

Computer Simulation of Heat Transfer Performance for Internally Rifled and Corrugated Boiler Tubes Under Steady Fluid State

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Abstract: Engineers are constantly working to improve the efficiency of boiler steam output rates for reason of both economics and environment. This can be accomplished by improving the efficiency of heat transfer through the boiler tubes. This is why a comparison of two distinct kinds of boiler tubes was done. By using computer simulation Ansys Fluent, this study aims to examine the characteristics of air flow inside the boiler tube with different wall designs (rifled and corrugated). A varied wall design for a boiler tube (rifled and corrugated) was studied for pressure drop effects at various flow rates, and the efficacy of heat transfer between internally rifled and corrugated boiler tubes was compared. To analyses the thermal analysis within the boiler tube when hot air passes through it at a fixed inlet temperature of 450K, CFD analysis was used. It was consumed that the ambient pressure was 101.325kPa and the inflow velocity ranged from 8m/s, 10m/s and 12m/s. In general, internally rifled tubes have a higher heat transfer coefficient than corrugated tubes, according to the graph. The average heat transfer coefficient of the internally rifled tube model was 5947.128W/m²K, whereas the corrugated tube model was 5761.365W/m²K. As a result, the corrugated tube had a larger pressure, which meant a faster pressure decrease toward the outlet. Researchers can use the simulation result as a starting point for additional research into the potential parameters of design in various fields and applications to be improved.

Keywords: CFD Computer Simulation, internally rifled tube, corrugated tube, heat transfer coefficient, heat transfer performance

1. Introduction

Rifled tubes with internal spiral ribs can prevent overheating failures in power boilers. Rifled tubes in a conventional boiler give a higher margin of safety for natural and aided circulation and various economic benefits, including weight reduction for downcomers, headers, drum and connecting pipe, pumping power reduction, and framework reduction [1,2]. In the boiler evaporator, the use of internally rifled tubes with spiral ribs causes a shift in heat and flow process. The fluid travels spirally inside the tubes, which serves to enhance heat transfer and if a boiling crisis arises, allows the water film on the tube surface to be maintained [3]. When corrugated tubes are used instead of smooth tubes, the heat transfer coefficient can be increased.

A thermos hydraulic test bench was created to analyze the effect of corrugated tube on heat transmission capability and pressure drop [4]. The rising cost of energy has put a premium on developing energy-efficient technologies. In the steam sector, boiler tube design is a critical challenge, hence the research into increasing heat transfer in boiler system has been improved. Practical trials and testing to collect essential design engineering data can be costly, so this study uses ANSYS Fluent software to compare the performance of internally rifled and corrugated tubes [5-7]. This software is chosen because it's free and because system has gone through profound advancement and development, making them more powerful and cost efficient [8]. This study will help industries run simulation remotely, saving time and money.

2. Methodology

In this part provides the methodology that introduces a data-collection structure. The purpose was to compare heat distribution along both tubes as hot air passes through them. Designing two tubes is followed by CFD simulation using ANSYS Fluent. The CFD simulation also evaluated air flow through both tubes, pressure drops when hot air travels through them and heat distribution along internally rifled and corrugated boiler tubes [9-10]. The CFD model is 3D. The assumptions taken when conducting this CFD simulations are as follows.

- Both tube dimensions are the same, the internal wall is different.
- The model is static.
- The input air at the inlet will be set to 450K and the outlet set to 300K (ambient temperature).
- The inlet velocity for this study are 8m/s, 10m/s and 12m/s with gauge pressure of 101.325kPa.
- Hot air is used to pass through the tube and water vapor is set as the fluid.

The more complicated the geometry, the longer it will take to solve the problem, increasing the computational cost at the same time. As a result, this study used a shorter tube which uses 500 mm tube length. Table below shows the parameters of the design geometry.

