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CFD Studies on Different Helical Rifled Boiler Tube

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***Abstract**: The heat transfer enhancement on different helical rifled tubes have been investigated using a commercial CFD tool. Performance of geometry of the tube was studied by varying its influencing geometrical parameter like height of rifling, length of pitch of rifling for a particular length. The effects of the different geometry such as plane, circular, rectangular, and triangular geometry and heat transfer were determined for flow through tube heat exchanger. The change in the geometrical shape gave substantial change in the heat transfer rate. The result reveals the effect of geometrical shape on heat transfer rate. The results showed that the heat transfer increased when compared with existing inner plane walled water tubes.*

***Keywords:**Boiler tube, Heat transfer enhancement, helical rifled tube, CFD Analysis.*

I. Introduction

The interest of more productive energy storage system in the previous couple of years increments quickly, this thusly urge the researchers to deal with more effective energy system and augment the heat transfer in heat exchangers. For improving heat transfer study figured out that, rifling or corrugation is discovered to be an intense heat exchange upgrading instrument. Inactively improvement methods by utilizing the unique surface geometries are utilized to upgrade the convection heat transfer. This issue is especially pivotal in applications in which the heat transforming of liquids are needed, for example, in process plant and different industries where the energy is obliged to exchange heat. Truth be told frequently in these conditions momentum transfer mechanism is fundamentally laminar and in this manner the adequacy of the warmth move mechanical assemblies in which the liquids are passed on is inescapably punished. In curved geometries thedistortion of the velocity boundary layer and the onset of vortices produced by thecentrifugal forceshas a beneficial outcome on the convective heat transfer mechanism [1]. This arrangement, which frequently creates helical sort stream, seems exceptionally intriguing likewise in the conditions in which the stream holds on in the laminar regime [2]. The most vital impact in the corrugated tubes is rather identified with the perceptible blending of the liquid, which actuated by the destabilization of the stream prompts the early onset of the transfer mechanism associated with the transitional/turbulent regime [3-4]. Zarnett and Charles [5] researched the two-stage stream examples and their works demonstrated that whirl stream was not acquired until a discriminating fluid shallow speed was come to. Web, R.L. et. al. [6] had tentatively created warmth exchange relationship for turbulent stream in repeated-rib roughness tube, the rib inside the repeated rib roughness tube was situated in transverse course with the estimation of relative roughness ranging from 0.01 to 0.04 while relative rib spacing between 10-14. From this trial, the friction data of the test had been very much connected utilizing law of the withwall similarity a logarithmic velocity distribution. Then again, the heat momentum transfer analogywhich was in view of law of thewall similarity, was discovered to be unrivaled in representing the impact of Prandtl number.

Han, J. C. et. al. [7] led test examination on rib-roughened surface to focus the impact of rib shape, approach and pitch to heightproportion on friction factor and heat transfer. It is noticed that the friction factor is decreases with approach diminishing or angle of attack. Further diminishing in approach, will bring about the heat transfer and the friction approaching the smooth wall case. The thermal hydraulic performance of the tried ribs was at ideal when angle of attack almost 45^0.

Cheng, L. X. & Chen, T. K. [8] directed experimental work on flow boiling heat transferand two-phase flow frictional pressure drop in a vertical rifled tube and smooth tube. It was discovered that the superheat wall temperatures in the rifled tube are smaller than in the smooth tube under equivalent heat fluxes and equivalent mass fluxes.

Lee, S. K. & Chang, S. H. [9] had studied experimentally the post dry-out with R-134a upward flow in smooth tube and rifled tube. It is found out that the wall temperature of the rifled tube in the post-dry out region were much lower than in the smooth tube. As a result, the thermal non-equilibrium in rifled tube was lowered which due to the swirling flow was caused by the ribs in the rifled tube. The authors had also proposed heat transfer correlation for rifled tube as a function of rib height and rib width.

Lee, S. K. & Chang, S. H. [9] had considered tentatively the post dry-out with R-134a upward stream in smooth tube and rifled tube. It is figured out that the wall temperature of the rifled tube in the post-dry out district were much lower than in the smooth tube. Subsequently, the thermal non-equilibrium in rifled tube was lowered which due to the swirling flow was created by the ribs in the rifled tube. The authors had additionally proposed heat transfer relationship for rifled tube as a function of rib height and rib width.

