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# Study and Analysis on Boiler Tubes for Performance Enhancement with Varying Corrugated Tube Shapes

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**ABSTRACT: In this research paper we are using a commercial computational fluid dynamics (CFD) tool for the connective heat transfer through grooved or fold channels has been enquired. Heat transfer improvement through corrugated tubes has been taken into study. By varying the influencing geometrical parameters of the corrugated tubes like rifling, height if rifling, and length of the pitch of rifling etc. it is easy to study the performance of geometry of corrugated tubes. Flow through the tube of heat exchanger were determined by the effects of different geometry of the corrugated tube such as triangular etc. The change in the shape of corrugated tubes gave the significant change in heat transfer. The result unveils that heat transfer rate is increased when it is compared with the inner plane wall of the water tube.**

**Keywords:** Heat transfer enhancement, Boiler tube, Multi-rifled tube, Corrugated geometry, Helical tube

## I. INTRODUCTION

Water tube and fire tube boilers are used by many popular industries. In water tube boilers, water is flowing through tubes and this set-up is enclosed by the furnace heated externally while in the case of fire tube boilers hot or flue gasses passed through tubes surrounded by water. The process of conversion of water into steam in a large scale production includes high operating cost. Because of economic and environment concern, engineers try continuously to increase the efficiency of steam production rate (Steingress 1970). This can be achieving by increasing the heating surface area which is in contact with the water. So that heat will maximum available for the utilization. Development of scales on the internal walls of tubes causes the inefficient heat transfer from flue gas to water contained in the tubes which will result in creep formation. The condition of boiler tubes also gets worse due to the wall thinning effect on the exterior walls of the tubes as it causes high hoop stress and thus, it shortens the life span of the boiler tubes. But in reality, water tube of boilers are the plane walled, due to this flow of water inside the tube is laminar. The use of smooth surface inside the tubes of the boiler results in poor performances and new geometries should be used to increase the rate of heat transfer through tubes. One of the main factors that affect the boiler efficiency is the proper design of inner wall of the tube which will increase the rate of heat transfer to the flowing water. In order to prevent the damage to the inner walls of tubes and to increase the rate of heat transfer, ribbed tubes are used in place of smooth walled tubes. Surface roughness can be done through knurling or threading etc. which promotes enhancement through disturbance of the sub layer which is very close to the surface. The heat transfer coefficient is also one of the important factors for the proper design and operation of inner walls of the tube which transfers heat on flowing water. Ali and Ramadhyani (1992) performed the experiment to study the corrugated channels for the developing flow region. They studied transitional and laminar flow for two different types of inter-wall spacing. For both channels, they analyzed that transition to unsteady flow at Re 500, accompanied by the increase in Nusselt number. As a result, in the transitional flow region, optimal heat transfer enhancement has occurred. Cheng, L.X. & Chen, T.K. (2001) had performed experimental work for flow boiling heat transfer and frictional pressure drop in a vertical rifled tube of the boiler in two-phase flow and condition of 0.6MPa in the smooth tube. Outside diameter of rifled tubes used in the experiment was 22mm, inner diameter 11.6mm, width if a rib was 5.5mm, the height of rib was 0.4mm-0.6mm and pitch of rib was3.5mm. The outside diameter of the smooth tube was 19mm and inside diameter of the smooth tube was 15mm. The results of this experiment show that flow boiling heat transfer and frictional pressure drop in the rifled tube in two-phase were 1.40-2.00times and 1.60-2.00 times, respectively as compared with the smooth tube. The authors had also concluded that if the mass flux increases then flow boiling heat transfer coefficient also increases, but there is a little effect of pressure on the flow boiling heat transfer coefficient. The main advantage of rifled tubes on smooth tubes is that it will produce the swirling effect on the flow. Chkim *et al.* (2005) had examined the performance of critical heat flux (CHF) for flow boiling of R134a in uniformly heated vertical rifled tube and smooth tube. In this experiment, an outer diameter of four head and six head rifled tube is 22.59 and minimum range of inner diameter is 15.22mm-15.39mm, outlet pressure 13, 16.5 and 23.9 bars and sub cooling temperature of inlet 5-40°C. The improvement in the performance of CHF not only depends on pressure and mass flux but it also depends on critical velocity and critical helix angle. The author used the relative velocity of vapor to explain the CHF enhancement and it is very interesting to know that when flow pressure is near to critical pressure, velocity is below 0.3m/s and the helical angle is above 70o then there will be the decrease in centrifugal acceleration. As a result swirling flow is diminished. Numerical investigation for performance enhancement of boiler tubes Lee, S.K. & Chang, S.H. (2008) had examined experimentally the post dry-out with R134a upward flow in the rifled and smooth tube. In this experiment three types of rifled tube used which had helix angle 60o, 4 head and maximum inner diameter of 17.04mm and volume based inner diameter of 16.49mm, 16.05mm and 16.79mm respectively. With the use of three types of rifled tube, the author studied the effects of geometry of rib and compared it with the smooth tube. The smooth tube which was used in an experiment had an outside diameter of 22.59mm and an inner diameter of 17.04mm. The results of this experiment show that wall temperature of the rifled tube in the region of post dry out was much lower as compared to the smooth tube. O'Brien and Sparrow (1982) performed one of the first studies of a corrugated channel for the fully-developed region for flow in the range of 1500<Re<25,000. They conclude that rate of heat transfer was approximately 2.5 times greater in the case of straight channel and then observed the effects of this variation. The increase in inter-wall spacing results in 30% increase in the fully-developed Nusselt number, but the friction factor is increased more than doubled. Sparrow and Comb (1983) conducted a similar type of study for a corrugated channel with inter-wall spacing. Inter-wall spacing Water tube and fire tube boilers are used by many popular industries. In water tube boilers, water is flowing through tubes and this set-up is enclosed by the furnace heated externally while in the case of fire tube boilers hot or flue gasses passed through tubes surrounded by water. The Process of conversion of water into steam in a large scale production includes high operating cost. Because of economic and environment concern, engineers try continuously to increase steam production rate (Steingress 1970).