Table 1 – Summary of design geometry

Tube type	Corrugated tube	Internally rifled tube
Outer diameter,	OD = 50.8mm	OD2 = 50.8mm
Inner diameter,	ID = 42.8mm	ID2 = 42.8mm
Wall thickness,	D = 8mm	G = 8mm
Pitch,	B = 30mm	F = 30mm
Helical angle,	E = 70°	H = 30°
Rib surface width,	C = 10mm	J = 8mm
Rib height	A = 3mm	I = 3mm
No. of Rifling	-	6
Length of tube	500mm	500mm
Material	Steel	Steel

The boundary conditions specified the tubes' inlet and outlet. Setup geometry was model checked. Fills were added to the cavity for both tubes which are not used in the study, although they do serve as a reference for defining boundary conditions.

3. Results and Discussion

The tube performance will improve in no time with ANSYS Fluent software. Fluent's physically validated modelling capabilities are reliable and precise results in CFD and Multiphysics applications. This chapter covers ANSYS Fluent analysis for tube flow with heat transfer effects. CFD was used to determine heat transfer and pressure drop along corrugated and internally rifled boiler tube with internal flow problem. In this study, the tube wall was not considered since the wall is too thin and the focus was primarily on the flow of air. Each tube was meshed at element size of 0.003 m.

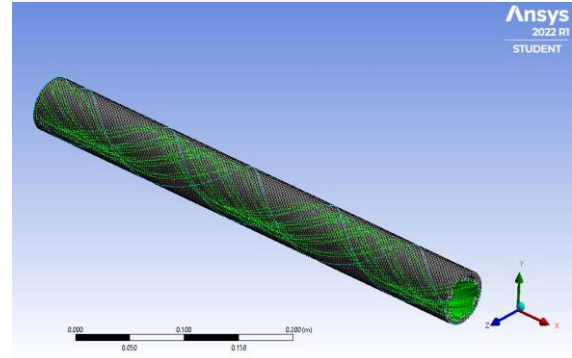


Fig. 1 – Internally rifled tube mesh

Table 2 – Detailed of internally rifled tube.

Internally Rifled Tube	
Element size	0.003 m
Nodes	69194
Elements	53072
Volume	0.00089896 m ³
Surface area	0.19805 m ²
Faces	308
Face surface area	0.0010635 m ³

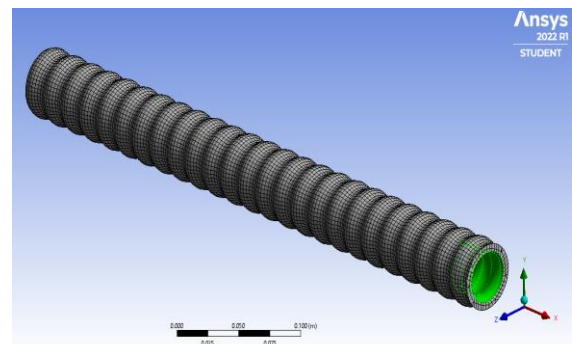


Fig. 2 – Corrugated tube mesh

Table 3 – Detailed of corrugated tube.

Corrugated Tube	
Element size	0.003 m
Nodes	82410
Elements	70400
Volume	0.0010131 m ³
Surface area	0.2688 m ²
Faces	66
Face surface area	0.0012527 m ³

3.1 Temperature distribution

Better tube design performs well in terms of temperature distribution. In this study, the inlet condition for both tube designs were set to the same value, which is 450K and pressure 101.325 kPa. The inlet velocity was set to 8 m/s, 10 m/s, 12 m/s. The temperature outside of the domain was set to 300K, which is the ambient temperature in Ansys software. Hot air enters a corrugated tube at 450K according to figure 3.

Due to inner wall's design, heated air whirled in the tube. The graph shows that the inlet is hotter than the rest of the tube. Yellow indicates a drop in the tube-midpoint heat. At 12 m/s inlet velocity, heat distribution is better along the contour line. The model's lighter side darkens as input velocity increases.

