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Simulation Studies on the Effect of Porous Twisted Plate Inserts on the Performance of Fire Tube Steam Packaged Boiler

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Abstract – *The effects of porous twisted plate as insert on heat transfer performance and flow characteristic in fire tube boiler are being investigated by simulation in this present article. The porous twisted plate was designed with different number of holes (1, 2, 3 and 4) with variation ranges of diameter (4mm, 8mm, 10mm, and 15mm). The designs was simulated by using ANSYS Fluent software in laminar flow condition with different Reynolds number (Re = 1350-1500). The data collected was compared to the plain twisted plate. The result shows that invention of holes on the twisted plate creates lower surface area. Nevertheless, the velocity is increase with increasing number of holes and reduce diameter of holes. Besides, the increasing velocity of the flow inside the tube was approached the turbulence flow thus allowing more heat transfer across the tube. The larger number of holes and the smaller the diameter of holes resulting better heat transfer rate.*

Keywords: fire tube boiler, coil plate, heat transfer enhancement, laminar flow, turbulent flow, number of holes, diameter of holes

1.0 INTRODUCTION

A boiler is a type of heat exchanger that converting water to steam through boiling process. It has been used in industrial application in various processes such as power generation, central heating and sanitation. It has been reported that the efficiency of this process is only up into a range of 70-80% [7]. Increasing the efficiency by enhancing the heat transfer will produce high capability heat exchanger with minimum capital cost. The main objective to enhance the heat transfer rate is to encourage the heat fluxes and leads to reduction size of heat exchangers and saving primary energy. Twisted plate inserts has been studied by many researchers as passive heat transfer enhancement technology [1-6]. The heat transfer in tubes could be enhance by generating swirls flow which increase the fluid mixing inside the tube and approach turbulence condition thus allowing more heat transfer [1]. One of the members in passive enhancement techniques is porous twisted plate which involved extensively in heat exchangers.

In the past works, Sarada et al. [2] studied the frictional and heat transfer characteristics in turbulent flow using various widths of twisted tape inserts under constant wall heat flux. Dewan et al. [3] described the effect toward the flow after implemented the augmentation techniques. Yadav [4] had conducted an experiment to investigate the influences of the half-length twisted

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tube inserts on pressure drop and heat transfer characteristics in U-bend double pipe heat exchanger. Naphon [5] carried an experiment to investigate the heat transfer characteristics and pressure drop with twisted tape inserts in the horizontal double pipes. Islam and Mozumder [6] was investigated the forced convection heat transfer performance of an internally finned tube. In the present work, the simulation was successfully done. The Ansys Fluent software was used to demonstrate the effect of number of holes and size of diameter to increase the rate of heat transfer in single fitted tube.

2.0 SIMULATION SET UP

In the simulation work, the twisted plate was designed and consists of five segments. Fig. 1 shows the example of one segment of the twisted plate. The twist ratio (y/L) and width ratio (w/D) are 0.25 and 0.84. These two parameters are kept constant throughout the simulation instead the diameter and number of the holes were created in difference size.

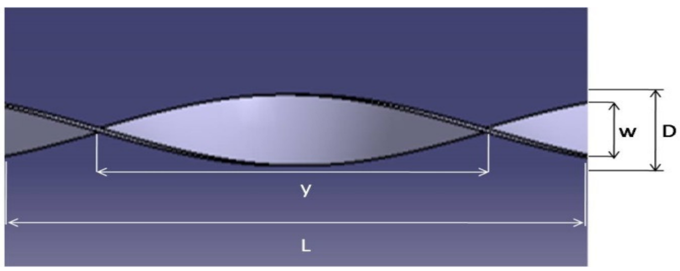
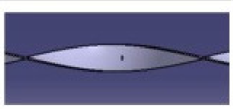
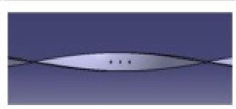
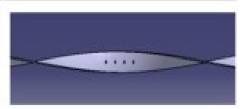
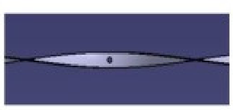
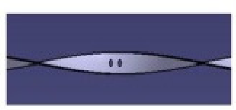
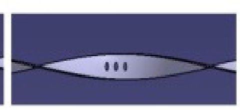
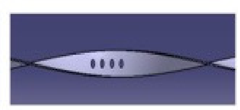
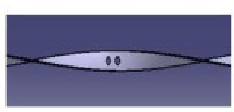
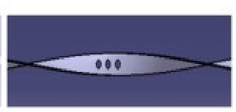
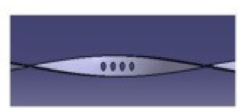
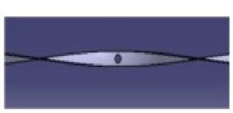
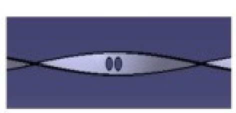
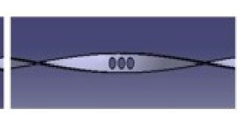
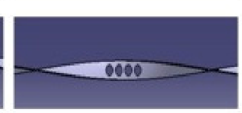