## II. OBJECTIVE AND SCOPE

The major source in industries for the combustion of fuel is boiler which generates process steam and electric power. It is the main device used to generate steam by an efficient burning of available fuel for the generation of power in power plant industries. The steam can be utilized in various processes such as driving an engine to generate electricity, heating processes and for other power plant applications. There are several types of boiler such as fire tube boiler, water tube boiler, fluidized bed combustion (FBC) boiler, atmospheric fluidized bed combustion (AFBC) boiler etc. The main aim of this written report is associated with the idea of the model of temperature fluctuations that co-occur within the tubes of the evaporator. The temperature is introduced by Numerical Investigation of boiler tube for performance enhancement. The basic knowledge of fluid dynamics and material conditions in the form of heat transfer is important in this work. Especially, this research paper's main objective is to-

1. Analyze the merits and demerits of using the internal rifled boiler tubes in power plant.
2. Analyze the pattern of flow of fluid inside the rifled tube.
3. Obtain the understanding of phenomenon resulting to unfair distribution of flow under different conditions.
4. The flow characteristic of rifled tubes is computed by the use of computational fluid dynamics (CFD) software.
5. Flow characteristic in the rifled tube and a smooth tube is determined by only single phase flow of water.
6. Rifled tube and smooth tube are supposed to be placed horizontally.

*A. Problem Statement*

Literature has show that research work regarding the rifled tube are more based on experiment work and less of them used numerical method for predicting the flow characteristics of the rifled tube.

Thus, in the present study, the Fluent i.e. numerical analysis by using CFD software shall be used to estimate the flow characteristic of the rifled tube. The use of CFD software is very useful in this research work as it reduces the cost of experimental set-up as well as it will save time also.