From the above literature, it is found that proper designs of the tube inner wall will increase the heat transfer to the flowing water; consequently it is one of the primary components for its fruitful utilization. In order to increase the heat transfer and prevent damage to the inner wall of tube, ribbed tubes are applied instead of the smooth walled tubes and the computational examination done here takes less time when contrasted with trial study was done above in literature.

II. Problem Setup And Modeling

In this 3 dimensional computational fluid dynamics study, four tubes of same diameter 5.08 cm is considered and the analysis was done for a length of 150 cm. In this modeling one plane walled tube and three tubes of helical rifling is provided with varying parameters like height of rifling, length of pitch of rifling. Figure 1 shows the helical rifled tube geometry. The material of the tube is considered as steel. CFD modeling is a useful method to explore the real phenomena which happens in places where the experimental investigations are difficult or expensive therefore the use of the commercial CFD software to model the fluid flow inside the rifled tube is very useful in this research as it will save time and cost in setting up an experiment.

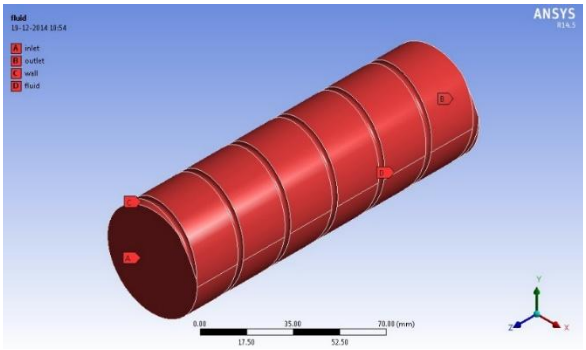


Figure 1: Geometry (helical rifling)

A 3D tube geometry with smooth tube and helical rifling is considered. The cross section was made by utilizing Ansys Fluent 14.5.The tube geometry subtle elements and working conditions are given beneath. Mesh Generation plays an imperative part in acquiring precise results. Mesh was created consistently all through the zone and analyzed by utilizing Ansys Fluent 14.5.
Length of Pitch: 25 cm
Height of rifling: 0.11cm

III. Equations

The governing equations are as follows:
3.1 Continuity equation

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

3.2 Momentum equations
3.2.1 Axial component (z-component):

$$\rho\bar{v}\left(\frac{\partial\bar{u}}{\partial r}+\bar{u}\frac{\partial\bar{u}}{\partial x}\right)=\frac{\partial\bar{p}}{\partial x}+\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial\bar{u}}{\partial x}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(\mu_{eff}\frac{\partial\bar{u}}{\partial r}\right)+\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial\bar{u}}{\partial x}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(\mu_{eff}\frac{\partial\bar{u}}{\partial r}\right) \qquad (2)$$

3.2.2 Radial component (r-component):

$$\rho\left(\bar{v}\frac{\partial\bar{v}}{\partial r}+\bar{u}\frac{\partial\bar{v}}{\partial x}\right)=-\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial\bar{v}}{\partial x}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\mu_{eff}\frac{\partial\bar{r}}{\partial r}\right)+\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial\bar{u}}{\partial r}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\mu_{eff}\frac{\partial\bar{v}}{\partial r}\right)-2\mu_{eff}\frac{\bar{v}}{r^2}+\rho\frac{\bar{w}^2}{r} \qquad (3)$$

3.2.3 Tangential component (θ- component)

$$\rho\left(\bar{v}\frac{\partial\emptyset}{\partial r}+\bar{u}\frac{\partial\emptyset}{\partial x}\right)=\frac{\partial}{\partial z}\left(\mu_{eff}\frac{\partial\emptyset}{\partial x}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\mu_{eff}\frac{\partial\emptyset}{\partial r}\right)-\frac{2}{r}\frac{\partial}{\partial r}\left(\mu_{eff}\,\emptyset\right) \qquad (4)$$

Here$\bar{u}$, $\bar{v}$ and $\bar{w}$ are the mean velocity components along z, r and θ directions respectively and the variable$\emptyset = r\,\bar{w}$.

The total effective viscosity of the flow is given by;

$$\mu_{eff} = \mu_l + \mu_t \tag{5}$$

Here μ_l and μ_t stands for molecular or laminar viscosity and eddy or turbulent viscosity respectively.

