Parametric Study of Bagasse Boiler Superheater for Heat Transfer Improvement using CFD

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Abstract-*In most of the process industries, boiler is an essential unit to generate steam for power generation. The heat may be supplied in boiler by means of conduction, convection and radiation. Various devices in the boiler system like economizer, air preheater and superheater etc. are used to recover heat from furnace gases. Superheater is an integral part of the boiler which is placed in the path of hot flue gases from furnace. The heat transfer and fluid flow characteristics of the superheater will help to study and control the various thermal losses occurring at boiler section. There are various heat losses occurring in the boiler during the working that affects the performance of the boiler and hence decrease its efficiency and effectiveness. The objective of this investigation is to compare the CFD results with experimental results, to perform a parametric study of super heater to find feasible solution for enhancement in heat transfer characteristics in the superheater. It was done varying different working parameters of the superheater. It was found that if the total number of super heater tubes is decreased by 5 then steam mass flow rate increases in super heater tube, then Nusselt number is found to be increases by 10.6% indicating heat transfer increases ultimately temperature decreases which assists to save the superheater from overheating. Turbulent kinetic energy at bending interior is increased by 18.26%, pressure drop is increased by 29.95 % and if the mass flow rate is increased by 13.6% then pressure drop increases by only 2.32%. Average Nusselt number decreases by 3.49% and turbulent kinetic energy at bending interior is increases by 28.83%.*

Keywords-CFD analysis, Superheater tubes, failure, ansys fluent

I. INTRODUCTION

Boiler is an essential unit to generate steam for power generation for most of the process industries. The heat in the boiler can be supplied through conduction, convection and radiation. Various devices in the boiler system like economizer, air preheater, superheater etc. are used to recover heat from furnace gases. Superheater is an integral part of the boiler which is placed in the path of hot flue gases from furnace. The heat recovered from the flue gases is used in superheating the steam before entering into the turbine. The superheater is directly exposed to a large amount of heat. Hence it is very essential to study and optimize the heat transfer mechanism occurring at super-heater section. The heat transfer and fluid flow characteristics of the super-heater will help to study and control the various thermal losses occurring at boiler section. 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. There are various heat losses occurring in the boiler during the working that affects the performance of the boiler and hence decrease its efficiency and effectiveness

Masoud Rahimi et al. [1] studied the reason for tubes damage in the superheater of plant. The boiler was meshed into almost 2,000,000 tetrahedral control volumes and the standard k–e turbulence model and the Rosseland radiation model were used in the model. J. S. Jayakumar and Tide P. S [6] reported that heat transfer in a helical coil is higher than that in a corresponding straight pipe

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 CFD tool can be used for control volume based technique to modify the governing equations which were solved numerically using the implicit method. The temperature distribution in the boiler tube is affected by many parameters like steam temperature, steam mass flow rate and feed water pressure and temperature. Increase in steam mass flow rate inside boiler tube causes to decrease in temperature in the inner tube wall [7]. 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 behaviour 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 behaviour inside the industrial boiler.

The existing superheater of boiler is made up of Texmaco Ltd. Kolkatta for Sahyadri Sahakari Sakhar Kharkhana Ltd. Situated in Yeshwantnagar, Karad Dist. Satara. This plant has capacity of one boiler as 70 tons/hr. The heated water and the steam from heating pipe is entered into the steam drum. There is a separator which separate the steam and water. The steam which is having a temperature below 573°K sent back to reheater for reheating purpose, only the steam that is having temperature above 573K is given to superheater in which the steam gets superheated due to transfer of heat between superheater and flue gas. The arrangement of superheater tubes inside boiler is shown in below figure 1.There are total 45 number of identical superheater tubes and the 70 tons/hour. The steam flow is divided equally throughout the tubes. As in this case due to symmetricity of the superheater tubes only a single tube is considered for further study and simulation. The boundary conditions are given according to flow inside single tube.