## III. MATERIAL AND METHEDOLOGY

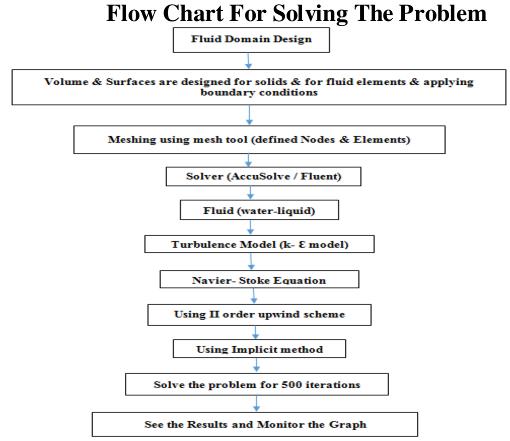
Present study is divided into four stages which are-

- Geometry modeling
- Pre-processing
- Processing
- Post-processing

The methodology of the present study can be divided into four stages of the process flow which are geometry modeling, pre-processing, processing, and post-processing. Various steps of methodology which are used as follows-

1. Mathematical modeling of the considered system.
2. Model is developed in SOLIDWORKS.
3. Present work is validated with the help of previous research work.
4. Heat transfer parameter is to be calculated.
5. Program is run to obtain plots with different boiler tube parameters.
6. Analysis and plotting of obtained plot.
7. At last, optimization of the system is done.

**Flow Chart For Solving The Problem**




*A. Geometrical Description*

The geometry used for analysis is of two different types of corrugated tubes which is made up of steel of 150 cm and hydraulic diameter 5.05 cm in which fluid flow occurs and further details are mention in table no. 4.1. Corrugations on the tubes were chevron design and the wave design, as shown in figure 1 and 2.

**Table 4.1 The dimension of rifled tube geometry parameters.**

| | |
|---|---|
| Tube type | Helical ridging |
| Outer diameter (mm) | 5.08 cm |
| Helix angle | 30o |
| Length | 150 cm |
| Tube material | Steel |
| Length of pitch | 25 cm |
| Height of rifling | 0.11 cm |

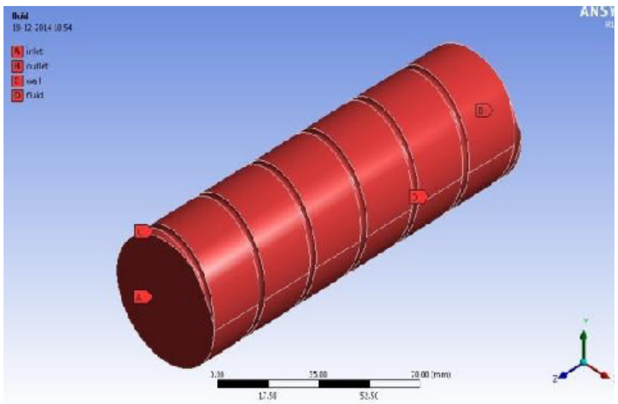



**Fig. 1**.Various Parts Of Tube.

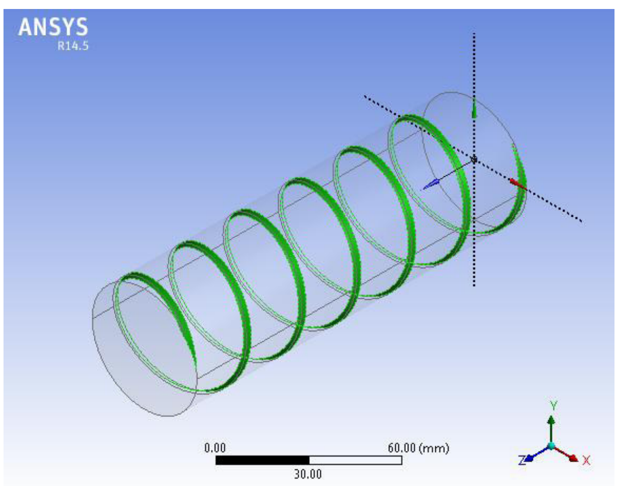



**Fig. 2**. Helical (Triangular) Ridging Inside the Tube.

## IV. GOVERNING EQUATIONS

The behavior of the flow is generally governed by the fundamental principles of the classical mechanics expressing the conservation of mass and momentum.

