

A Numerical Analysis of Heat Transfer Enhancement in a Boiler Tube

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ABSTRACT: Improving the boiler efficiency has become a wide research interest in the recent past. Boiler tube design has also undergone drastic changes for improving the efficiency of the engine. In this regard boiler tubes with lead rifled tubes have gained more prominence due to its ability to avoid heat loss at walls due to film condensation. So the aim of the present study is to enhance the heat transfer rate of boiler tubes further by using inserts like central helical twisted ribbon and full helical twisted ribbon or circumferential insert.

In this study four different tubes were considered like plain boiler tubes, Lead Rifled boiler tubes, boiler tubes with center helical ribbon and full ribbon tubes. Numerical analysis has been carried out on these tubes using ANSYS CFX. The results are compared with lead rifled tubes which showed a rise in temperatures for center helical ribbon and full ribbon or circumferential inserted tubes. A highest temperature of about 892°K has been obtained at the outlet for full ribbon or circumferential inserted boiler tubes. On average it is found that there is a 20% rise in the temperatures at outlet of the full ribbon boiler tube than MLR.

KEYWORDS: Heat Transfer Enhancement, Boiler tube, Film condensation, Multi Lead Rifled tubes, Central helical Ribbon, Full Ribbon or circumferential inserted boiler tubes.

I. INTRODUCTION

The primary elements of a boiler are the heat transfer surfaces, which transfer the heat from the flue gases to the water/steam circulation. The objective of the boiler designer is to optimize thermal efficiency and economic investment by arranging the heat transfer surfaces and the fuel-burning equipment. Heat transfer surfaces in modern boilers are furnaces, evaporators, super-heaters, economizers and air pre-heaters.

The increasing cost of energy in the past years aroused the need for using more efficient energy systems. This in turn encouraged researches in the field of augmenting heat transfer in heat exchangers. Several Passive and active techniques were recognized for the study of heat transfer enhancement out of which, rifled tubes, Central helically twisted ribbon and Circumferential Full Helical ribbons inserts in boiler tubes are found to be most powerful heat transfer enhancing tools. In this study main geometrical parameters like width, thickness, Number of twists of the inserts, material configuration of the inserted tube and pitch of the ribbon are taken into consideration. The influence of geometric parameters depends upon the operating conditions means operating pressure, temperature, mass flow rate etc. So the optimization of the geometry used for particular operating condition is the important criteria for heat transfer augmentation.

In this study heat transfer of lead rifled, central helically twisted ribbon and circumferential inserts or full helical ribbon inserted tubes are analyzed with operating conditions [1]. In real condition the boiler tubes are plain walled. So the optimized three different geometries of boiler tubes performances are compared with the performance of inner plane walled tube. The analysis of the tube flow was done using ANSYS R15.0 and geometry was modeled using CATIA V5, meshing was done using ICEM CFD. Material properties of steel and water were copied from the data base of ANSYS CFD software.

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Problem Overview and approach:

- By using general plane walled boiler tubes in the water tube boiler for effective steam generation the following problems can be predicted:
 1. Steam film Condensation at inner inner walls of the boiler tube due to this proper heat transfer cannot be Obtained and tube outer walls gets heated up which leads tube failure.
 2. Due to film condensation and uneven tube heating, scaling will be formed at the inner walls of the boiler tube which leads to decrease of the heat transfer rate and efficiency of the boiler.
 3. Due to laminar flow inside the plane boiler tube only normal boiling occurs and its deviates from the Nucleate boiling which leads to the Dry out condition at the inner walls of the boiler tubes.
 4. Due to lack of proper heat transfer Optimum use of energy resources cannot be obtained and tube material also gets wasted up due to uneven heating of tube and slag formation.
- So to improve the performance of heat exchanging devices for reducing material cost and decreasing the difference for heat transfer thereby for reducing external irreversibility, lot of techniques have been used. Among different passive means to increase heat transfer coefficient, twisted tape inserts are promising. The secondary flow (swirl flow) generated by twisted tape effects fluid flow across the tape-partitioned tube, promotes greater mixing and higher heat transfer coefficients
- In order to minimize the dry-out and to increase the pressure drop at the steam boiler furnace in the Thermal Power Plant, inner rifled wall tubes are designed with many spiral grooves cut into the bore and the boiler tubes with twisted tape inserts with different orientations are implemented which prevents film boiling and enables the nucleate boiling for better efficiency of the boiler with minimum tube failure.
- In case of non uniform heat load critical heat fluxes can be reached in the convective zone of the most loaded evaporating tubes which leads to the burnout condition this can be avoided by rifled tubes implementation instead of smooth tubes.

