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EXPERIMENTAL INVESTIGATION ON HEAT TRANSFER ENHANCEMENT BY USING POROUS TWISTED PLATE AS AN INSERT IN A FITTED TUBE

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ABSTRACT

This article reports the investigation on the effects of porous twisted plate as insert to enhance heat transfer performance and flow characteristic fora single fitted tube. The porous twisted plate was designed with 3 different numbers of holes (1Hole, 2Holes and 3Holes) with 4mm diameter on each segment. The actual fitted tube of the boiler was used and inserted with plain and porous twisted plates. The collecting result was compared with the plain tube without any insert. The result shows that creation of holes changed the flow profile and generating secondary flow and approaching turbulence flow. Furthermore, the velocity of the flow was increased and allowing more fluid mixing inside the tube thus provide more heat transfer across the tube. Porous twisted plate with larger numbers of holes enhance better heat transfer rate compared to plain tube and plain twisted plate.

Keywords: heat transfer, porous twisted plate, tube, fluid mixing.

INTRODUCTION

Heat transfer enhancement in heat exchangers has been reported critically in recent years. The aim is to produce efficient heat exchangers with less expensive and pumping power required but operates as standard heat exchangers. The enhancement technique can be segregates into three categories which is active, passive and compound technique [1]. However, majority of the researchers are attracted into passive technique since it does not require any external power source and less cost involved.

Twisted plate as inserts in fitted tube has been explored widely since it is easy to install, has simple configuration and cost effective. Twisted plate provides enhancement by generating swirl flow and allow fluid mixing on near and central region of the flow inside the tube thus increase the overall heat transfer rate [2-10]. Modification on surface geometry of the twisted plate has proved the potential of twisted plate to enhance heat transfer in heat exchangers. By establishing a higher heat per unit base of surface geometry, the enhancement will be accomplished [11]. In this work, the modification on the surface area was made by creating holes on the segment of twisted plate. The porous surface area has expected to increase the heat transfer coefficient without significantly changing effective surface area, A. These will resulting in boundary-layer separation and exchange the fluid between the wall and core region of the flow thus increase the heat transfer rate inside the tube.

In the past works, Dewan *et al.* [11] described the effect toward the flow after implemented the augmentation techniques. Yadav [12] had conducted an experiment to investigate the influences of the half-length twisted tube inserts on pressure drop and heat transfer characteristics in U-bend double pipe heat exchanger. The investigation of heat transfer characteristics and pressure drop with twisted tape inserts in the horizontal double pipes was studied by Naphon [13]. Islam and Mozumder [14] were investigated the forced convection heat transfer performance of an internally finned tube Heat transfer enhancement by tapered twisted tape as inserts was studied by Piriyarungrod *et al.* [15]. Chang *et al.* [16] were investigated the influence of ribbed spiky twisted tape with and without edge notches on thermal performance of tubular flow. An experimental study on the effect of rotated axis length by inserting uniform/non uniform twisted tapes with alternate axes have been studied by Eiamsa-Ard S. *et al.* [17]. Sheikholeslami *et al.* [18] have done an experimental study on the influence of perforated circular ring using sensitivity analysis. The effect of porosity ratio on perforated twisted tape as inserts in fitted tube was study by Bhuiya *et al.* [19] and they found the potential of perforated twisted tape to enhance heat transfer in fitted tube. Presently, very few articles reported on heat transfer enhancement in laminar fitted tube with porous surface area. Therefore, the experiment was conducted to study the temperature distribution and heat transfer characteristic for fitted tube with porous surface area as inserts and the result gained was compared with the plain tube and plain twisted plate data.

Data reduction

The mass flow rate was calculated by

$\dot{m} = \rho A V$ (1)

where: ρ = the density of air, A = cross sectional area of test section, V = mean in let velocity.

The heat was absorbed by the fluid was calculated by

$$Q = \dot{m}Cp\ (To - Ti) \quad (1)$$

where Cp = specific heat of air, Ti = inlet temperature of air, To = outlet temperature of air.
The heat flux was obtained from

$$q = \frac{Q}{\Pi\ D\ L} \quad (3)$$

where D = diameter and L = length of the tube

The local heat transfer coefficient, *hx* was achieved from

$$hx = \frac{q}{Twx - Tbx} \quad (4)$$

where Twx = local wall temperature, Tbx= bulk fluid temperature.