Assumptions-

1. Flow is steady.
2. Flow is incompressible.
3. Flow is turbulent.

### *A. Continuity Equation*

Continuity Equation also called conservation of mass. According to continuity equation, the amount of fluid entering in certain volume leaves that volume or remains there and according to momentum equation tells about the balance of the momentum. The momentum equations are sometimes also referred as Navier- Stokes (NS) equation. They are most commonly used mathematical equations to describe flow. The simulation is done based on the NS equations and then K-Epsilon model. Continuity equation can be expressed as-

$$\frac{\delta(\rho\bar{u})}{\delta x} + \frac{1}{r}\frac{\delta(\rho r\bar{v})}{\delta r} = 0$$

### *A. Momentum Equation*

Axial component (z-component)

$$\rho\bar{v}\left[\frac{\delta\bar{u}}{\delta r} + \bar{u}\frac{\delta\bar{u}}{\delta x}\right] = \frac{\delta\bar{p}}{\delta x} + \frac{\delta}{\delta x}\left(\mu_{eff}\frac{\delta\bar{u}}{\delta x}\right) + \frac{1}{r}\frac{\delta}{\delta r}\left(\mu_{eff}\frac{\delta\bar{u}}{\delta r}\right) + \frac{\delta}{\delta x}\left(\mu_{eff}\frac{\delta\bar{u}}{\delta x}\right) + \frac{1}{r}\frac{\delta}{\delta r}\left(\mu_{eff}\frac{\delta\bar{u}}{\delta r}\right)$$

Radial component (r-component)

$$\rho\left[\bar{v}\frac{\delta\bar{v}}{\delta r} + \bar{u}\frac{\delta\bar{v}}{\delta x}\right] = -\frac{\delta\bar{p}}{\delta z} + \frac{\delta}{\delta x}\left(\mu_{eff}\frac{\delta\bar{v}}{\delta x}\right) + \frac{1}{r}\frac{\delta}{\delta r}\left(r\mu_{eff}\frac{\delta\bar{r}}{\delta r}\right) + \frac{\delta}{\delta x}\left(\mu_{eff}\frac{\delta\bar{u}}{\delta r}\right) + \frac{1}{r}\frac{\delta}{\delta r}\left(r\mu_{eff}\frac{\delta\bar{v}}{\delta r}\right) - 2\mu_{eff}\frac{\bar{v}}{r^2} + \rho\frac{\bar{w}^2}{r}$$

Tangential component

$$\rho\left[\bar{v}\frac{\delta\phi}{\delta r} + \bar{u}\frac{\delta\phi}{\delta x}\right] = \frac{\delta}{\delta z}\left[\mu_{eff}\frac{\delta\phi}{\delta x}\right] + \frac{1}{r}\frac{\delta}{\delta r}\left[r\mu_{eff}\frac{\delta\phi}{\delta r}\right] - \frac{2}{r}\frac{\delta}{\delta r}\left[\mu_{eff}\phi\right]$$

### *B. Turbulent Modelling*

1. KAPPA-EPSILON MODEL

$$\rho\left[\bar{u}\frac{\delta k}{\partial x} + \bar{v}\frac{\partial k}{\partial r}\right] = \frac{\partial}{\partial x}\left[\left(\mu_l + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x}\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\left(\mu_l + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial r}\right] + \rho g$$

## V. RESULT AND DISCUSSION

This mathematical model is studied, solved and validated using an ANSYS (FLUENT) programmed in the present work. Present work also includes parametric study of boiler tube geometry and obtaining heat transfer characteristics of boiler tube with different geometry and compared it with the smooth tube.

**Table 5.1 Different sets of boiler tube parameters having simple geometry.**

| Type | Inlet | Outlet |
|---|---|---|
| Total Heat Transfer Rate (W) | 422.101 | 3381.392 |
| Temperature (K) | 300 | 391 |
| Heat Transfer Coefficient ($W/m^2$-K) | | 2636.6 |

**Table 5.2** Different sets of boiler tube parameters having triangular geometry

| Type | Inlet | Outlet |
|---|---|---|
| Total Heat Transfer Rate (W) | 279.582 | 6709.544 |
| Temperature (K) | 300 | 412.0129 |
| Heat Transfer Coefficient ($W/m^2$-K) | | 5322.3 |

The post processor was carried out in Fluent, and during the process, the following observations were encountered. The post processor was carried out in Fluent, and during the process, the following observations were encountered.