II. RELATED WORK

Literature Review:

The unique characteristics of the boiler to obtain highest efficiency have drawn the attention of many researchers. Apart from active techniques some passive techniques has also been adopted by the researchers to improve the efficiency of the boiler. The passive methods includes usage of additives , inserts etc... In this regard

T C Mohankumar, Nice Thomachan 2013 [1] explained about the merits of multi lead rifled [MLR] tubes in vertical water tube boiler using CFD tool. Heat transfer enhancement of MLR tubes was mainly taken into consideration. Performance of multi lead rifled tube was studied by varying its influencing geometrical parameter like number of rifling, height of rifling, length of pitch of rifling for a particular length. The heat transfer analysis was done at operating conditions of an actual coal fired water tube boiler situated at Apollo Tyres LTD, Chalakudy, India for saturated process steam production. The results showed that the heat transfer increased when compared with existing inner plane wall.

Vincent.H.Wilson, M.Hajee Mohamed [2] studied about the Super Heater Tube Portion which to be affected by High Flue Gas Temperature. The Identified Super Heater Tube Portion to be shielded with SS Plates. The Shield Plate will safe guard the Super Heater Tube where the weak portion has been find out. Providing SS plate Transfer the Heat safe manner to Super Heater Tube. Due to this, the Super Heater Tube Leakage, can be avoided and there is maintenance of Super Heater Tubes, Improve the Power Production without any plant shutdown, subsequently will Improve the Power Plant Income.

Ajay N. Ingale & Vivek C. Pathede [3] analyzed the tube leakage through CFD Modeling considering two temperature, one for steam flowing inside the SH tube and other for temperature of flue gases flowing over the SH tube. Based on the temperature plots they found that the SH tube bend to be exposed to the high temperature region. This may lead to fatigue and cracks near the weld joints of the tube resulting in change in

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shape and cracks near the corners. **Prashant Kumkale [4]** has carried out investigation on super heater tubes through CFD analysis with various temperature plots, and found that velocity is high at SH tube bend and pressure drop more at the tube bend.

Aditya Kumar Pandey [5] conducted flue gas flow distribution on low temperature super heater (LTSH) tube through CFD analysis and found that flue gas flow changes direction as it flows from extended pass to LTSH tube bundles. Extended pass is tapered. Due to this no uniform velocity distribution can occur at the top of LTSH.

Raja Saripally et al. [6] conducted a simulation of thermal flow in an industrial boiler using a CFD package. Computer simulation has been employed to understand the thermal flow in the boiler to resolve the operational problem and search for optimal solution. The combustion and thermal flow behavior inside the boiler is studied to make the boiler more efficient, less emissive and less prone to tube rupture. The study performs a detailed simulation of combustion and thermal flow behavior inside the industrial boiler. Due to excessive heating the rupture of super heater tubes may lead to boiler shutdown, increasing the expenses incurred. 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.

Rahman and Sukahar [7] presented about the Tube Temperature distribution in a water tube boiler through application of finite element method (FEM). The Two-dimensional FEM models were developed and axis-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.

Purbolaksono et al. [8] investigated the Re-Heater Tube Failure through FEM Modeling to find out that main cause of tube failure due to scale formation on internal tube surfaces which will reduce the heat transfer area (HTA) across the Tubes.

From the literature review it is observed that most of the researcher tried to improve the efficiency of the boiler through heat transfer Augmentation by employing many passive techniques like MRL tubes, tubes with different inserts instead of plain walled boiler tubes via experimental setup and by numerical simulation. They have analyzed that heat transfer enhancement can be done by increasing Nusselt No, Reynolds No, friction factor and heat transfer coefficient which in turn depends design parameters like twist ratio, pitch, width and thickness of inserts employed in the boiler tube.

