Heat transfer enhancement in fire tube boiler using hellically ribbed tubes

Miss Simantini Balasaheb Kute

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Abstract

Computational fluid dynamics were used to simulate and study the heat transfer of both plain tube and helically ribbed tube for fire tube boiler. The operation condition was taken from Thermax Limited and used in a boundary condition accordingly. The result indicates the helically ribbed tube has higher heat transfer rate than plain tube.

Keywords- Heat transfer enhancement, Fire tube boiler, Plain tube, Helically ribbed tube.

1. Introduction

Recently the energy drives the economy which leads to enhancement of energy efficiency. The researchers are interested in power generation field to control the use of energy and the economy as well. This study is about improving the heat transfer coefficient in tubes of fire tube boiler. The increase of heat transfer coefficient is occurred by change the internal geometry of the tube by helically ribbed shape. This helically ribbed shape generates a centrifugal force on the fluid and forces the flow to be turbulence. A plain tube has a problem which is the excessive time to heat the tube and this problem needs to be tackled. The objective of this study is to determine the heat transfer rate for both helically ribbed tube and plain tube.

Smith, J. W. et al. [1] studied the turbulent heat transfer and temperature profiles in a rifled pipe. The rifled pipe was made by fitting snugly the continuous spiral rib inside a smooth brass tube which had the inner diameter of 2.058 inch. The continuous spiral rib was created from 0.25 inch x 0.25 inch copper bar with pitch to diameter ratio of 2.58. Zarnett, G. D. & Charles, M. E. et al. [2] studied the flow patterns of two phase flow in horizontal tubes fitted with internal spiral tubes (rifled tube) which their pitch to diameter ratios is 1.57 and 2.79 respectively. Webb, R. L. et al. [3] studied the heat transfer and friction correlations for turbulent flow in repeated-rib roughness tube. The correlation which was proposed by the authors specifically apply to ribs of rectangular cross-section, whose thickness is small relative to the rib spacing. Iwabuchi, M. et al. [4] studied the heat transfer characteristics of rifled tube in the near critical pressure region. In this experiment, smooth tube and rifled tube were tested to study their heat transfer characteristic. The experiment result shows that when pressure exceeds 20.6MPa, the swirl effect will diminishes and CHF condition appears even in the sub cooled region. However, the wall temperature rise is suppressed to a comparatively lower lever. Dirar, S. et al [5] studied the CFD analysis of normal and rifled tube with a convergence check. As a result of CFD analysis, the maximum outlet temperature in rifled tube is higher than the normal tube.

2. Theoretical analysis

In the nucleate boiling regime, the rate of heat transfer strongly depends on the nature of nucleation, which is difficult to predict. The type and the condition of the heated surface also affect the heat transfer. These complications made it difficult to develop theoretical relations for heat transfer in the nucleate boiling regime, and we had to rely on relations based on experimental data. The most widely used correlation for the rate of heat transfer in the nucleate boiling regime was proposed in 1952 by Rohsenow, and expressed as;

$$q_{nucleate} = \mu_1 h_{fg} \left[\frac{g(\varrho_l - \varrho_v)}{\sigma}\right]^{1/2} \left[\frac{C_{pl}(T_s - T_{sat})}{C_{sf}.h_{fg}.Pr_l^n}\right]^3$$

$$= 11064.04\ W/m^2$$

$$Q_{boiling} = q_{nucleate} \text{ x Area}$$

$$\boxed{Q_{boiling} = 2317.5\ W}$$

3. CFD Analysis

3.1 Definition of Geometry

The following section includes the design or the geometry of the Plain Tube and Helically Ribbed Tube. The CAD model is designed in CATIA V5R19 according to the specifications mentioned in the following Table 1.

Table 1. Geometry parameters of the plain tube and helically ribbed tube.