Figure: 1 Actual Photograph of Superheater inside Boiler

Table 1: Operating Parameters

Working Properties	Value
Inner diameter of super heater pipe	0.041 m
Specific heat of steam	2916.19 J/kg-K
Inlet Temperature	573 K
Constant Wall temperature	873 K
Outlet Pressure	40 kg/cm^2
Inlet mass flow rate	0.4320 kg/s
Thermal conductivity of steam	0.05194 W/kg-K
Density of steam	18.46 kg/m^3
Number of super heater pipe from the steam drum	45
Total heating surface area of super heater	160 m^2
Total length of super heater pipe	28.07 m

II. COMPUTATIONAL MODEL

In the present investigation, the geometric model was built in CATIA V5 and then the geometry was imported in ANSYS 16.0 for simulating the flow. Fluent 16 was used as a solver SIMPLE algorithm was used for pressure linked equation. The geometry is meshed with 638129 elements. To get the optimal results fine meshing is done near the walls of superheater. To investigate the turbulent flow behaviour inside the superheater tube, standard K-εpsilon model is used for simulation and near wall treatment is given.

a. Governing Equations:

Following equations are used for the simulating the flow inside tubes.

i. Continuity Equation

$$\frac{D\rho}{Dt} + \rho\Delta V = 0$$

ii. Momentum Equation

X- Component

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

Y- Component

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

Z- Component

$$\rho\frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + \frac{\partial\tau_{zx}}{\partial x} + \frac{\partial\tau_{zy}}{\partial y} + \frac{\partial\tau_{zz}}{\partial z} + \rho f_z$$

iii. Energy Equation

$$\begin{aligned}\rho\frac{D}{Dt}\left(e + \frac{v^2}{2}\right) = {} & \rho q + \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) \\ & - \frac{\partial}{\partial x}(up) - \frac{\partial}{\partial y}(vp) - \frac{\partial}{\partial z}(wp) + \frac{\partial(u\tau_{xx})}{\partial x} \\ & + \frac{\partial(u\tau_{yx})}{\partial y} + \frac{\partial(u\tau_{zx})}{\partial z} + \frac{\partial(u\tau_{xy})}{\partial x} + \frac{\partial(u\tau_{yy})}{\partial y} \\ & + \frac{\partial(u\tau_{zy})}{\partial z} + \frac{\partial(u\tau_{xz})}{\partial x} + \frac{\partial(u\tau_{yz})}{\partial y} + \frac{\partial(u\tau_{zz})}{\partial z}\end{aligned}$$

b. Boundary Conditions:

While doing simulation of flow inside the tubes, some assumptions are made. These assumptions are made by different researchers during analysis. These assumptions are,

1. The steam is considered as incompressible.
2. Constant temperature is specified on the wall of super heater tube.
3. No slip velocity conditions are given at all walls.
4. 1% of turbulence intensity level is considered**.**

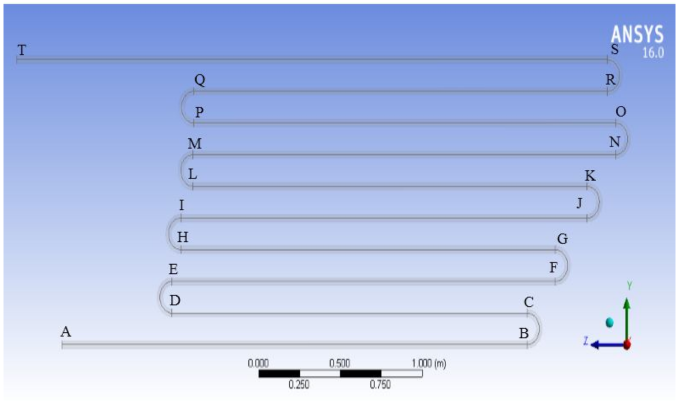

Figure 2: Numerical Model in this study

In this case, the geometric model of superheater is divided into 19 parts to analyse the fluid flow behaviour from inlet to the outlet and to analyse the miscellaneous thermal properties at the different sections of the super heater tube as shown in the figure 2. Centre line is drawn inside the geometric model as shown in figure 2 to measure the pressure and temperature at the various sections in the super heater tubes.