As twist ratio and clearance space decreases turbulence increases and thereby Nusselt No. and friction factor also increases with higher Reynolds no values but due to more friction it causes less mass flow rate. So there is compromise between heat transfer enhancement and mass flow rate due to increased friction. So modified helical middle and full ribbon design with less twist ratio and less frictional drag enables more heat transfer and mass flow rate. Hence the present study is an Endeavour to enhance the heat transfer rate in a boiler tube using helical ribbon type inserts

III. DESIGN AND MODELING

The modeling software tool used to design the Boiler Tube and various inserts is CATIA V5 R20. CATIA is widely used to design and model 2D and 3D objects which are imported to numerical tools to carry out the simulation. The modeling software has a wide range of accessibility and integrated with advanced design tools which make it simple and little time consuming to design various objects for engineering applications.

The tool used to carry out the CFD analysis is ANSYS 15.0 and the solver chosen is CFX. The Continuity, Momentum and Energy equations are the principle equations or laws used in CFD to solve for the required solution. The ANSYS CFX tool is used to discretize the spatial domain using a mesh. A several set of finite volumes are constructed which are subjected to Gauss Divergence theorem which converts volume integrals comprising gradient operators and divergence to surface integrals. The approximation accuracy is a function of mesh spacing and the time step factor of higher order terms in the series expansion. ANSYS CFX uses shape functions and second order

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approximations where the variations in each element such as tetrahedral, hexahedral, pyramid and wedge are described by tri-linear shape functions.

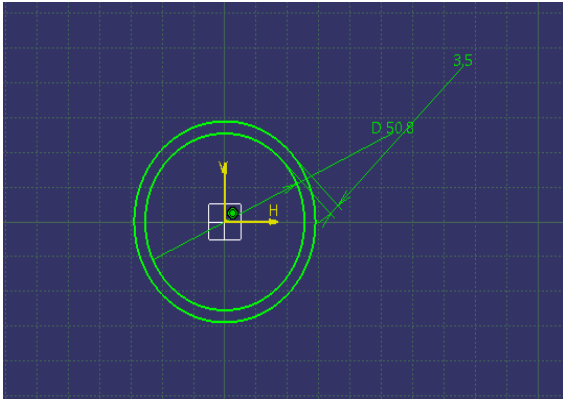


Figure 1 :2D-Front view of plane wall boiler tube

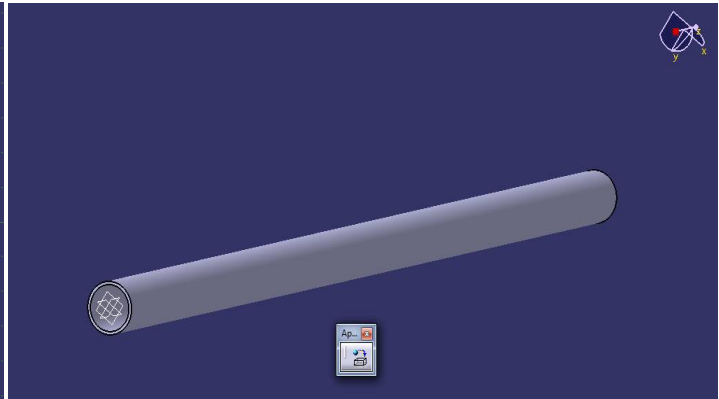


Figure 2 :Generated 3D model of plain boiler tube

In this 3 dimensional CFD study a tube of 50.8 mm outer diameter with a thickness of 3.5 mm is considered and the analysis was done for a length of 1500 mm. The commercial CFD software employs a control volume based technique to convert the governing equations which are solved numerically using the implicit method. In the segregated formulation the governing equations are solved sequentially, as it is segregated from one another.