Figure 1: The geometry of coil plates

Meanwhile, the diameter of the holes is varied from 4mm, 8mm, 10mm and 15mm and the number of holes is consists of one, two, three and four holes. Table 1 shows the configurations of twisted plate with difference number of holes and diameter sizing.

Table 1: Boundary conditions and numerical setup

	1 hole	2 holes	3 holes	4 holes
4mm				
8mm				
10mm				
15mm				

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The hot air flowing inside the generating tube is assumed to be laminar flow with temperature inside 160°C. The air is incompressible and steady. The hot air is also assumed to have a constant heat flux with no slip condition. There is no heat conduction occur at the surface of the coil plates. The hot air is flowing from the inlet at certain velocity and goes out through the outlet. The constant and varied parameters are shown in the Table 2 below.

Table 2: Boundary conditions and numerical setup

Parameters	Value	Constant /Varied
Inlet Velocity	(m/s) 1	Constant
Inlet Tube Temperature	(K) 433	Constant
Inner Tube Wall Temperature	(K) 433	Constant
Twist ratio	0.25	Constant
Width ratio	0.84	Constant
Number of Holes	0, 1, 2, 3, 4	Varied
Diameter of Holes	(mm) 4, 8, 10, 15	Varied

The heat transfer across the tube can be defined as Eq.1:

$$\dot{Q} = hA_s(T_s - T_\infty) \quad (1)$$

The Reynolds Number is defined as Eq.2:

$$Re = \frac{VD}{\nu} \quad (2)$$

From the Reynolds number obtained, the value of Nusselt number can be determined based on the Eq.3:

$$Nu = 1.86\left(\frac{Re \Pr D}{L}\right)^{\frac{1}{3}}\left(\frac{\mu_b}{\mu_s}\right)^{0.14} \quad (3)$$

By obtaining the value of Nusselt number, the heat transfer coefficient, h also can be determined and it is expressed as Eq.4:

$$Nu = \frac{hD}{k} \quad (4)$$

The pressure drop can be calculated using the Eq.5:

$$\Delta P = f\frac{L}{D}\frac{\rho V^2}{2} \quad (5)$$

3.0 RESULTS AND DISCUSSION

3.1 Static Temperature Contour Plots

Fig. 2 shows the static temperature contour plot for plain tube, plain twisted plate and porous twisted plate with different diameters. It can be observed that the 4mm diameter design with 4 numbers of holes has the greater temperature distribution and the 15mm diameter design with 4 numbers of holes has the lowest one. Higher hot temperature distribution means more efficient mixing of hot air inside the tube and better heat transfer. It also can be observed that

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the plain tube has the normal distribution of temperature because there is no secondary flow that been created. Larger number of holes and smaller diameter of holes will produce more reversed flow between the tube wall and the coil plate surface.

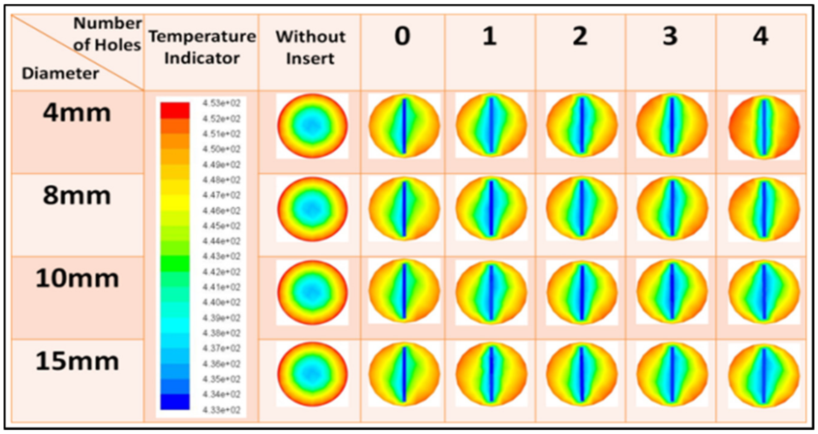

Figure 2: Static Temperature Contour Plots

3.2 The Effect of Reynolds Number and Nusselt Number

Fig. 3 presents the variation of Reynold Number for difference diameter of holes with difference number of holes. It can be observed that by increasing the number of holes higher Reynolds Number will produce. The increase in Reynolds Number is due to swirl flow generated which leads increment of velocity inside the tube. The indication by Reynolds number proves that the flow started to approach the turbulence flow with larger number of holes with smaller size of diameter.