III. RESULTS AND DISCUSSION

Pressure Drop Calculation:

Pressure drop from inlet to outlet is given as

$$\Delta p = f\rho v^2 \frac{(x_2 - x_1)}{(2D)}$$

Where,

$(x_2 - x_1)$ = Length of pipe

Friction factor is given as,

$$f = (0.79 \times \ln(Re) - 1.64)^{-2}$$

Dittos Bolter equation,

$$Nu = 0.023\ Re^{(0.8)}\ Pr^{(0.4)}$$

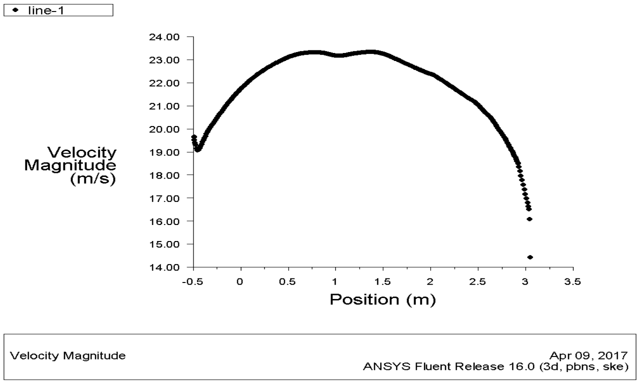

Figure 3: Velocity Magnitude Plot for Superheater Section AB

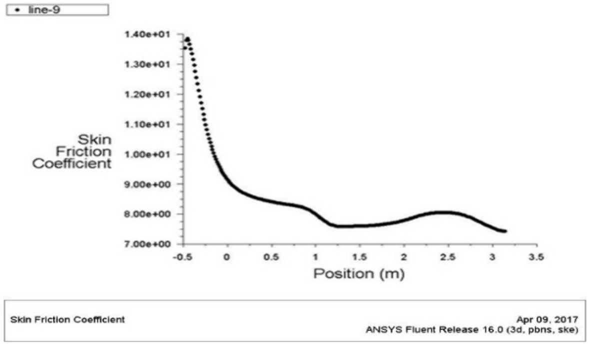

Figure 4: Wall Skin Friction Coefficient Plot for Superheater Section ST

From figure 3 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. There will be an adverse pressure gradient generated from the curvature with an increase in pressure, therefore a decrease in velocity close to the convex wall, and the contrary will occur towards the outer side of the pipe. Skin friction coefficient also high at the bending section of the super heater and decreases along the wall of super heater as shown in figure 4.

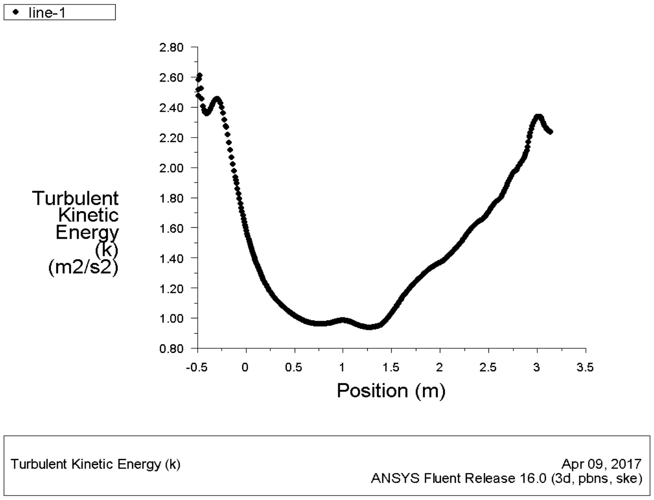

Figure 5: Turbulent Kinetic Energy Plot for Superheater Section ST

The surface nusselt number is decreases from inlet to outlet of super heater wall. It is minimum at the superheater of a wall. At outlet the temperature is increased along the super heater section AB. Temperature along super heater section AB temperature increases from 868K to 871K. Highest temperature occurs at the outlet of super heater that is 871 K.