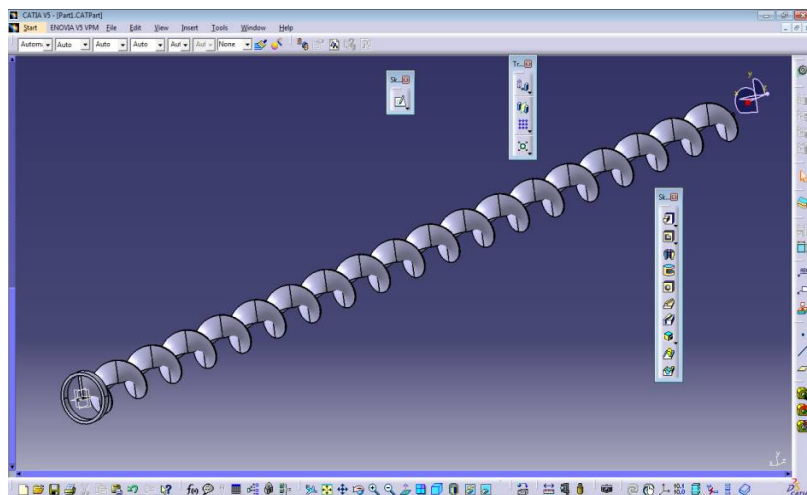


Figure 3 : 3D model of full Helical twisted Ribbon Insert

Parameter	Dimension
Pitch length	80 mm
Height of twist(IR)	25.4 mm

Parameter	Dimension
No of twists	19
Width of Twisted Ribbon	25 mm

IV. MESHING &SIMULATION OF THERMAL FLOW

The most important step in CFD analysis next to modeling is Meshing. Meshing decides the degree of accuracy and time taken for analysis. There are many types of meshes like hex, tetra, staggered, etc., of which Triangular, Hex mesh and tetra mesh are important. Triangular and Hex meshes are mostly used for fluid analysis where tetra meshes are used for solid boundaries. The developed 3D models as shown in the previous sections are imported into the design module

of the workbench. Later on using ICEM CFD the geometries are meshed. As mesh quality decide time taken for analysis and accuracy, on each model grid independent test is conducted. Grid independent test avoids the inappropriate results due to less number of elements or more number of elements.

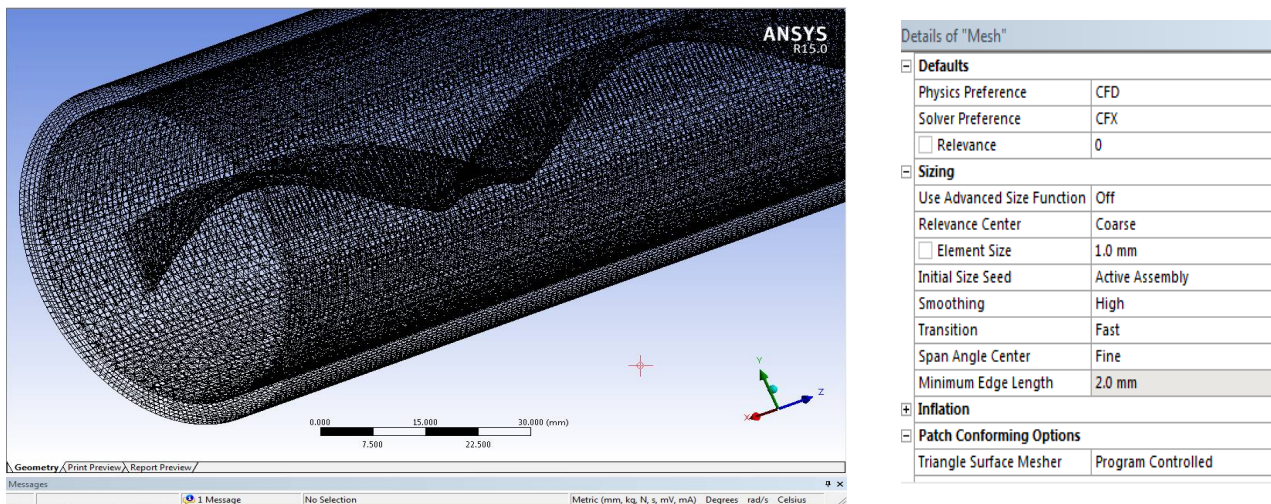


Figure 4: Mesh with course refinement

COMPUTATIONAL DOMAIN WITH BOUNDARY CONDITION:

The flow and thermal variables are defined by the following boundary conditions.