Fig. 4 presents the variation of Nusselt Number for difference diameter of holes with difference number of holes. The Nusselt number is increased by increasing the number of holes with smaller size of diameter. Higher Nusselt number corresponds to better convection heat transfer inside the tube. The observations indicate that by decrease the size of diameter, the intensity of heat transfer due to swirl flow is increase since the surface area contact to the flow was increased and provides more heat transfer rate by convection.

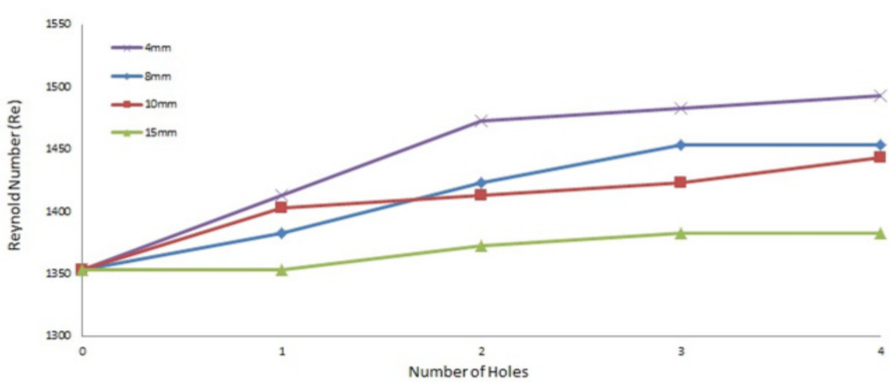

Figure 3: Variation of Reynolds Number

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Fig. 5 presents the variation of Nusselt Number with Reynolds Number for difference diameter of holes with difference number of holes. The heat transfer augmentation is increased conservatively with Reynolds Number which indicates better heat transfer rate.