3.3 Kappa- Epsilon Model

3.3.1 K- Equation

$$\rho\left(\bar{u}\frac{\partial k}{\partial x} + \bar{v}\frac{\partial k}{\partial r}\right) = \frac{\partial}{\partial x}\left[\left(\mu_l + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x}\right] + \frac{1}{r}\frac{\partial}{\partial r}\left(r(\mu_l + \frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial r}\right) + \rho g - \rho\epsilon \tag{6}$$

3.3.2ϵ- Equation

$$\rho\left(\bar{u}\frac{\partial \epsilon}{\partial x} + \bar{v}\frac{\partial \varepsilon}{\partial r}\right) = \frac{\partial}{\partial x}\left[\left(\mu_l + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x}\right] + \frac{1}{r}\frac{\partial}{\partial r}\left(r(\mu_l + \frac{\mu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial r}\right) + C_{s1}G\frac{\varepsilon}{k} - C_{s2}\frac{\epsilon^2}{k} \tag{7}$$

Where G is the production term and is given by;

$$G = \mu_t\left[2\left\{\left(\frac{\partial \bar{v}}{\partial r}\right)^2 + \left(\frac{\partial \bar{u}}{\partial x}\right)^2 + \left(\frac{\bar{v}}{r}\right)^2\right\} + \left(\frac{\partial \bar{u}}{\partial r} + \frac{\partial \bar{v}}{\partial x}\right)^2\right] \tag{8}$$

The production term represents the transfer of kinetic energy from the mean flow to the turbulent motion through the interaction between the turbulent fluctuations and the mean flow velocity gradients.

Here C_{s1}, C_{s2}, σ_k, σ_ε are the empirical turbulent constant. The values are considered according to the Launder, et. al. (1974).

IV. Simulation Of Thermal Flow

Computational Domain with Boundary Conditions

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

Inlet watertemperature…………....300 K
Outlet wall temperature………..….1000 K
Mass flow rate………………..……0.034 Kg/sec
Operating pressure....................…...1 bar

The commercial CFD programming utilizes a control volume based method to change over the representing mathematical statements which are comprehended numerically utilizing the implicit method. In the segregated formulation the governing equations are solved successively, as it is isolated from each other.

The solution convergence is acquired by observing the continuity, momentum, energy, and turbulence equations independently. A convergence criterion of 10-4 is utilized for mass conservation and 10-6 for energy conservation. The temperature of the vent gas is 1000 K and warmth is exchanged to the water inside the tube. The temperature of the water inside the tube comes to more or less 391 K in the smooth tube, 406 K, 410 K and 412 K in the rifled geometry having circular, rectangular and triangular geometry individually. The temperature circulation in the boiler tube is influenced by numerous variables, for example, mass flow rate of steam, steam temperature, feed water temperature and pressure. Consequently, impact of these variables is likewise considered by running a predetermined number of simulations.