Working pressure : 2157 kPa

Inlet water Temperature : 500 °K

Outer wall Temperature : 1000 °K

Mass flow rate : 0.034 kg/sec

Saturation temperature : 490 °K

The solution convergence is obtained by monitoring the continuity, momentum, energy, turbulence and species equations separately. Interior temperatures of some bodies remain essentially uniform at all times during a heat transfer process. The temperature of such bodies is only a function of time. The heat transfer analysis based on this idealization is called transient heat analysis or lumped heat analysis. ANSYS CFX is used to carry out the transient analysis numerically . The main equations that governs the transient heat transfer in a long cylinders is :

$$\frac{1}{r} \frac{\partial}{\partial x} \left(r \frac{\partial T}{\partial r} \right) = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

The temperature of the flue gas is 1000 K and heat transfer takes place to the water inside the tubes. The temperature of the water inside the tube reaches approximately 550 K. 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. Therefore, effect of these variables is also considered by running a limited number of simulations by using the CFD simulation the result will contains the enhanced heat transfer due to the increased wetted perimeter of the boiler tube and some other effects due to rifling. The main heat transfer enhancement in actual case is due to the increased heat transfer area and the enhanced contact of water to the tube wall. During flow boiling wet steam generated will flow through the water tube, may be in some region steam may in contact with the tube wall, heat absorption capacity of steam is poor when compared with water, so sufficient tube cooling may not take place at that region . In optimized tube geometry there will be a swirling flow and that centrifugal force will separate steam and water, denser water will be taken away to the wall region by keeping less dense steam at the centre region. This effect of optimized geometrical design of boiler tube will make the heat transfer more efficient than ordinary plane boiler tube

V. RESULTS AND DISCUSSIONS

Enhancement in the heat transfer in boiler furnace will reflect in the performance of the boiler. A small increase in the heat transfer of the tube will make huge change in the overall performance of the boiler. The boiler which is studied having 332 vertical tubes arranged from its bed coil to the top of the boiler (steam drum) each tube having a height of 11.58 meters .Sample length is analyzed in the software and the resultant temperature contours at tube outlet and longitudinal tube section are shown below along with plots of Momentum and mass, heat transfer, Turbulence and temperature graph with respective to time step 0-90 seconds.

In the present study transient analysis is carried out for MLR tubes, tubes without inserts, tubes with center helical ribbon and tubes with full ribbon. The accumulated time step considered in the processes is 0-90. The convergence of momentum equation, heat transfer and turbulence equation with time step are shown for various tubes which are considered for analysis are plotted as shown below.

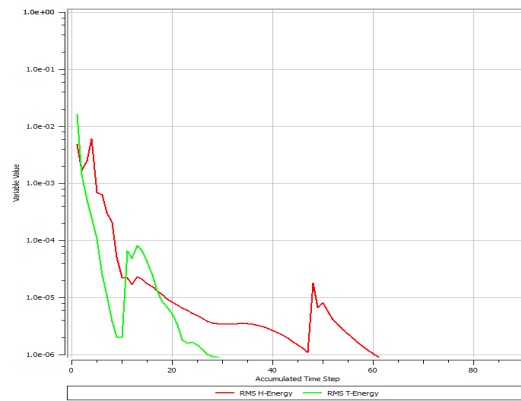
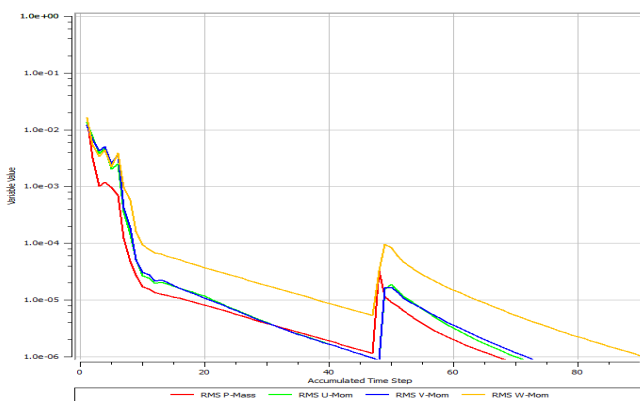


