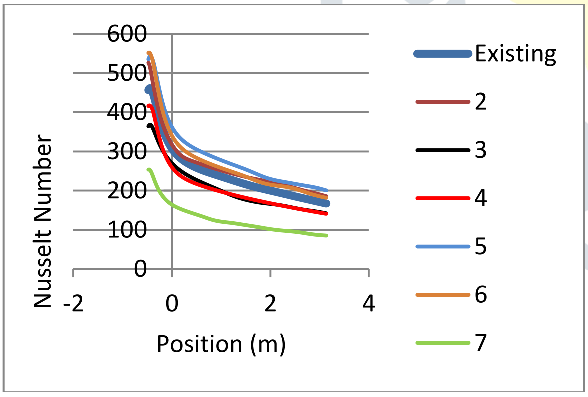


Fig.9 Nusselt Number comparisons super heater section ST

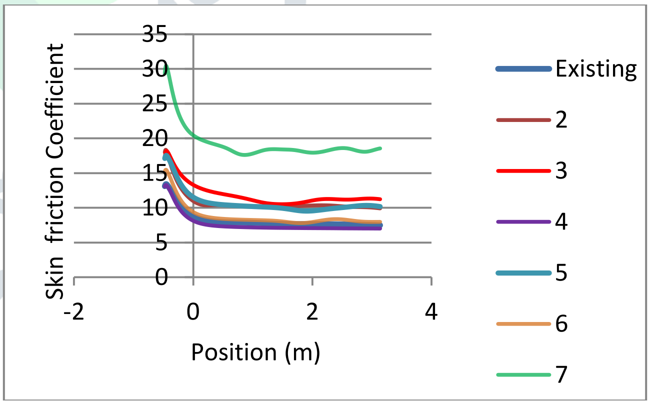
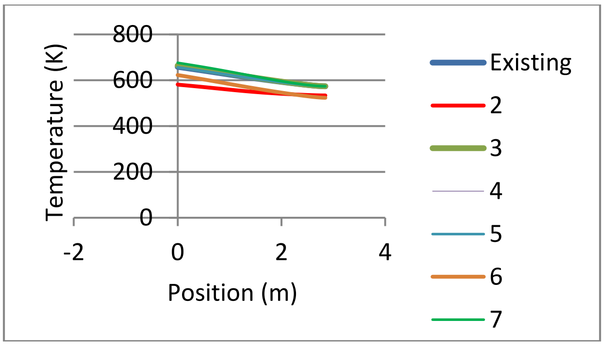


Fig.10 Skin friction coefficient comparisons super heater section ST



Condition	**Pressure drop(pa)**
1 Existing Super heater	22198.3
2 Mass flow rate increases	22773.5
3 Diameter of Super heater tube increase	29501.8
4 Mass flow rate decrease	20767.5
5 Total number of super heater tubes decreases	29544.5
6 Inlet Temperature decreases	23879
7 Diameter of Super heater tube decrease	61223.3

Fig.11 Temperature comparisons super heater section ST **Table 3 Pressure drop result**

From above result it is observed that if the diameter of super heater decrease then pressure drop increases also if mass flow rate decrease then pressure drop also decrease. If the total number of pipe decreases then pressure drop increases because mass flow rate increase. If the mass flow rate increases the 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 super heater increases then Nusselt number also increases. If the diameter decrease then skin friction coefficient along the wall of super heater increases. If the mass flow rate decrease, skin friction coefficient along the wall of super heater decrease. The diameter of super heater tube increases, the heat transfer also increase. It is evident that the mass flow rate strongly influences the temperature distribution of the water tube boiler. 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 higher steam inlet temperature increases thermal efficiency but operating boiler with higher temperature has some disadvantages . Higher operating temperature can also increase scale growth.

VI Conclusion

From above results and study it is concluded that

1. For existing super heater the heat transfer decreases along the length of a super heater pipe, and temperature range, surface Nusselts number is also same at sections OP ,QR and ST of a super heater pipe. Thus the super heater length can be reduced to avoid thermal losses as well as financial losses.
2. If the mass flow rate of steam in super heater is decreased then temperature of the steam inside super heater tube increases.
3. If the total number of super heater pipes is decreased by 5 then mass flow rate increases in the tube so that average Nusselt number increases by 10.97%. The heat transfer increases and temperature decreases which assists to save the super heater from overheating. Turbulent kinetic energy at bending interior is increased by 18.06%, pressure drop is increased by 24.86 %.
4. If the mass flow rate is increased by 13.6% 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 28.95%.

VI Acknowledgment

It gives me great pleasure to express my deep gratitude to my project guide Dr. C. R.Sonawane for his support and help from time to time during this work. It is my pleasure to acknowledge deep sense of gratitude to Mr. Nagesh Bhujbal chief Engineer Shrinath Mhaskoba Sakhar Karkhana Ltd. for their great support and encouragement in project work. I would like to thank Asst. Prof. Nitin Chavan, PG Moze College of Engineering, Pune for their valuable cooperation during my paper work.