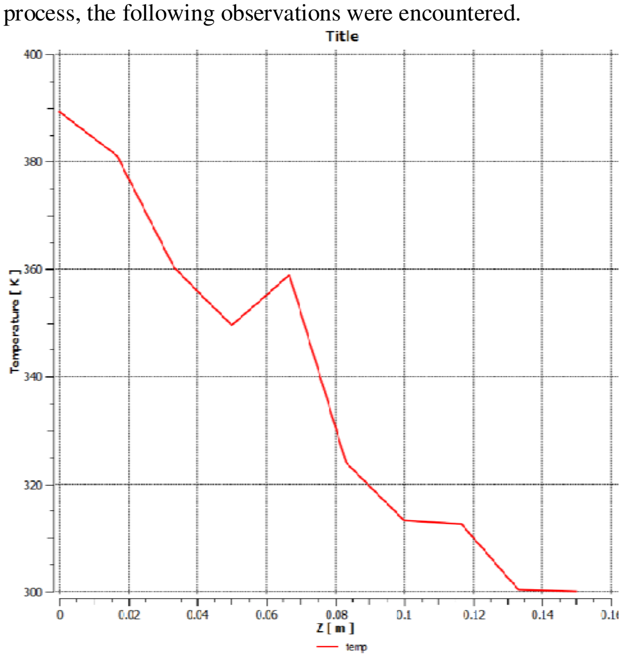



**Fig. 3.** Variation Of Temperature Profile With The Position Of The Tube For Smooth Tube Having Plane Geometry

The result for smooth tube having plan geometry and triangular geometry of total heat transfer rate, total heat transfer cofficient and temeperature at inlet and outlet are present in table number 5.1 and 5.2, which shows a major between them, it is observe from temperature distribution graph that temperature is increasing when fluid flowing from inlet to outlet of the tube. The variations are clearly shown in figure 3 and 4.