The bulk fluid temperature was obtained from

$$Tbx = Ti + \frac{qWX}{\dot{m}Cp} \quad (5)$$

where W= wetted perimeter, X=axial distance of the tube

The Nusselt number is calculated by giving equation

$$Nu = \frac{hD}{k} \quad (6)$$

where k = thermal conductivity of air

Experimental setup

The schematic diagram of the experimental set-up is shown in Figure-1. Hot gas emitted from the boiler was used as working fluid of the experiment with degree 100-200°C. The exhaust of the boiler was connected to a single pipe that connects to the test section which was integrated with thermocouples to measure the wall temperature. The hot gas emitted from the boiler will enter and circulate to the pipe and enter the test section. The test section was original fitted tube of the boiler has been heated by a heater with nichrome wire to provide constant boundary layer condition. The test tube has inner diameter 24.5mm and outer diameter25 mm with total length 1500 mm. The inlet and outlet temperature were measured by using thermocouples that inserted in small holes on the test tube and sealed to prevent leakage. The calibrated thermocouples were used to measure the temperatures. In order to measure the wall temperature inside the test tube, holes were drilled outside of the test tube with 5mm diameter at 4 different axial locations, with length between each location is 300mm. Thermocouples were placed at each location and sealed with glass wool to prevent heat loss. All the temperatures including inlet, outlet and wall temperatures were manually observed 5 times with accuracy of 0.1°C, in every of 5 minutes, and the average values were taken for further analysis. The pressure drop across the test section was measured by using u-tube manometer and hot wire anemometer was used to measure the flow velocities. The heat transfer was conducted in constant heat flux at Reynolds number 3000 to 18,000.

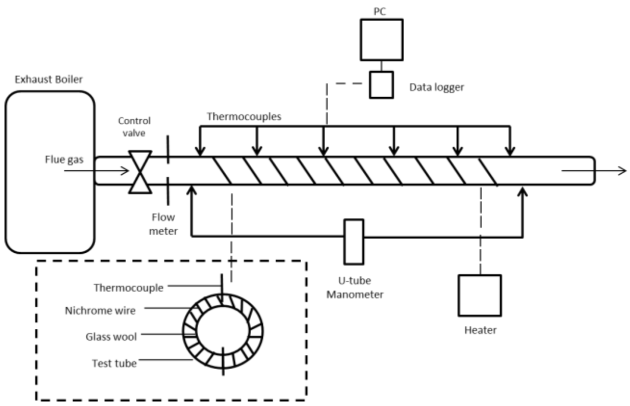

Figure-1. Schematic diagram of experimental set-up.

For enhancement purpose, 4 pieces of twisted plate were used and each piece with thickness of 1mm, width ratio of 0.8 and relative twist ratio of 3.5 were fitted in the full length 1500 mm of tube. All pieces were made from copper and have same specifications. For fabrication of porous twisted tape, the twisted plates were drilled with 4mm diameters on surface of each segment with different number of holes between 1 to 3 holes respectively as shown in Figure-2. The porous twisted tapes were fully inserts into the test section for enhancement.

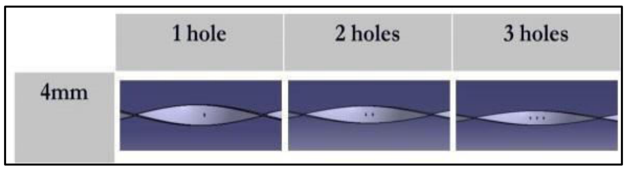

Figure-2. Configuration of hole for twisted plate.

RESULTS AND DISCUSSIONS

The result that effects on thermal performance were investigated in this study. The experiment was conducted to obtain the thermal performance inside the test section by using plain twisted plate, porous twisted plate and without any insert. The temperatures distribution at different axial location were presented which followed by explanations on thermal performance. The result obtained by porous twisted plate was compared with plain tube without insert and plain tube equipped by plain twisted plate.