Tube Type	Plain Tube	Helically Ribbed Tube
Outer Diameter (mm)	38.1	38.1
Length (mm)	1750	1750
Rib Height (mm)	-	0.9
Rib Width (mm)	-	4.78
Helix Angle (°)	-	55
Number of starts	-	10

The geometric modeling of plain tube and helically ribbed tube is shown in Fig.1 and Fig. 2

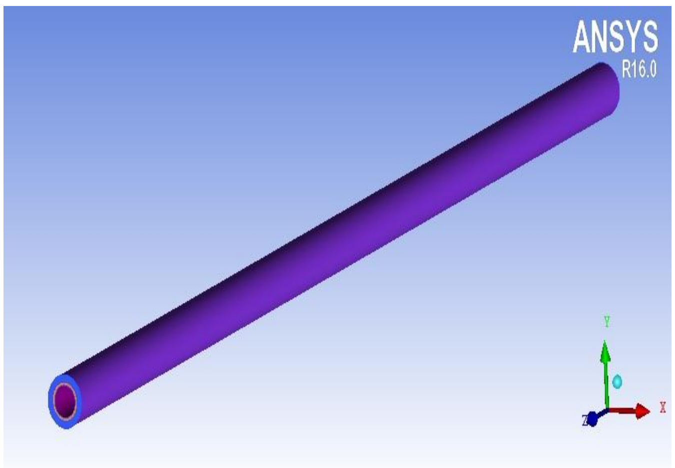
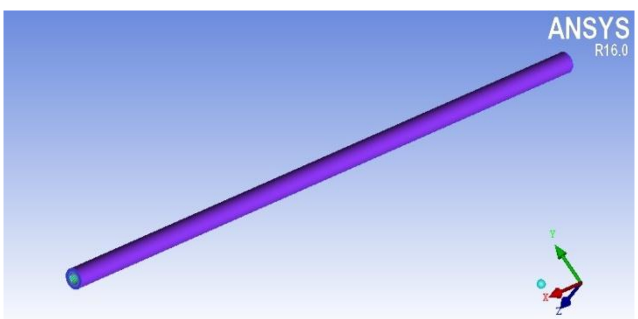


Fig. 1. Model of Plain Tube



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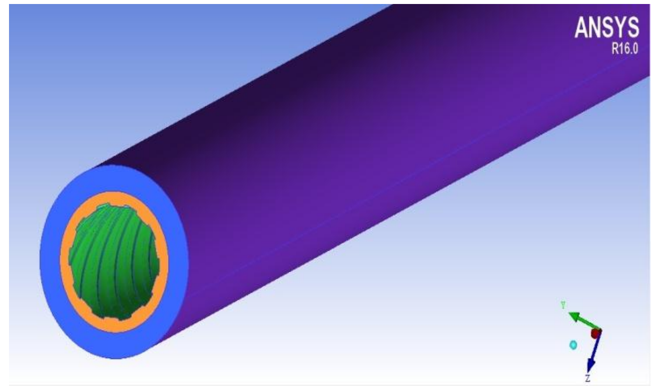
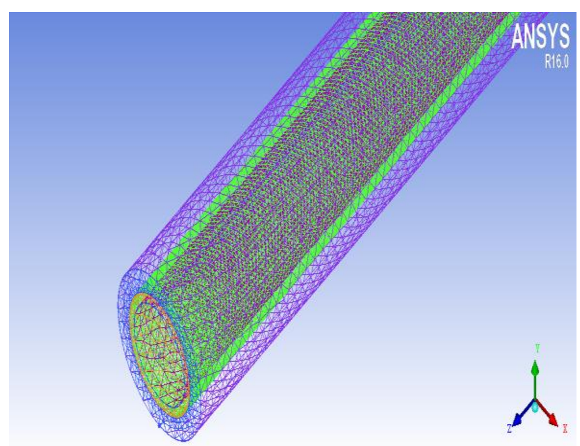


b)

Fig. 2. Model of Helically Ribbed Tube

3.2 Grid generation

The meshing is done in ICEM CFD 16.0 after modeling, the total number of elements is 2077644 and the total number of nodes is 467785 for Plain Tube and the total number of elements is 8592287 and total number of nodes is 1802255 for Helically Ribbed Tube. The element type is tetrahedral type. In order to capture both the thermal and velocity boundary layers the entire model is discretized using tetrahedraltype mesh elements which are accurate. Fine control on the mesh near the wall surface allows capturing the boundary layer gradient accurately. The entire geometry is divided into two fluid domains i.e. Fluid Flue gases and Fluid Water and remaining i.e. solid thk is considered as solid domain. The following Fig. 3-6 represents the mesh of plain tube and helically ribbed tube with wireframe display and simple solid display.