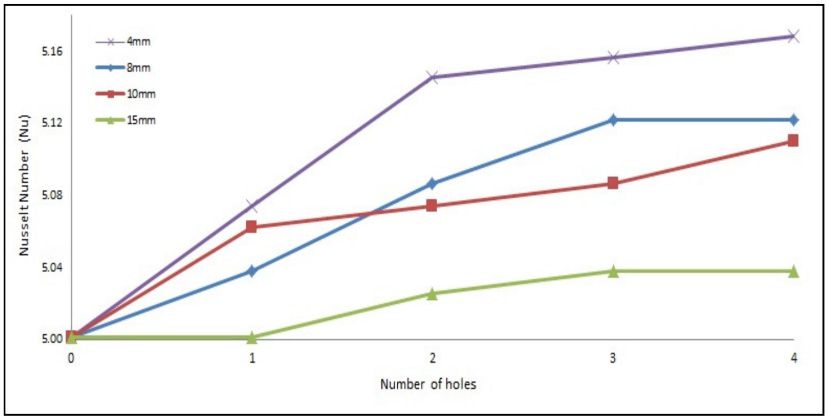

Figure 4: Variation of Nusselt Number

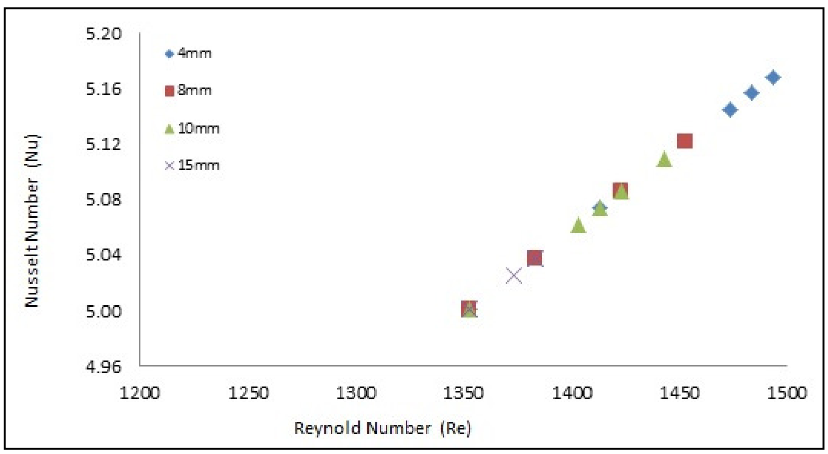

Figure 5: Nusselt Number vs Reynold Number

3.3 The Effect of Heat Transfer and Pressure Drop

Fig. 6 presents the heat transfer distribution for difference diameter of holes with difference number of holes. The highest value of heat transfer rate was determined from 4mm diameter with 4 numbers of holes. It also can be seen that the heat transfer rate was decreasing for 15mm diameter. The effect of reduction in velocity leads to not-fully developed of fluid mixing inside the tube. As surface area of the coil plate decreased in the present of holes creation, the velocity of fluid inside the tube is increased. Since the parameter that increases the value of heat transfer rate $\dot{Q}$ is the heat transfer coefficient, h which is affected by the velocity of the fluid, the increment in velocity of the fluid will increase the heat transfer rate.

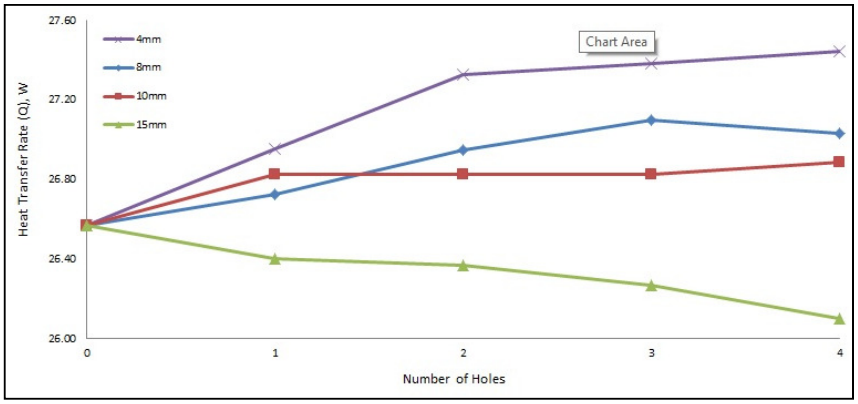

Figure 6: Heat transfer rate distribution

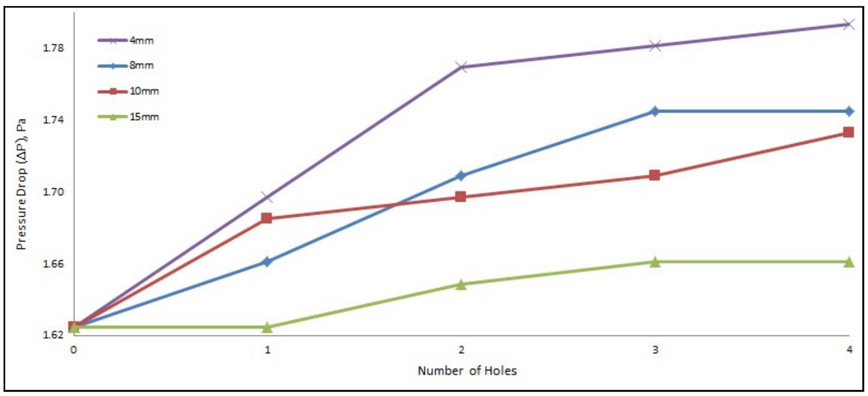

Figure 7: Pressure drop distribution

Fig. 7 presents the pressure drop distribution for difference diameter of holes with difference number of holes. The 4mm diameter design coil plate has the highest value of pressure drop, ΔP, which is approximately 1.90 Pa for 4 numbers of holes. It also can be seen that the smaller the diameter of holes, the higher the pressure drop produced. Increasing number of holes also will increase the pressure drop. By inserting the coil plate into the generating tube, it will leads to a pressure drop as stated by Prajapati et al. [1] and has been proved in the graph shown above. Since the velocity of the fluid affect the value of pressure drop, increment in flow velocity will increase in pressure drop.

4.0 CONCLUSSION

The investigation revealed the effect of number of holes and size of diameter of the porous twisted plate to increase the rate of heat transfer in single fitted tube by studying the effect of the coil plate's geometry in enhancement of heat transfer using simulation software. It is found that the selection of geometry of twisted tape play a vital role in enhancing the heat transfer rate. The surface modification twisted tape increases higher heat transfer compare to plain twisted tape and plain tube.

The main conclusion is summarizes as below:

a) Porous twisted plate produced higher heat transfer compare to plain twisted tape.

b) Smaller diameter and higher number of holes created better heat transfer rate, Reynolds number, Nusselt number and pressure drop.

c) The increment in velocity of the flow will developed fully fluid mixing along central region and enhanced heat transfer coefficient.

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