Figure-8: Momentum and Mass V/S Time Step Figure-9: Heat Transfer V/S Time Step

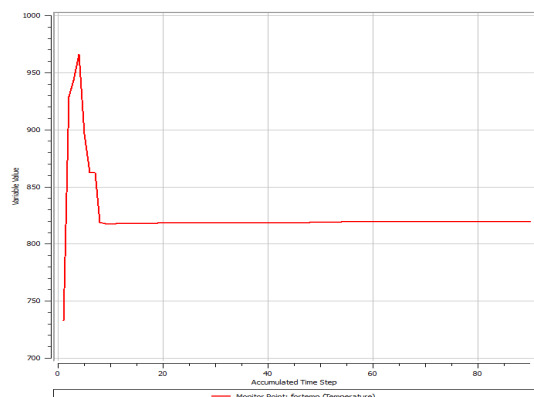
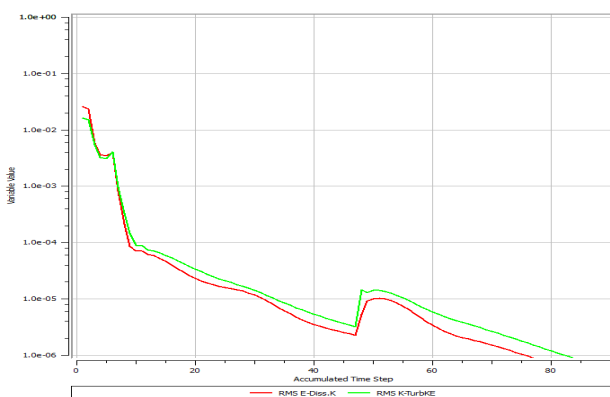


Figure-10: Turbulence V/S Time Step Figure-11: Temperature V/S Time Step

In the above Plots the transient analysis of tubes with full ribbon showed a great convergence of the basic governing equations up to e-6. The temperature plot also showed a similar pattern of initial rise and latter decrease of temperature. The degree of rise in temperature for full ribbon tubes is high while compared with MLR and other tubes in both transient and steady analysis. This is mainly due to the increase in turbulence and resident time of the fluid inside the tubes. The increase in resident time of the fluid will definitely increase the rate of heat transfer.

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The higher the convergence rate the more accurate are the results. A highest temperature of 850⁰K is obtained for helical inserts at the outlet. It can be seen from the temperature plot that, there is a drastic rise in temperature up to 900K and then became a constant. The initial rise of the temperature can be asserted to the turbulence which is drastic while compared with other tubes like MLR and Simple plain tube.

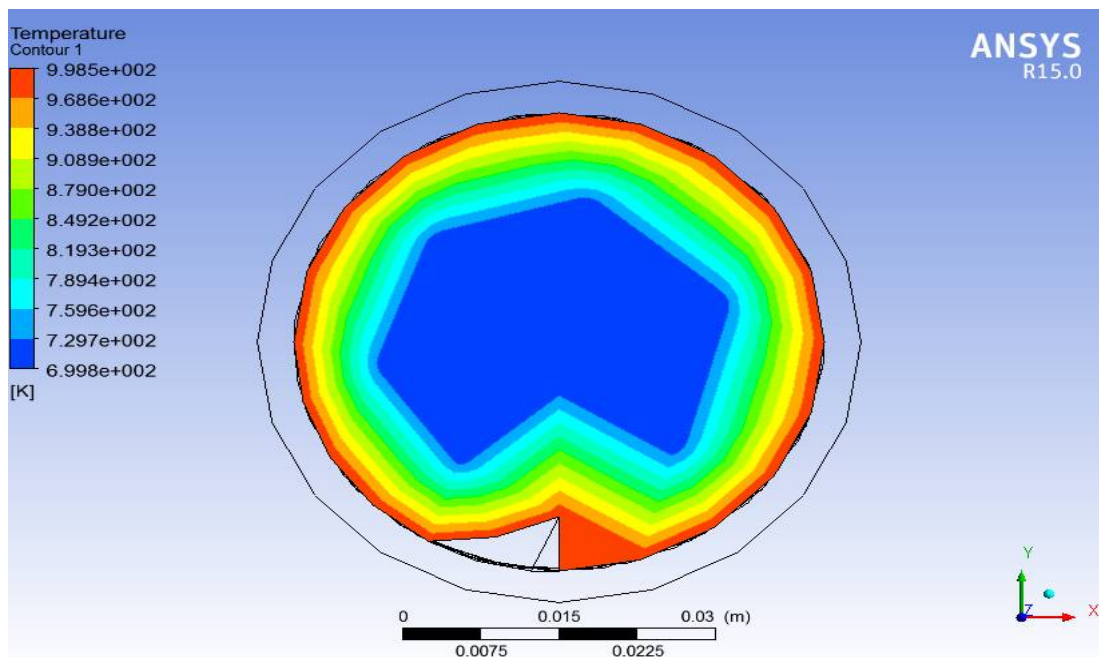


Figure-6 Temperature Contour for full helical ribbon inserted boiler tube at outlet.