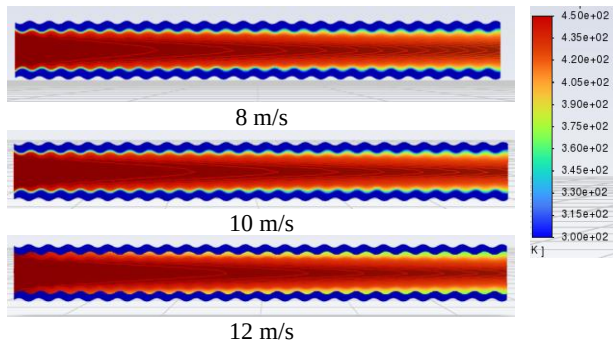


Fig. 3 – Heat distribution for corrugated tube

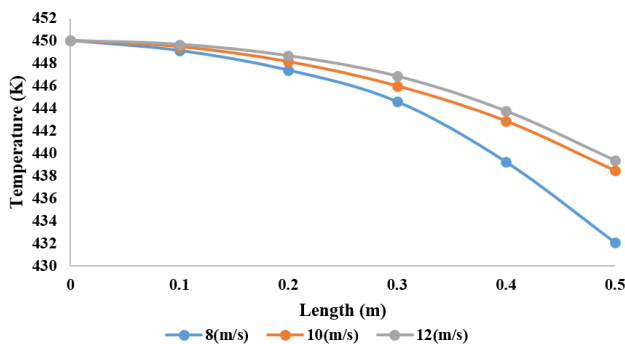


Fig. 4 – Temperature distribution in corrugated tube with inlet velocity

Figure 5 shows the hot air flow inside the internally rifled tube. The air has the same temperature (450K) despite its varied velocity. Using this data, we may determine that the tube's temperature decreased toward the outlet. Inflow velocity increased heat distribution. Corrugated models deliver heat more efficiently and quickly. The tube's outlet has slight temperature variations. Colored lines on a corrugated tube's inner wall indicates poor heat distribution. Internally rifled tube has larger inner wall area than corrugated tube. This reduces surface heat flow, which helps the wall.

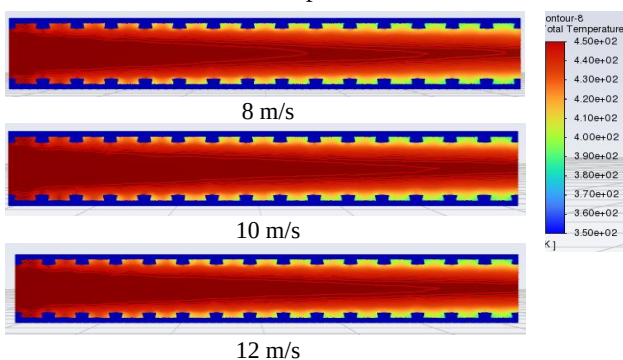


Fig. 5 – Temperature distribution for internally rifled tube

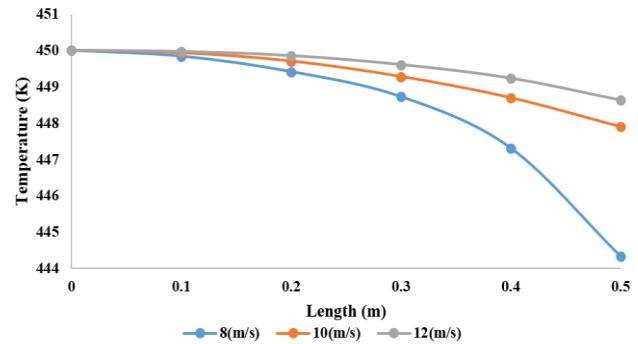


Fig. 6 – Temperature distribution in internally rifled tube with inlet velocity

Heat transfer in the boiler furnace improves boiler performance. A minor increase in tube heat transfer will boost boiler performance. Corrugated and internally rifled tubes' heat transfer performance was measured utilizing total surface heat flux and heat transfer coefficient. According to 7 and 8, when inlet velocity increased, so did the internal rifled tube's heat transfer coefficient. Inlet velocity increases surface heat flux. Heat entering the surface's outer wall is positive; heat exiting the wall is negative. Induced heat flows from hot to cold.