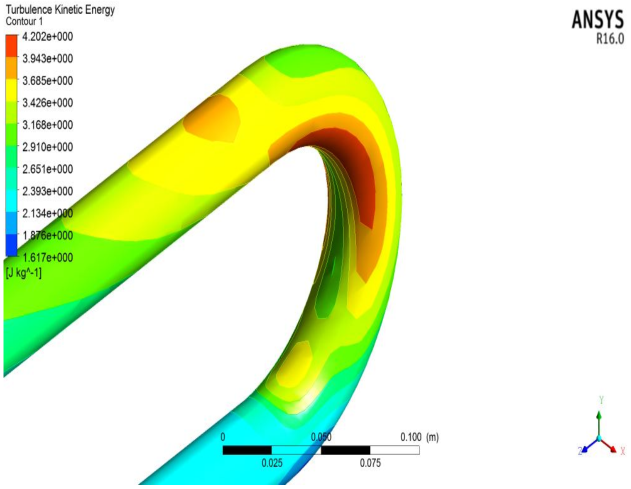

Figure 6: Contour of Turbulent K.E. along interior at the Bending section

Figure 5 and figure 6 shows that turbulent kinetic energy and turbulent dissipation Rate is same at inlet and outlet of the super heater pipe, but high turbulence occurs at U-turn bending of the super heater pipe. Maximum turbulent dissipation is observed at the bending of the super heater pipe.

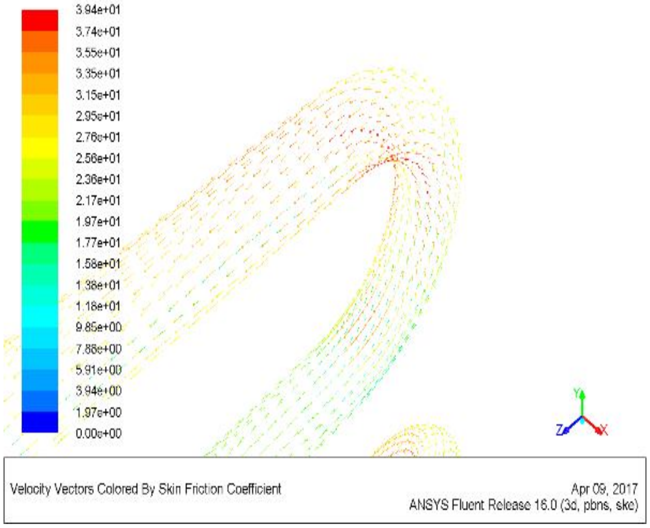

Figure 7: Contour of Velocity Vector of Skin Friction Coefficient along the Bending wall of Superheater

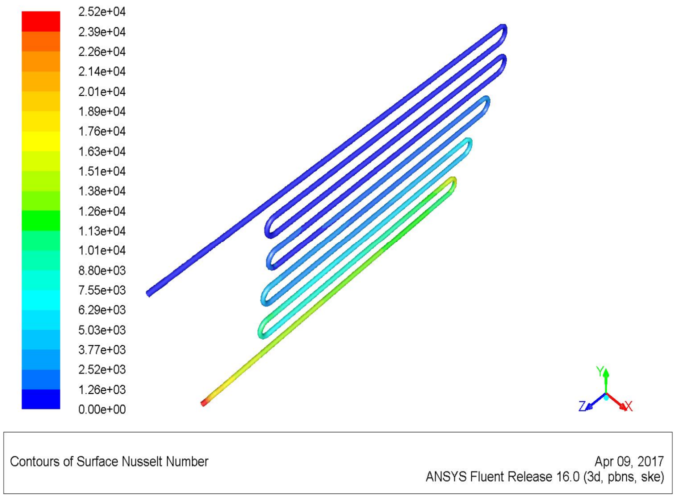

Figure 8: Contours of Surface Nusselt Number

Pressure is found to be 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.