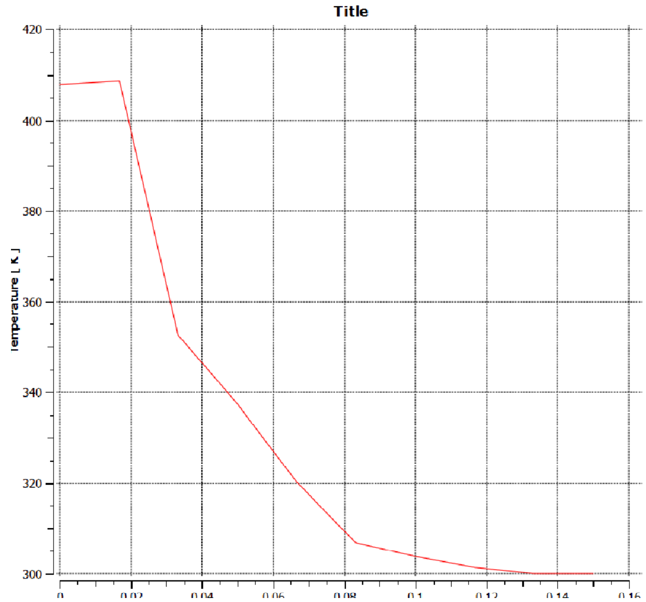



**Fig. 4.** Variation Of Temperature Profile With The Position Of The Tube For Triangular Geometry.

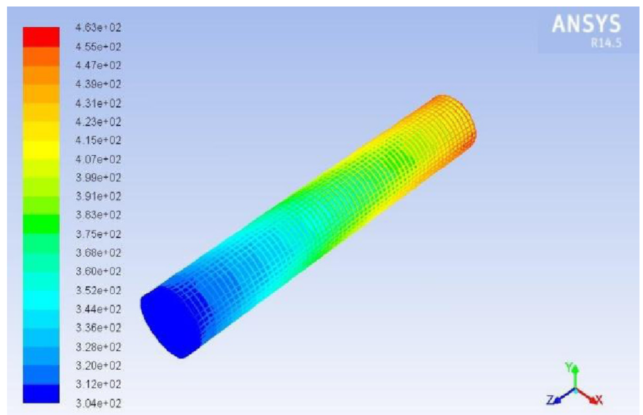



**Fig. 5.** Contours of Static Temperature for Smooth Tube.

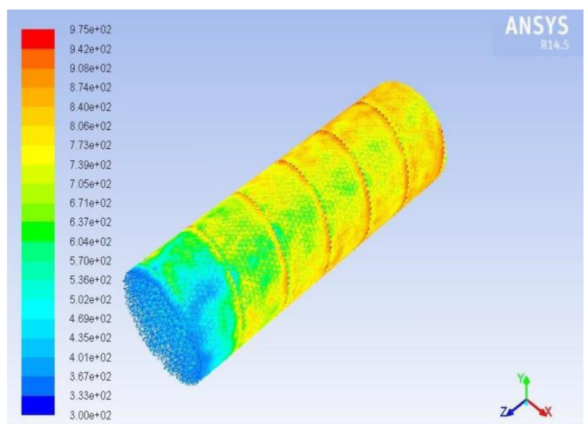



**Fig. 6.** Contours of Static Temperature for Triangular Geometry of the Tube.

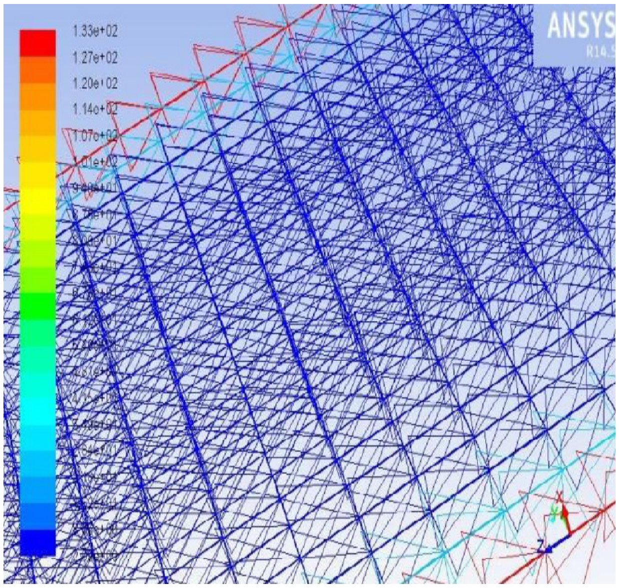



**Fig. 7.** Velocity Vector for Smooth Tube.

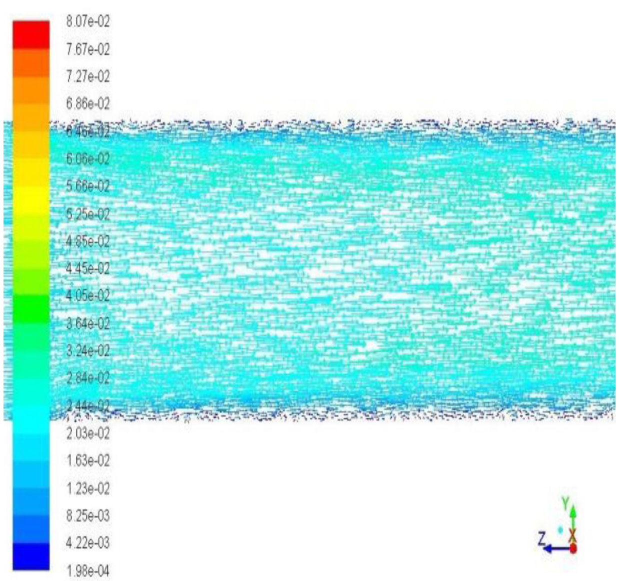



**Fig. 8.** Velocity Vector at the Corrugation for Triangular Tube.

The contour of smooth tube having plan geometry and triangular geometry shows the variations of temperature through different colours which is shown in figure 5 and 6. The Velocity is similar to a specification of direction of motion (e.g. 60 km/h to the north) and speed. Velocity is a major concept in kinematics, the branch of classical mechanics that explain about the body's motion. Velocity is a vector quantity which has both magnitude and direction. So, it is necessary to know about the velocity vector which shows the direction and magnitude of flowing fluid inside the boiler tube for smooth tube having plan geometry and triangular geometry which is shown in figure 7 and 8.