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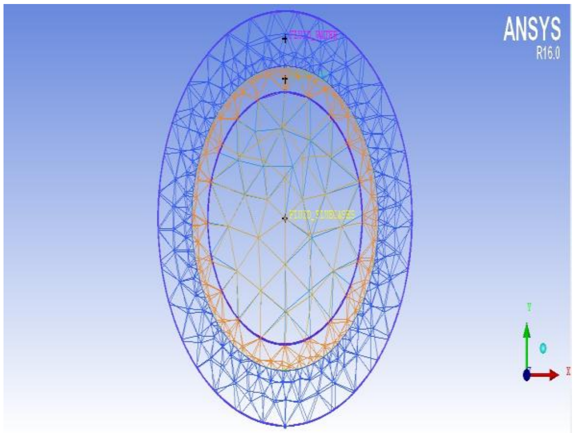

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Fig. 3. Mesh of Plain tube with wireframe display.

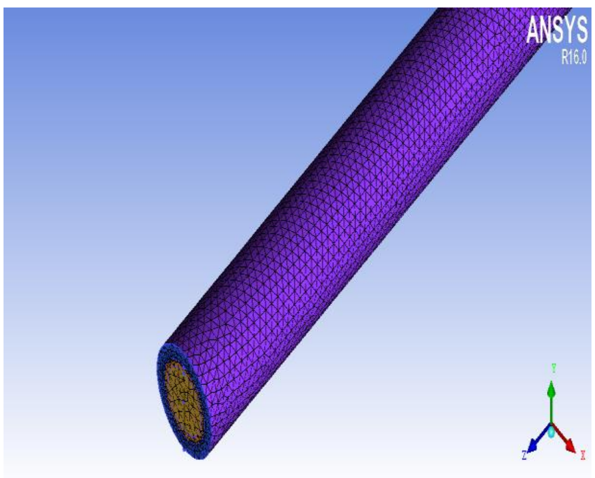
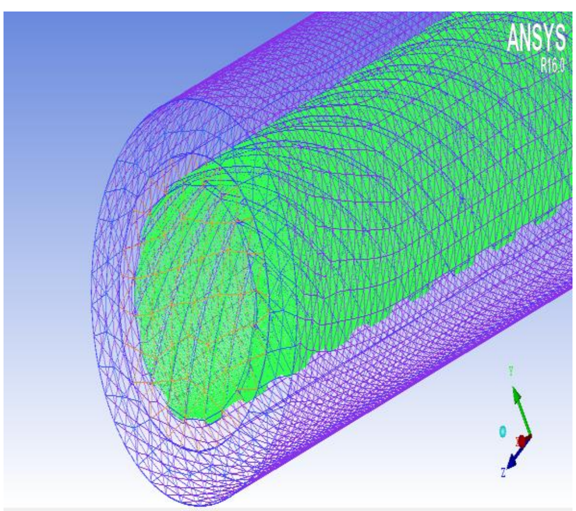


Fig. 4. Mesh of Plain tube with simple solid display.



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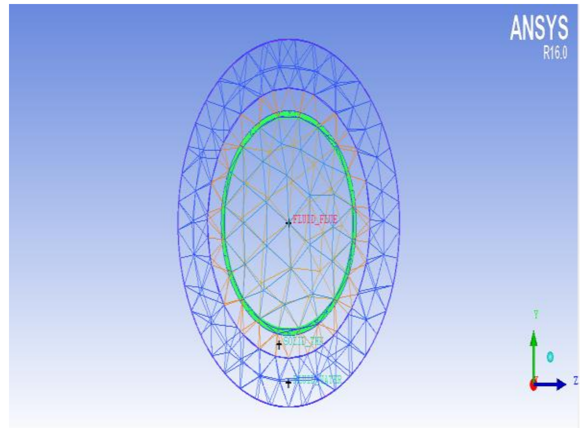

b)

Fig. 5. Mesh of Helically ribbed tube with wireframe display.