Nusselt number for the super heater wall is high at the inlet then decreases across the length of super heater pipe from inlet to outlet shown in the figure 8. As Nusselt number decreases, heat transfer coefficient (h) also decreases along the wall of super heater. It is estimated that at the end sections of the super heater tubes i.e. at OP, QR and ST Nusselt number is found to be same.

Result Comparison:

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

Parameters	**Experimental**	**CFD**	**Deviations in Result %**
Pressure drop (Pa)	24679.54	24776.2	0.39
Total surface heat flux (W/m^2)	106919.42	112705.2	5.13
Outlet temperature (K)	767	870.73	11.91
Heat transfer coefficient (W/m^2K)	186.595	192.711	3.173

IV. PARAMETRIC STUDY

The aim of present investigations is to enhance the heat transfer characteristics. In view of that various modifications are done to analyse the thermal flow behaviour.

Sr. No.	**Conditions**	**Diameter (mm)**	**Mass Flow Rate (kg/s)**	**No. of tubes**	**Inlet Temperature (K)**
1	**Existing super heater**	41	0.433	45	573
2	**Increase in Mass flow rate**	41	0.5	45	573
3	**Increase in diameter of super heater tube**	45	0.433	45	573
4	**Decrease in mass flow rate**	41	0.4012	45	573
5	**Decrease in Total number of super heater tube**	41	0.4861	40	573
6	**Decrease in inlet temperature**	41	0.433	45	523
7	**Decrease in diameter of super heater tube**	38	0.433	45	573

From figure 10, it is estimated that if the mass flow rate of steam increases then nusselt number increases. If the total number of superheater tubes of decreases then nusselt number and mass flow rate increases. If the diameter of super heater tube increases then nusselt number also increases.

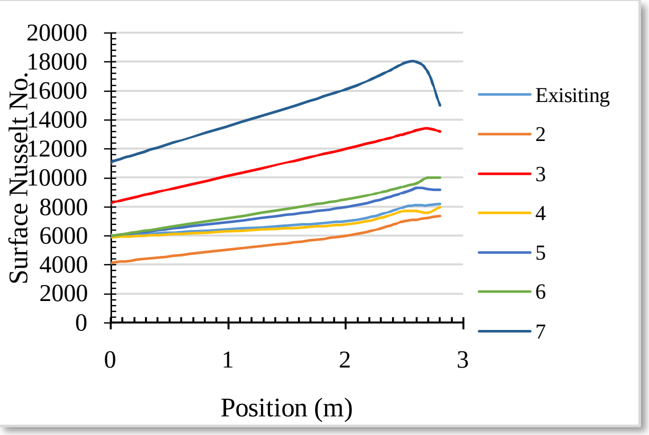

Figure 9: Nusselt Number Comparisons along the Wall of Superheater Section AB

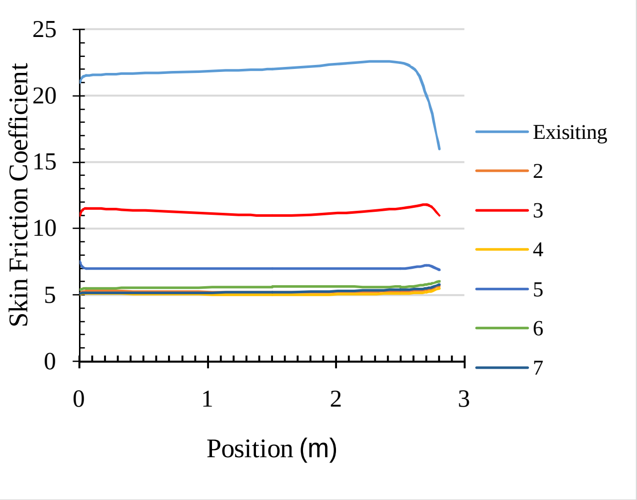

Figure 10: Skin Friction Coefficient Comparisons along the Wall of Superheater Section AB