The Above Figure-6 shows the profile of temperature distribution inside the full helical ribbon inserted boiler tube. After Simulation the isothermal contours for boiler tube with full Ribbon insert is a non-uniform distribution of thermal contours depicting a strong swirl motion inside the tube. A highest temperature of about 1000⁰K has been recorded at the tubular walls where there is lesser temperature of about 825⁰K in the middle of the tube. Generally in multi-phase flows due to film condensation at tubular wall and due to bubbly flow there is less temperature for the fluid flowing in the middle of the tubes. But with the usage of boiler tubes with full Ribbon inserts, we can effectively overcome the problems of loss of heat transfer due to film condensation. In addition a swirl flow will enhance mixing, residence time and helps in effective heat transfer in the boiler tubes.

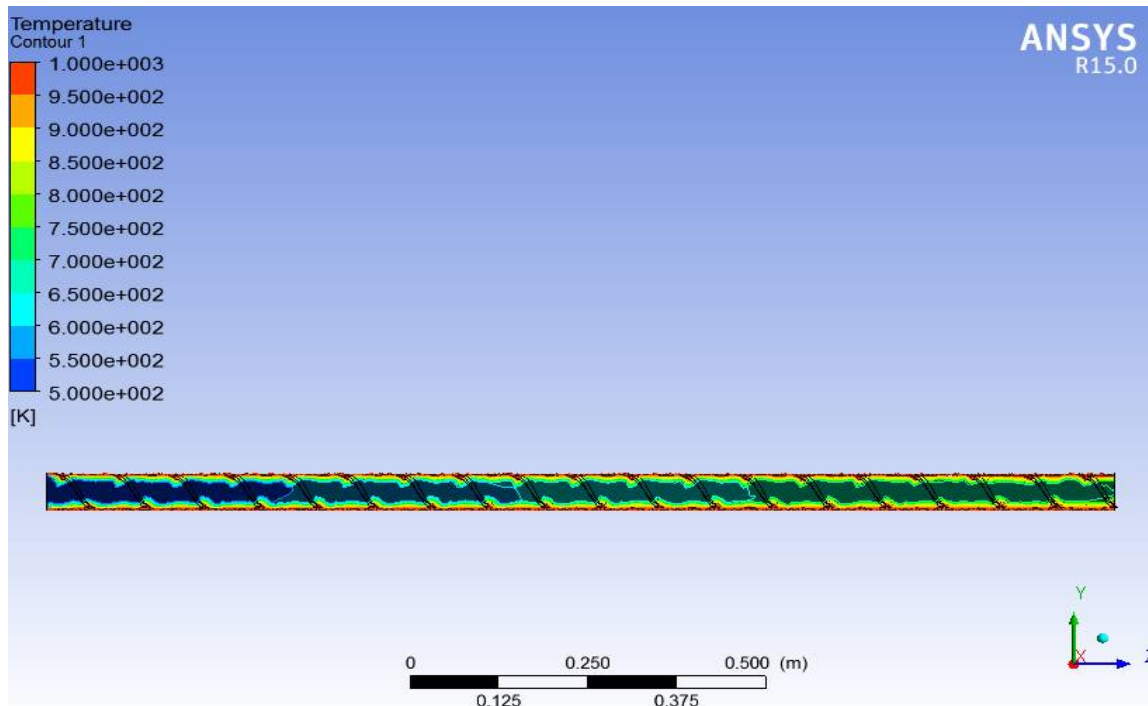


Figure-7 Temperature Contour for full helical ribbon inserted boiler tube along longitudinal section.

From the above figures, isothermal contour at the outlet of the pipe it is observed that there is less blue in the middle unlike other tubes. It is also observed from the contour that there is a high rate of heat transfer from the walls to the fluid. This is mainly due to the rise of turbulence and friction factor with helical inserts. A highest temperature of 850K is recorded at the tube outlet by taking point reference. The isothermal contour at the outlet and along the pipe has shown a competent increase in heat transfer from wall to the fluid and from inlet to outlet of the boiler tube respectively.

VI. CONCLUSION

From the numerical study carried out for measuring heat transfer enhancement in boiler tubes with different types of inserts such as lead rifles, Central Helical Ribbon and Full Lead or circumferential Inserts, the following conclusions can be drawn from the results obtained.