References

[1] Raja Saripalli, "Simulation Of Combustion And Thermal Flow in an Industrial Boiler" , ESLIE-05-05-42 , Proceedings of the Twenty-Seventh Industrial Energy Technology Conference, New Orleans, LA, May 10-13, 2005
[2] Rahimi Masoud, Abbas Khoshhal and Syed Mehdi Shariati, (2006) CFD modeling of boiler tubes rupture. Journal of Applied Thermal Engineering, 26, 2192-2200.
[3] J.S. Jayakumar , "CFD analysis of single-phase flows inside helically coiled tubes " Elsevier Ltd., Computers and Chemical Engineering 34 (2010) 430–446 February 2009.
[4] Ajay N. Ingale,"CFD Analysis of Super heater in View of Boiler Tube Leakage", International Journal of Engineering and Innovative Technology (IJEIT) Volume 1, March 2012 ISSN: 2277-3754.
[5] Shaji kumar K.R , "An Investigation on Tube Temperature Distribution in a Water Tube Boiler" IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) *ISSN: 2278-1684* Volume 2 (Sep-Oct. 2012), pp 45-50.
[6] Shahida Begum, "Analysis of End Crack in Boiler Tube'' Advanced Materials Research Vol. 576 (2012) pp 749-752.
[7] Bingzhi Li, "CFD investigation of slagging on a super-heater tube in a kraft recovery boiler" Fuel Processing Technology Volume 105, January 2013, pp 149–153.
[8] Raquel Antunes Hess, "Analysis of Heat Transfer and overheating failures associated with wall temperatures in Steam Superheaters",22nd International Congress of Mechanical Engineering (COBEM 2013) pp 3-7.
[9] Amit N Parit , Tadamalle A. P. and Mrs. V. Ramaswamy "Failure Investigation of Secondary Super Heater using CFD/CAE Technique",IJERT Vol. 2 October – 2013 ISSN: 2278-0181.
[10] Prashant M Khanorkar , "Cfd Analysis of Natural Convection FlowThrough Vertical Pipe" Int. J. Mech. Eng. & Rob. Res. 2013 ISSN 2278 – 0149 ,vol. 2, No. 3.
[11] Raja Saripally, Ting Wang and Benjamin Day. (2005) Simulation of combustion and thermal flow in an industrial boiler, Proceedings of 27th Industrial Energy Technology Conference, New Orleans, Louisiana.
[12] A. Rahmani , "Assessment of boiler tubes overheating mechanisms during a postulated loss of feedwater accident", Applied Thermal Engineering 29 (2009) 501–508.
[13] Dr T C Mohankumar, "CFD Studies on Multi Lead Rifled [MLR] Boiler Tubes", *Nice Thomachan et al. Int. Journal of Engineering Research and Applications ,Vol. 3, Sep-Oct 2013, pp.24-26*
[14] Atul Shivakar Tambi ,"Numerical Analysis Of Solid Phase In A Circulating Fluidized Bed Boiler" , S.R.M. Engineering College, Kattankulathur Anna University: Chennai 600 025 May 2006.

[15] Qaiser Abbas, "Numerical Simulation and Experimental Verification of Air Flow through a Heated Pipe", International Journal of Mechanical & Mechatronics Engineering ,IJMME-IJENS April 2010 vol:10 No:02.
[16] Hardeep Singh, "Thermal-Structural analysis of High Pressure Super heater 1 of a Heat Recovery Steam Generator", Arizona State University August 2012.
[17] Nicholas J. Mulvany, "Steady-State Evaluation of 'Two-Equation' RANS (Reynolds-averaged Navier-Stokes) Turbulence Models for High-Reynolds Number Hydrodynamic Flow Simulations ." ,DSTO Platform Sciences Laboratory 506 Lorimer St. Fishermans Bend,Victoria 3207 Australia.
[18] Louise K.C. Axelsson , "Modelling Heat Transfer in the Cooling Pass of a Refuse-Fired Fluidised Bed Combustor" Louise K.C. Axelsson, 2012. Technical Report No. T2012-381.
[19] A. Khoshhal , "CFD investigation on the effect of air temperature on air blowing cooling system for preventing tube rupture" , International Communications in Heat and Mass Transfer 36 (2009) 750–756.
[20] Ang Wei Bing, "Development Of Iterative Analytical Procedure For Boiler Tube Analysis In Matlab" , Universiti Tunku Abdul Rahman ,April 2013.
[21] Anna Lundborg KTH, " Simulation of the flue gas flow through the superheater in a recovery boiler " Sodahuskommittén 2006.
[22] J. P. Hollman, "Heat Transfer", McGraw-Hill, New York, 1985.
[23] Fluent User's Guide by Fluent Inc.