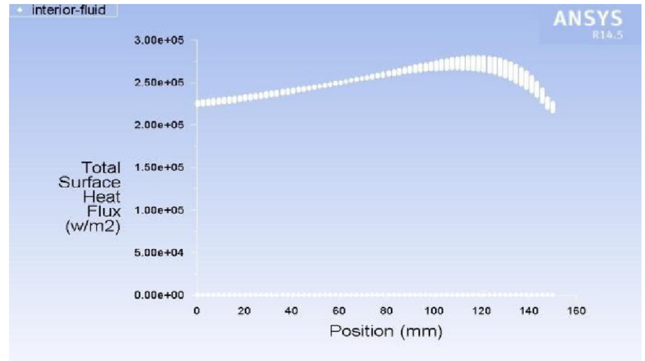



**Fig. 9**. Plot of Total Surface Heat Flux for Smooth Tube.

The figure 9 and 10 shows the result of total surface heat flux along the tube length for smooth tube having plan geometry and triangular geometry, it is observe from the plot of total surface heat flux for smooth tube having plan geometry have better results than triangular geometery due to which we obtain high value of total heat transfer coefficient.

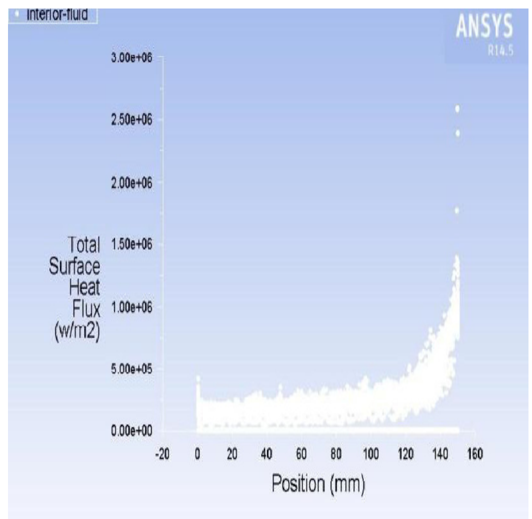



**Fig. 10.** Plot of Total Surface Heat Flux for Triangular Corrugated Tube Design.

## CONCLUSION

In this study, heat transfer rate has been analyzed and its dependent nature on the geometry of the boiler tubes. A small increase in the heat transfer coefficient will make a huge change in the overall efficiency of the boiler. The sample length of boiler tubes has been studied in the software, enthalpy contours, plots and the resultant temperature. Corrugated channels of the boiler tube induced the turbulence of the fluid which gives higher heat transfer rate. As shown from the study, different geometries give different results. After study different geometries we have found that the temperature is increased in the corrugated channel (triangular geometry) as compared to the plane geometry i.e. in the case of plane or simple geometry, the inlet temperature is 300K but after the heat transfer between the boiler tube and the fluid the outlet temperature becomes 391K but in the case of triangular geometry, the inlet temperature of the fluid is 300K but after the heat transfer between the boiler tubes and fluid the outlet temperature becomes 412.0129K which is more than the outlet temperature of the simple geometry. So, this shows that heat transfer rate is increased when we changed the design of geometry or we can say that by changing the design of corrugated tubes we can enhance the performance of boiler. Contours of static temperature show the temperature variation throughout the length of the tube. Red color shows the highest temperature of the tube, the yellow color is slightly less in temperature as compared to the red color and at the last blue color shows a medium or low temperature of the tube. Contours of plane geometry and triangular geometry shows change of blue color at the inlet into the yellow color at the outlet which indicates that as the heat transfer takes place between the tube and the fluid the color of the tube changes from blue color (high temperature) to yellow color (low temperature). From the variation of temperature profile with the position of the tube for plane geometry shows that temperature is decreased with the increase in the length of the tube but after certain point it increased and then decreased with the length but in the case of triangular geometry temperature is decreased with the increase in length there is no increase in temperature as in the case of plane geometry. From the above, we can conclude that heat transfer rate is increased with the change in the design of corrugated tube or with the increase in the length of the tube.

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