Average heat transfer coefficient and surface heat flux increased linearly with inflow velocity. Inner wall design affects both tubes' heat transmission. Compared to corrugated tube, internally rifled tube had a greater average heat transfer coefficient and surface heat flux. The corrugated tube design is more heat efficient.

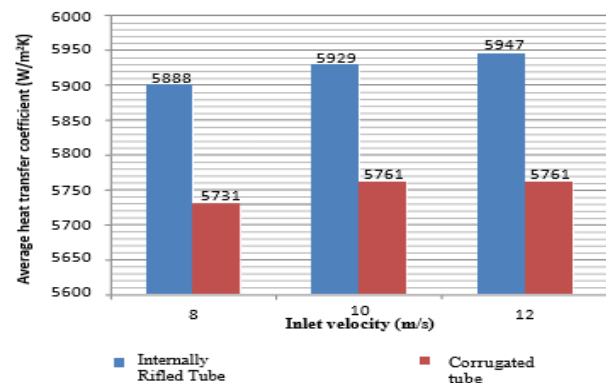


Fig. 7 – Average heat transfer coefficient vs inlet velocity

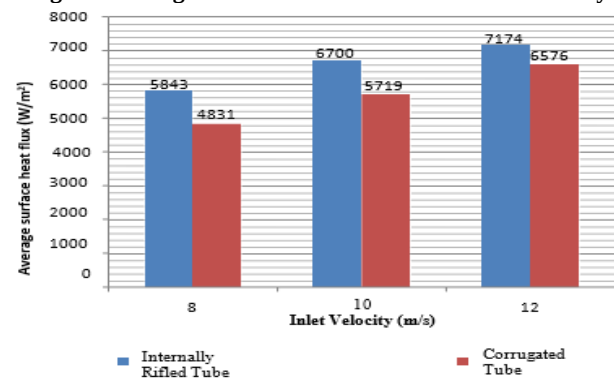


Fig. 8 – Average surface heat flux vs inlet velocity

3.2 Pressure distribution

The pressure loss in a corrugated tube with varied inlet velocity is shown in figure 9. with a velocity of 8m/s, the pressure began to drop in the early region of the tube model. In the subsequent model, when the entrance velocity rise, the pattern of the pressure contour changed and become more red and yellow from the tube's inlet. The results revealed that the model with a 12 m/s input velocity has higher temperature value, which affects the heat distribution within the tube.

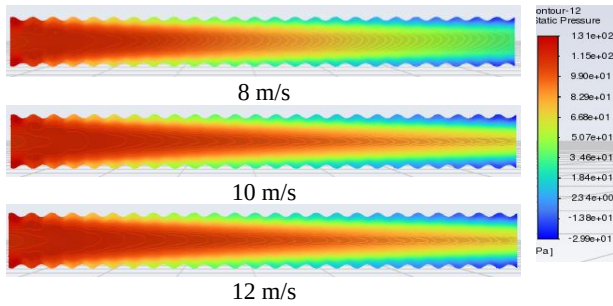


Fig. 9 – Pressure distribution for corrugated tube

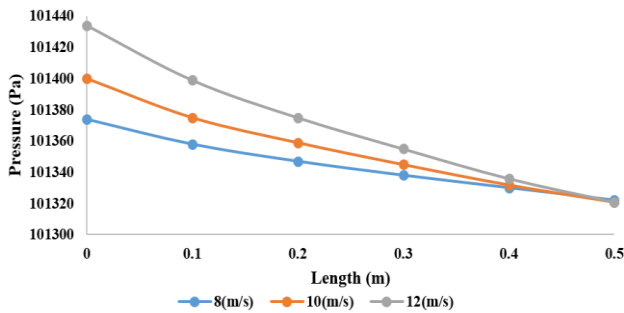


Fig. 10 – Pressure distribution in corrugated tube with inlet velocity

Figure 11 shows the tube's pressure drop. The color contour of the three models with varied entrance velocity was identical to that of the corrugated tube, whose pressure is lower in the slowest model. Rifled tube lost pressure faster than corrugated tube. Finned, rifled walls helped reduce tube pressure. Hot air gradually collided with the flow barrier fins, causing friction. Fluid-pipe friction causes pressure loss [6].