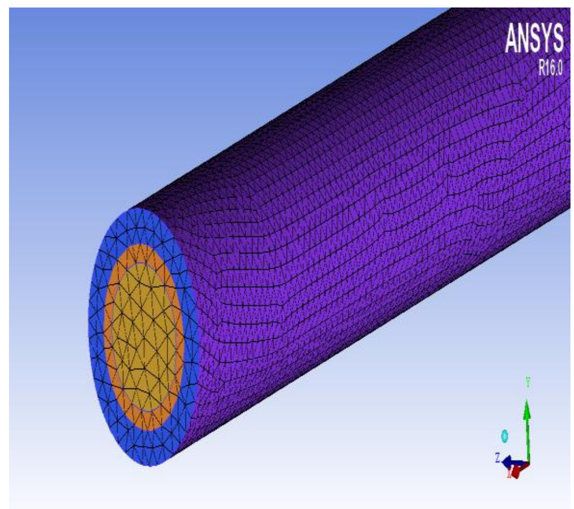

Fig. 6. Mesh of Helically ribbed tube with simple solid display.

3.3 Solver

The continuity, momentum and energy equations will be used by CFD and convert them to algebraic equations by using Finite volume method and then run the solution by using implicit scheme second order upwind. Flue gases will be used as working fluid. Inside the tube with inner diameter (31.7 mm) and the thickness (3.2 mm) the helically ribbed tube is consists of four additional parameters, which are Number of ribs, Height of ribs, Width of ribs and lead angle. The CFD simulation is applied on Plain tube and helically ribbed tube under constant mass flow rates. The following boundary conditions are given to the tubes in FLUENT 16.0. In the present study, the flow is considered to be in steady state condition and since there is no uniform heating on the outer wall of the tubes, constant fluid properties such as density and viscosity is used. No slip boundary condition, uw = 0 is imposed.

Table 2. Boundary conditions to Plain Tube and Helically Ribbed Tube.

Boundary Conditions	Plain Tube	Helically Ribbed tube
For Hot Flue Gases through the tube: 1. Mass flow rate 2. Specific Heat 3. Thermal Conductivity 4. Inlet Temperature	0.0054 Kg/s 1006.43 J/kg k 0.0242 W/m k 450°c	0.0054 Kg/s 1006.43 J/Kg k 0.0242 W/m k 450°c
For Water surrounding the tube: 1. Specific Heat 2. Thermal Conductivity	4182 J/Kg k 0.6 W/m k	4182 J/Kg k 0.6 W/m k

3.4 Post-Processor

At the end of this step we obtain the results in the form of contours, velocity vectors and residuals. In the present study, the k-epsilon Realizable model is used with near wall treatment having standard wall functions. The solving is done in FLUENT 16.0 and post processing is done in CFD-Post 16.0. Fig. 7 and fig. 8 show the comparison between the plain tube and helically ribbed tube surface temperature contours. The maximum surface temperature in plain tube is approximately 209 °C and for helically ribbed tube is around 247 °C. The study proves that the helically ribbed tube has better heat transfer than plain tube and hence higher heat transfer rate than plain tube.

