CFD Study for Normal and Rifled Tube with a Convergence Check

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Abstract—Computational fluid dynamics were used to simulate and study the heated water boiler tube for both normal and rifled tube with a refinement of the mesh to check the convergence. The operation condition was taken from GARRI power station and used in a boundary condition accordingly. The result indicates the rifled tube has higher heat transfer efficiency than the normal tube.

Keywords—Boiler tube, Convergence Check, Normal Tube, Rifled Tube.

I. INTRODUCTION

RECENTLY the energy drives the economy which leads to the 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 water tube of the boiler which consists of several tubes heated in a close vessel. The increase of heat transfer coefficient is occurred by change the internal geometry of the tube by swirl and helical shape, this swirl shape generates a centrifugal force on the fluid and forces the flow to be turbulence. The rifled tube ensures a sufficient cooling for the wall of tubes. Moreover, the critical heat flux gets higher values compared to normal tube [1]. A normal 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 characteristic of flow for both rifled and normal tubes with convergence check. There are many studies of this area have shown that the heat transfer coefficient in a rifled tube is better than heat transfer coefficient in normal tube.

II. MODELING AND SETUP

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. Water liquid will be used as the working fluid. Inside the tube with the inner diameter (42.8 mm) and the thickness (8 mm) the rifled tube is consist of four addition parameters, which are number of Ribs height of Ribs width of Ribs and lead angel as shown in Table I.

The (CFD) simulation was applied on a vertical orientation of steel tube (rifled and normal) under constant mass flow rate (0.34kg/sec). Fig. 1 shows the rifled tube's geometry. The heat flux is acting as a hot flue gases inside the boiler and it is also constant for both tubes (rifled & normal) which is equal to ($150 kw/m^2$).

TABLE I
DIMENSION OF A RIFLED TUBE

Number of Ribs	Height of Ribs	Width of Ribs	Lead Angel
8	1.2 mm	3.23 mm	30°

Fig. 1 Geometry of Rifled Tube

The mesh must be sufficiently fine with excellence mesh quality to obtain the stability of the numerical solution and the accuracy of the computational results [2]. Table II shows the mesh quality for normal and rifled after the refinement of the mesh.

TABLE II
MESH QUALITY

Type of Tube	Maximum Aspect Ratio	Minimum Orthogonal	Maximum Skewness
Normal Tube	6.14452e+00	0.232941211220033	0.794668925300881
Rifled Tube	21.467	0.143265497154706	0.970347690029145

III. THEORETICAL CALCULATION

The inlet temperature of the water entering the tube is 500 k and the inlet pressure is 110 bar. The normal tube has a circular flow cross section. Regarding to the rifled tube the hydraulic diameter must be used as in (1) instead of the circular diameter [3]. The Boussinesq approximation will be assumed in this paper therefore the continuity equation will be used to obtain the velocity inside the tube and then the Reynolds number for both normal and the rifled tube, the Reynolds number will be used to find the turbulence intensity and the friction factor to estimate the wall shear stress.

$$D = \frac{4A}{B} \qquad (1)$$

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where D refers to hydraulic diameter, A is a cross sectional area of the tube and B is the wetted perimeter.

IV. RESULTS AND DISCUSSION

Computational fluid dynamics do not provide an exact solution to all problems, but in many cases it is a reliable tool that can provide useful results when it is employed by an experienced user [4]. As shown in Figs. 2 and 3 the residuals are applied to each discredited equation in this study, the white line is represents the continuity equation and it has the highest error accounted for around 0.01. The second highest residual are both K and epsilon, with yellow and pink respectively. The least residual was found in energy equation, at approximately 0.0000001. The other equations X, Y and Z velocities have fairly similar figures, with blue, green and red respectively. Overall, the solutions are convergent in both normal and rifled tubes.