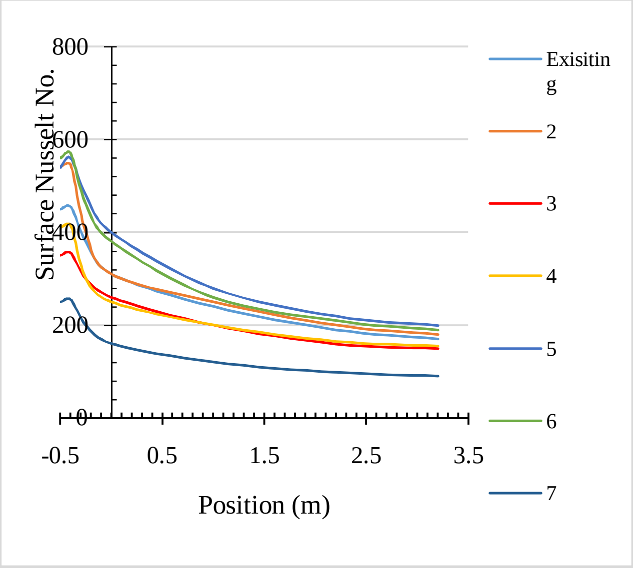

Figure 11: Nusselt Number Comparisons along the Wall of Superheater Section ST

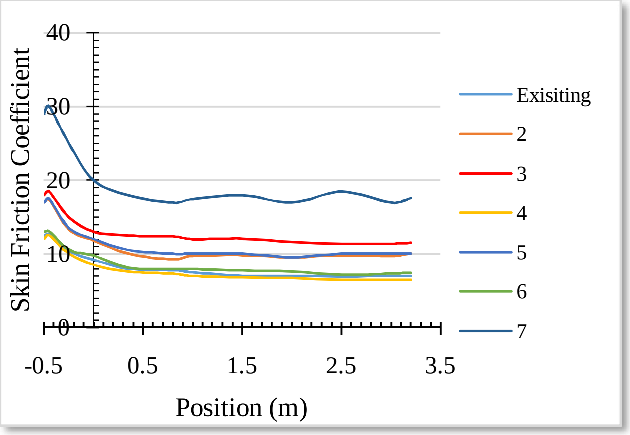

Figure 12: Skin Friction Coefficient Comparisons along the Wall of Superheater Section ST

Sr. No.	**Conditions**	**Pressure drop (pa)**
1	Existing super heater	24776.2
2	Mass flow rate increase	25351.4
3	Diameter of super heater tube increase	32079.7
4	Mass flow rate decrease	23345.4
5	Total number of super heater tube decrease	32122.4
6	Inlet Temperature decrease	26457.4
7	Diameter of super heater tube decrease	63801.2

From above observation it is clear that if the diameter of super heater decrease then pressure drop increases also if mass flow rate decreases then there is decrease in pressure drop. If the total number of superheater decreases then pressure drop is found to be increases because mass flow rate increase. Increasing the superheater tube diameter cause to increase in Nusselt number. Increasing the diameter of tube cause increase in skin friction coefficient at the wall of super heater. If the mass flow rate decreases then skin friction coefficient along the wall of super heater decreases. In case of increase in diameter of super heater tube cause to increase in the heat transfer also.

It is observed that the mass flow rate strongly affect the distribution of temperature in 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 behaviour 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.

V. CONCLUSION

From above results and study it is concluded that

- Temperature of the steam inside superheater tube is found to be increases when mass flow rate is decreased.
- Heat transfer is observed to be decreased throughout the length of existing super heater. Temperature and surface Nusselt number at the end section i.e. OP, QR and ST of a super heater tubes is found to be approximately same. Thus the length of super heater tubes can be reduced to avoid thermal losses and financial losses.
- If the total number of super heater tubes are decreases by 5 due to this the steam mass flow rate increases and average Nusselt number increases by 10.6%. It also enhances heat transfer but temperature decreases which assists to secure the superheater from overheating. Turbulent kinetic energy at interior bending section is increased by 18.26%, pressure drop is increased by 29.95 %.
- If the mass flow rate is increased by 13.8% then Pressure drop increases by 2.32%. The Nusselt number decreases by 3.49% and turbulent kinetic energy at interior bending section is increases by 28.83%.

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