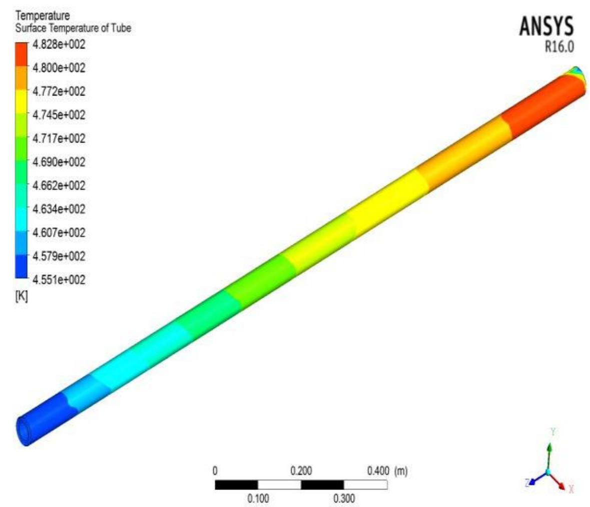

Fig. 7. Plain tube surface temperature contour.

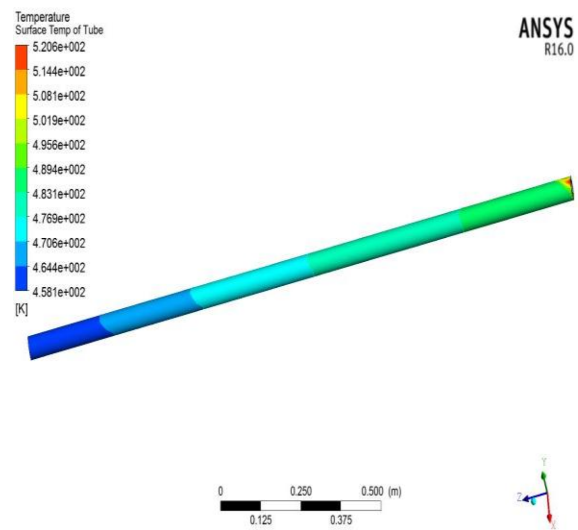

Fig. 8. Helically ribbed tube surface temperature contour.

4. Results and Discussion

4.1 Results

According to CFD analysis, the total heat transfer rate of plain tube is 2309 W and for the helically ribbed tube is 2407 W. The surface temperature of plain tube is 209 °C and for helically ribbed tube is 247 °C. The following fig. 9 and fig. 10 shows results.

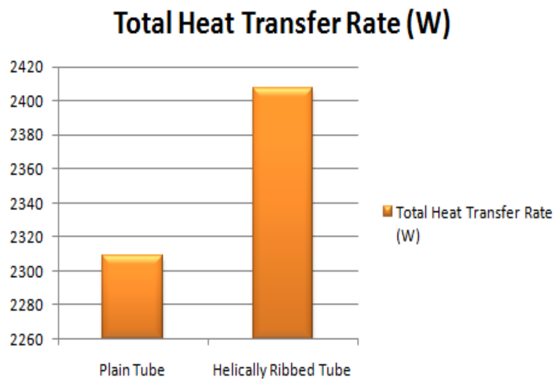

Fig. 9. Comparison between Total Heat Transfer Rate of Plain Tube and Helically Ribbed Tube.

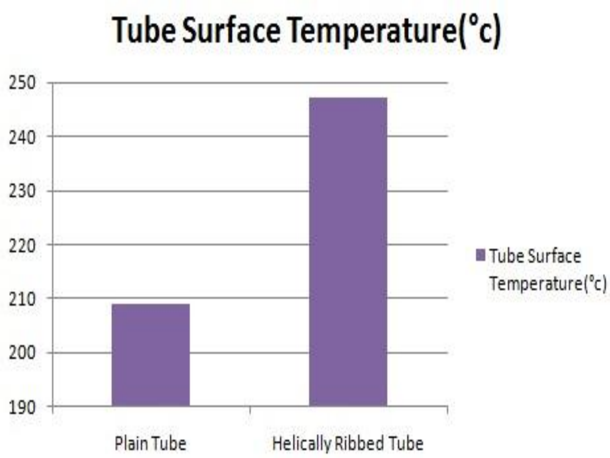

Fig. 10. Comparison between surface Temperature of Plain Tube and Helically Ribbed Tube.