The energy transferred in a boiler takes greater power and time more than the automobile does; therefore, it is important to improve the use of this energy [5]. The outlet temperature in the normal tube is 506 k and for the Rifled tube is 507 k, the increase of 1 k in the section of 0.5m means that the normal tube takes more time to heat the working fluid than the rifled tube. Figs. 4 and 5 show the comparison between normal and the rifled tube in total temperature in the section of 0.5m. The maximum outlet temperature in the normal tube is approximately 527 k and for the rifled tube is around 548 k. As shown above, the red color indicates to higher temperatures. Therefore, in the normal tube the higher temperatures are almost near to the wall of tube and vice versa in the rifled tube, where there is not much red color appeared in the wall as the normal tube. Overall, it can be seen that, the rifled tube provides a sufficient cooling to the wall of tube, which avoids overheating and mix between cold and hot water. This study assumes that the working fluid has incompressible flow that means the change in enthalpy is equal to the change in internal energy. The maximum enthalpy in the smooth tube is (959000 j/kg) and for the rifled tube is (1040000 j/kg) which is higher than in the smooth tube. All of this proves that the rifled tube has a good heat transfer coefficient and therefore less energy consumption but the energy is not only in the heat transfer characters which mean there are different parameters that control the energy, like pressure. As shown in Figs. 6 and 7, the comparison between smooth and rifled tubes in pressure drops. For the smooth tube the total pressure in the section of (0.5 m) is (64.9 Pascal) and for the rifled tube is (122 Pascal). The pressure drop in the rifled tube is 1.8 times then the pressures drop in the smooth tube. This high pressure drop in the boiler tubes affects the natural circulation and forced circulation factor of the boiler, it will be need an additional HP in the pump to cover this pressure drop.
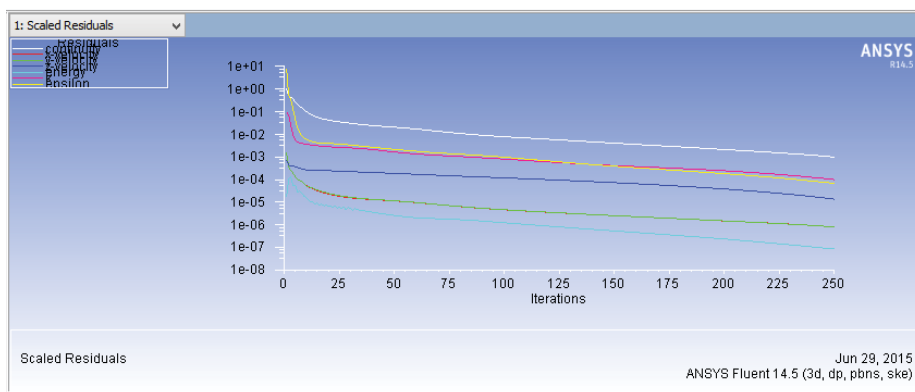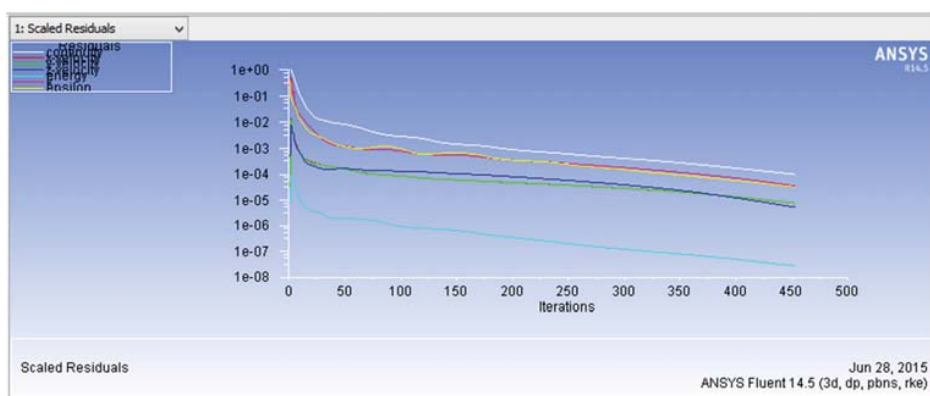