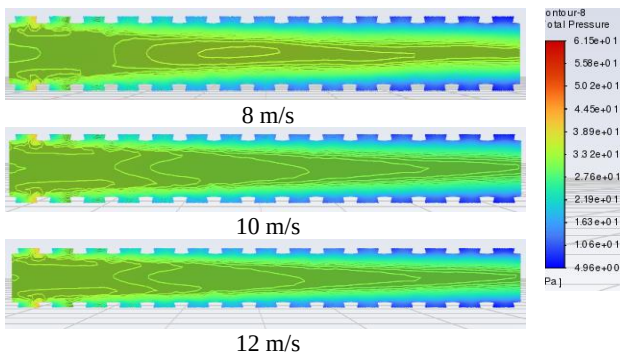


Fig. 11 – Pressure distribution for internally rifled tube

Figure 12 compare the pressure drop in a corrugated tube with different intake speeds. The graph shows that intake velocity increases pressure. As observed in the graph, the model with an input velocity of 8 m/s has the lowest pressure value. High-velocity models had a bigger pressure difference than low-velocity models. For 12 m/s model, it was revealed that the tubes' entrance and output have a large pressure difference. Bernoulli's Principle [5] states that as a fluid accelerates, some of its random motion energy is used to go faster in its direction. As the higher flow rate exerts less pressure, the tube's outlet pressure drops faster.

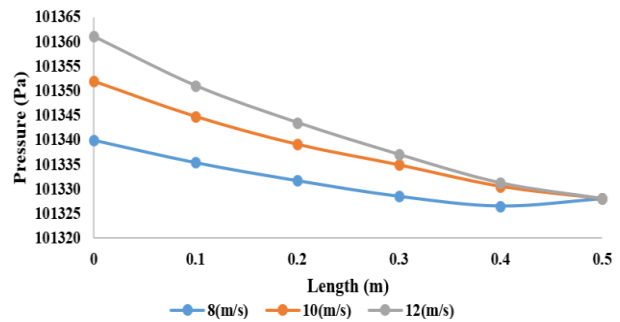


Fig. 12 – Pressure distribution in internally rifled tube with inlet velocity

The pressure decrease in an internally rifled tube with variable input velocity is depicted in figure 11 and 12. It is possible to see that the pressure in three models lowered by a tiny amount. The graph trend reveals that the model with the fastest velocity has the highest outlet pressure, which decreases gradually. Bernoulli's Principle states that a model with a higher inlet velocity has a greater pressure differential.

4. Conclusion

Different tube designs have varying effects, as demonstrated by the study. From the tube's inlet to distance of 0.2 m, the corrugated tube has a somewhat lower temperature than the internally rifled tube. From that point on, the temperature in the corrugated tube proceeds decreasing until it reaches the outlet of the tube. The internally rifled tube model provides a greater exit temperature value. The boiler's total efficiency will be drastically altered by a slight increase in its heat transfer coefficient. An internally rifled tube's heat coefficient is better than internally corrugated tube for a variety of input velocities. Internally rifled tube has a higher average surface flux, which is advantageous for heat transfer performance. In addition, the pressure difference between internally corrugated and internally corrugated was greater. The temperature distribution along a tube increases as pressure increases. Consequently, these results demonstrates that the temperature distribution along the internally rifled tube is more efficient than internally corrugated tube. These flow patterns have influenced the efficiency with which heat can travel along their lengths toward the tube walls.

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