4.2 Discussion

According to the results of CFD analysis of plain tube and helically ribbed tube, for the same length of 1750 mm: i)The helically ribbed tube gives higher heat transfer rate than plain tube, ii)The total pressure of plain tube is 3.05 pa and 3.13 pa for helically ribbed tube, iii)Performance evaluation criteria for plain tube is 757.05 and 769 for helically ribbed tube. For same heat transfer rate of plain tube and helically ribbed tube: i)The length of helically ribbed tube can be used as 700 mm. In helically ribbed tube, the film boiling takes place after 700 mm length. So it is better to use 700 mm length tube instead of 1750 mm to avoid the damage to metal of tube, ii)Total pressure of plain tube is 3.05 pa and 1.251 pa for helically ribbed tube, iii)Performance evaluation criteria for plain tube is 757.05 and 1845.7 for helically ribbed tube. The following fig. 11 and fig. 12 represent the results of discussion.

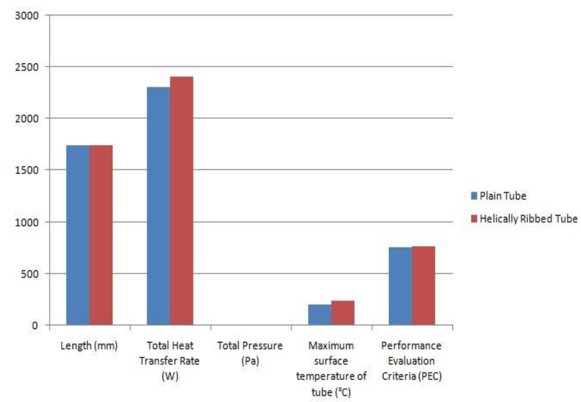

Fig. 11. Comparison between total heat transfer rate of tubes with same length

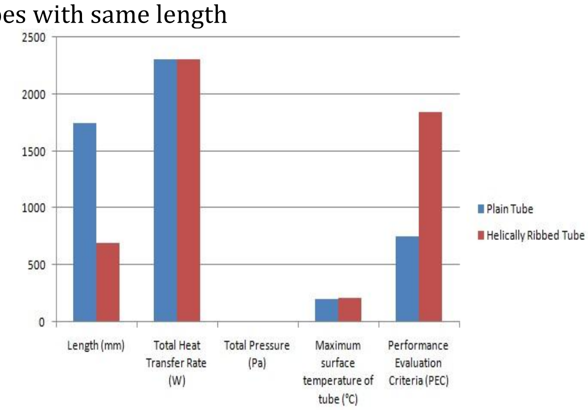

Fig. 12 Comparison between length of tubes with same heat transfer rate

5. Conclusion and Future scope

5.1 Conclusion

Theoretical and CFD analysis is done to compare the heat transfer of plain tube and helically ribbed tube. The geometry was drawn with same diameter for both plain tube and helically ribbed tube. The mesh was created with good mesh quality. The result shows that:

- For the same length of 1750 mm, the total heat transfer rate of helically ribbed tube (2407 W) is higher than the Plain tube (2309 W) by 4%.
- For the same total heat transfer rate, the helically ribbed tube can be used with 700 mm length and plain tube with 1750 mm length.
- By using helically ribbed tubes, the compact design of oil fired fire tube boiler can be achieved.

5.2 Future Scope

Using the Helically ribbed tubes instead of Plain Tubes in Oil Fired Fire Tube Boiler;

- The heat transfer in the boiler will increase.
- The efficiency of the boiler will increase.
- Fuel saving takes place
- Lower fuel consumption results in lower emission of NOx and other pollutants.
- Due to the additional turbulence created near the wall, helically ribbed tubes are self-cleaning to a great extent and have been foul less than plain tubes, even with particulate laden flue gas inside tubes.

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Nomenclature

Cp	: Specific Heat (J/kg K)
K	: Thermal Conductivity (W/m K)
m	: Mass flow rate (kg/s)
µ	: Dynamic viscosity (kg/m s)
ϱ	: Density (kg/m^3)
Q	: Total heat transfer rate (Watt)

Subscripts

w	: Water
g	: Flue Gas

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