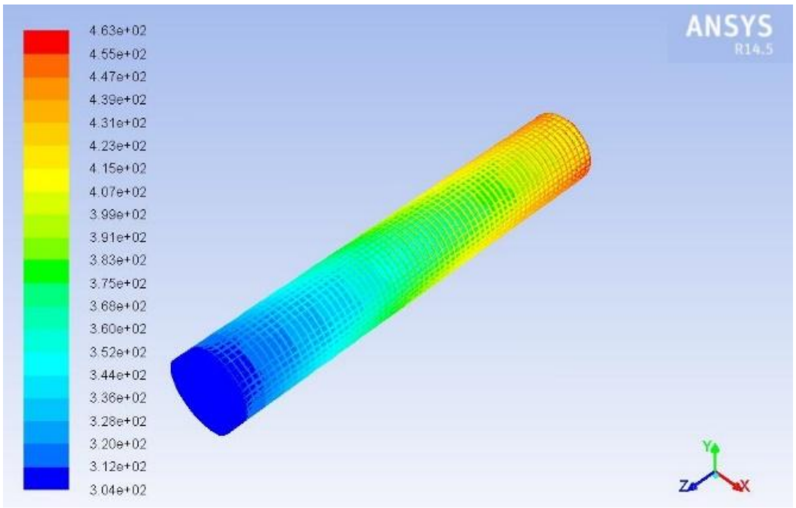
V. Results And Discussion

5.1 Effect of Rifled Geometry onHeat Transfer Enhancement inthe Tube

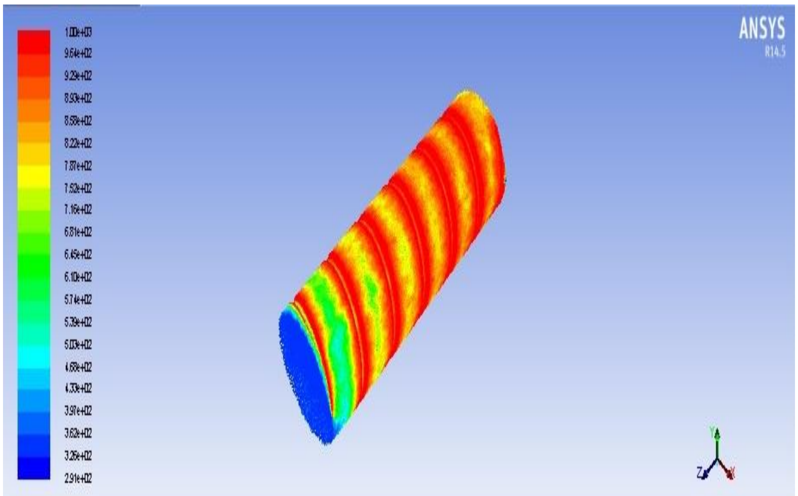
It has been observed that the total heat transfer rate, temperature and enthalpy at the outlet of the channel is increased significantly by applying corrugated geometry inside the boiler tube. This is due to increased roughness surface area for same mass flow inlet. Lower the low value of mass flow inlet higher will be the surface area and tube get heated uniformly and in relatively shorter time as compare to high mass flow inlet and smooth tube.

5.2 Temperature Distribution Due To Different Geometries ofthe Tube

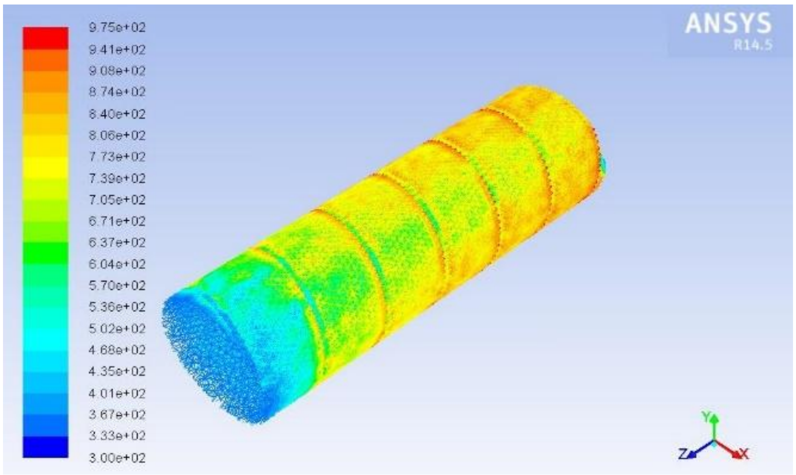
At the point when liquid to be heated goes into the tube, because of convective heat transfer the liquid inside the tube get warmed. Because of wall heat transfer coefficient and region item liquid get heated at first up to a certain length and after quite a while liquid spans to a uniform temperature. When liquid gets changed over into steam it is presently accessible to supply where required. Fig. 2 demonstrates the temperature circulation for distinctive geometry of the tube. The mean temperature of the working liquid increments with the separation from the passageway of course. Additionally expected, the increment is fast closer the wall due to high heat transfer rates in this locale because of higher temperature contrasts between the wall surface and the liquid.