Fig. 2 Scaled Residual for Normal Tube

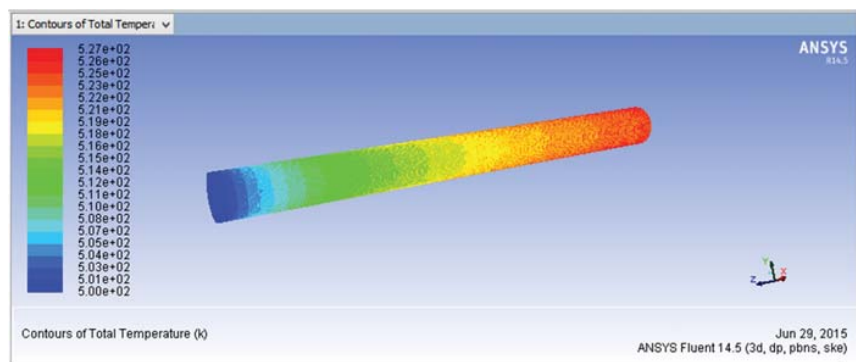Fig. 3 Scaled Residual for Rifled Tube

Fig. 4 Contours of total temperature for a normal tube
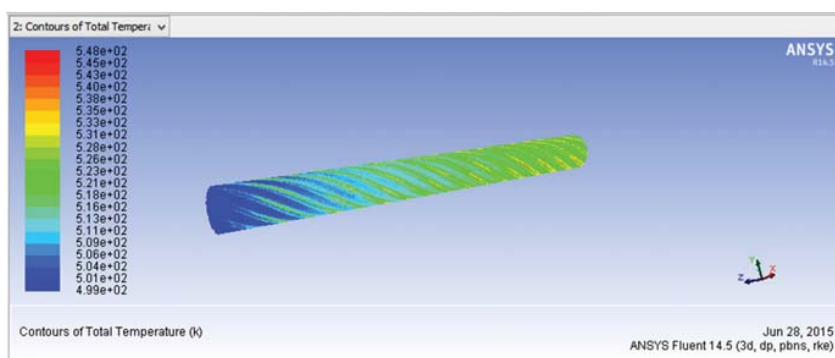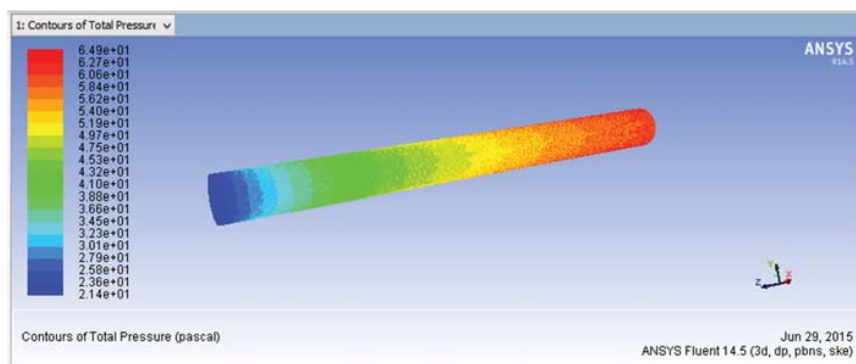

Fig. 5 Contours of total temperature for a rifled tube
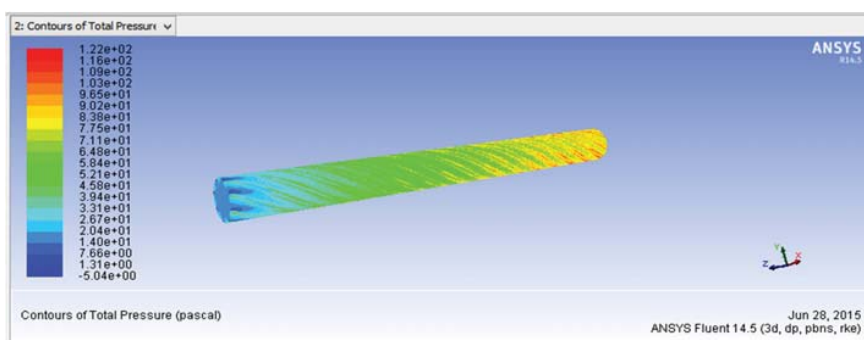

Fig. 6 Contours of total pressure for a normal tube

Fig. 7 Contours of total pressure for a rifled tube.

V. Conclusion

The geometer was drawn with same diameter for both normal and rifled. The mesh was created with a good mesh quality. The result showed that the heat transfer is increased in a rifled tube but the pressure drop is high in rifled tube.

Acknowledgment

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