- The results showed that conventional boiler tubes have low temperatures and more losses.
- It is also observed from the numerical results that Full helical Ribbon inserted tubes are effective in preventing the loss of heat transfer in the tube due to film condensation at walls. An improvement in the temperatures is also cited.
- Boiler tubes with full lead or circumferential insert as shown in fig. showed improved performance when compared with conventional and multi lead rifflled tubes[1]. A high temperature of 850 K has been obtained at the outlet of the tube in 0-90 seconds time step.
- Finally it can be concluded that when compared with conventional and MLR boiler tubes, tubes with circumferential inserts(Full Ribbon Boiler Tubes) has high heat transfer rates and temperatures which is highly desirable in boilers as it improve its efficiency and performance of boiler.
- The transient analysis of different tubes also proved that tube with full insert has good heat transfer rates than other the others.

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REFERENCES

- [1] Nice Thomachan et al. "CFD Studies on Multi Lead Rifled [MLR] Boiler Tubes" - Int. Journal of Engineering Research and Applications Vol. 3, Issue 5, pp.24-26, Sep-Oct 2013.
- [2] Vincent.H.Wilson; M.Hajee Mohamed. "Analysis of Boiler Super Heater Tubes from High Flue Gas Temperature" - International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-216 Volume 1 Issue 12 ,December 2014.
- [3] Ajay N. Ingale, Vivek C. Pathade – "CFD Analysis of Super Heater in View of Boiler Tube Leakage" – International Journal of Engineering and Innovative Technology (IJEIT) Volume 1, Issue 3, March 2012.
- [4] Prashant Kumkale - "COMPUTATIONAL STUDY OF FLOW THROUGH A SUPER HEATER FOR STUDY THE VARIOUS HEAT TRANSFER CHARACTERISTICS" - International Journal of Advance Research In Science And Engineering – IJARSE - ISSN-2319-8354(E), Vol. No.3, Issue No.9, September 2014.
- [5] Aditya Kumar Panday & L.A. Kumaraswamidhas - "Analysis of Flow Induced Vibration In Super Heater Tube Bundles in Utility Boilers Using Computational Method" – International Journal of Computational Engineering Research/ISSN:2250-3005.IJCER\\Vol.2\\Issue No.2\\481-486\\Mar-Apr 2012.
- [6] Raja Saripally, Ting Wang and Benjamin Day. *Simulation of combustion and thermal flow in an Industrial boiler*, Proceedings of 27th Industrial Energy Technology Conference, New Orleans, Louisiana, (2005).
- [7] M.M.Rahman and Sukahar, (2008). Tube temperature distribution in water tube boiler – A parametric study by Finite element method. International Conference on Construction and Building Technology, ICCBT, 14, 157-170, 2008.
- [8] Purbolaksono, J., Khinani A, Ali A.A., Rashid A.Z., and Nordin.N.F (2009) Iterative technique and finite Element simulation for supplemental condition monitoring of water-tube boiler. *Journal of Simulation Modeling Practice and Theory*, 17, 897-910, 2009.
- [9] Efim Korytnyi, Roman Saveliev, Miron Perelman and Boris Chudnovsky "Computational fluid dynamic Simulation of coal fired utility boilers: An emerging tool, Fuel, Elsevier, 2008.
- [10] Naga Sarada, S., Ramireddy, P., Gogulothu Ravi., "Experimental Investigations on Augmentation of Turbulent flow heat transfer in a horizontal tube using square leaf" , *International Journal of emerging Technology and Advanced Engineering*, vol. 3, Issue 8, 2013.
- [11] Promvongse, P., Eiamsa-ard, S., "Heat transfer behaviors in a tube with combined louvered-ring and twisted-tape insert", *International Communications in Heat and Mass Transfer*, vol. 34, pp. 849–859, 2007.
- [12] Naga Sarada, S., Sita Rama Raju, A.V., Kalyani Radha, K., Shyam Sundar, L., "Enhancement of heat transfer using varying width twisted tape inserts", *International Journal of Engineering, Science and Technology*, vol. 2, Issue 6, pp. 107-118, 2010.
- [13] Sunil Jamra, Pravin Kumar Singh & Pankaj dubey, "Experimental analysis of heat transfer enhancement in circular double tube heat exchanger using inserts", *International Journal of Mechanical Engineering and Technology*, vol. 3, Issue 3, pp. 306-314, 2012.

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