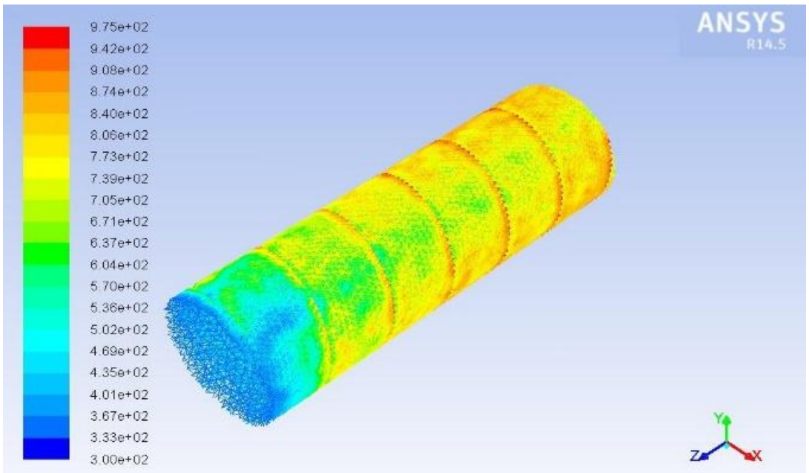
(a) Plane Walled Tube Geometry



(b) Circular (helical rifled) Tube Geometry



(c) Rectangular (helical rifled) Tube Geometry



(d) Triangular (helical rifled) Tube Geometry

Figure 2: Contours of Temperature for Different Geometry ofthe Tube

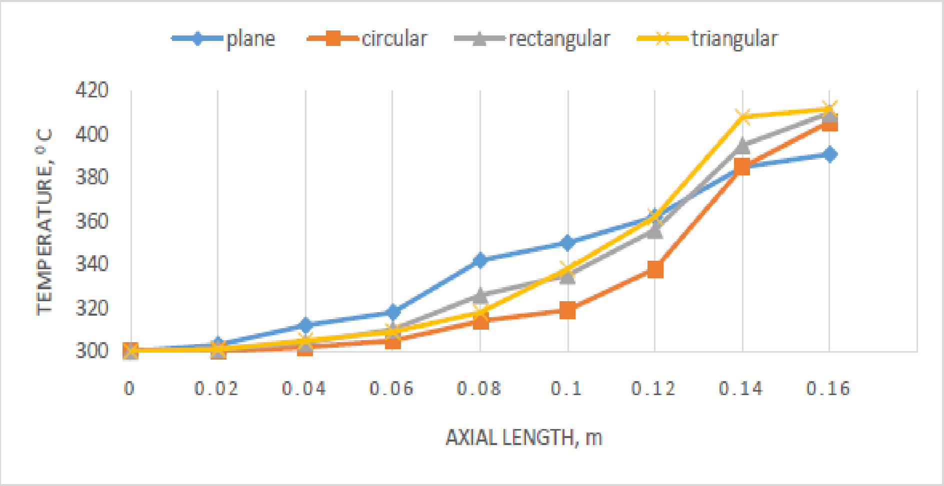


Figure 3: Temperature profile along axial distance for various geometry of the tube

A little increment in the heat transfer of the tube will improve the execution in its application, for example, in boiler and roll out immense improvement in general execution of the boiler. From the Fig. 3 as demonstrated below, it is been watched that the figure demonstrating temperature profile of smooth tube having straightforward geometry is not proficient when contrasted with the chart of different figures having corrugated geometry. Temperature of smooth tube geometry goes up to 391 K from starting temperature of 300 K while the temperature of corrugated tube having circular, rectangular and triangular geometry goes up to 406 K, 410 K, and 412 K individually.

The heat transfer enhancement impact in corrugated channel is basically because of instigated turbulence which gives higher heat transfer rate. As indicated from the study, diverse geometries give distinctive results for the same stream conditions (mass-flow rate). The decision of fitting geometry does not generally rely on upon mass-flow rate values, but rather consistency and very nearly steady conduct through a low mass-flow rate reach, assumes an essential part.

VI. Conclusion

The heat transfer in the tube has been broke down, and its reliance on geometry is accounted for in this study. A little increment in the heat exchange of the tube will upgrade the execution in its application, for example, in boiler and roll out tremendous improvement in general execution of the boiler. As indicated by the study, the decision of suitable tube geometry relies on upon the application. The folded configuration is demonstrated to give better convective properties (more or less 19% more convective transfer). The model was made utilizing Solid Works 2012 and meshed with Fluent, and the flow analysis is finished with Ansys 14.5. The outcomes demonstrating that the heat transfer is increased. The enthalpy and temperature increment with flow is progressing when compare with normal plane walled boiler tube. So the execution of Optimized Helical

Ridging evaporator tube in the boiler is advisable. The study demonstrate that the change in furnace heat transfer can be accomplished by changing the interior plane surface to a rifled tube.

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