VOL. 10, NO 21, NOVEMBER, 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Heat transfer characteristic

Figure-3 shows the variation of wall temperatures along the 4 different axial locations of the test tube at the same Reynolds Numbers for plain tube, plain and porous twisted plate. It can be seen clearly that at constant Reynolds Number, the wall temperatures that passing through the test section is higher for porous plate inserts, followed by plain twisted plate and plain tube. Porous surface with 3 holes on each segment was produced the highest surface temperature distribution followed by 2 holes and 1 hole at any location. Since the plain tube has less contact area with the working fluid, the tendency of the fluid to flow stagnantly in laminar flow profile is higher compared to inserted tube. Therefore, the ability to transfer heat was low and surface temperature was lower along the test section.

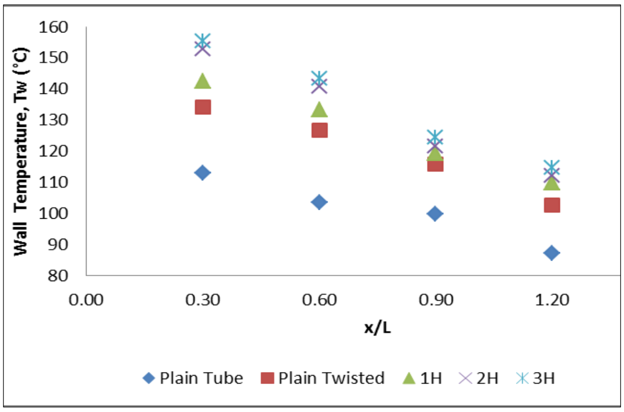

Figure-3. Wall temperature distribution.

The axial variation of bulk fluid temperatures along the test section for plain tube and inserted tube is shown in Figure-4. At constant heat flux condition, the calculated bulk temperatures increased linearly. From the observation, test tube with porous insert has higher bulk temperatures than other inserts and the twisted plate with 3 holes was produced highest bulk temperature distribution. This indicates that more heat was transferred from the tube wall as the hot gas passing through the test section.

Figure-5 shows the comparison of local heat transfer coefficient along the test section area for plain tube, plain twisted plate and porous surface plate. Figure-5 indicates that fitted tube with insert produced higher heat transfer coefficient. The heat transfer coefficient for plain tube was lower since the boundary layer has minimum disruption.

For fitted tube with porous surface area, the Reynolds number was found higher than plain tube and plain twisted tape. The holes surface area attributed to increment of turbulent intensity and generated swirl flow. The boundary layer along the tube wall would be thinner with the increment of swirl flow which led to more heat flow through the fluid. As a result, it increased the Reynolds number and the total heat that took away along the test section. The secondary flow was generated at the entrance region thus exchanged the fluid between wall and core region. When the portion of boundary layer closet to the wall, the disruption between these layers was increased and boundary layer separation was occurred. The separation of these layers significantly increased the amount of heat that took away between the wall and working fluid. As the temperature difference between the wall and working fluid lower in inserted tube, the heat transfer coefficient in the inserted was higher than in the plain tube.

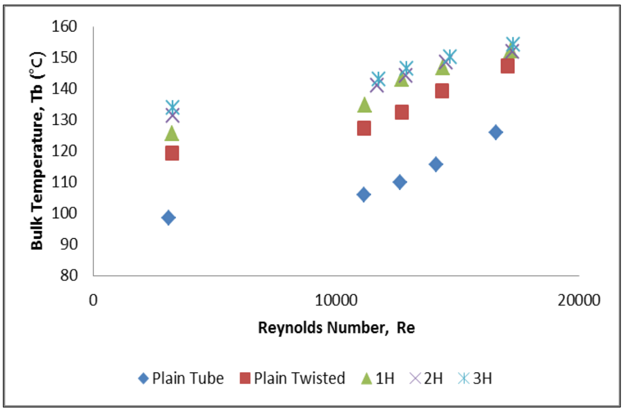

Figure-4. Bulk temperature distribution.

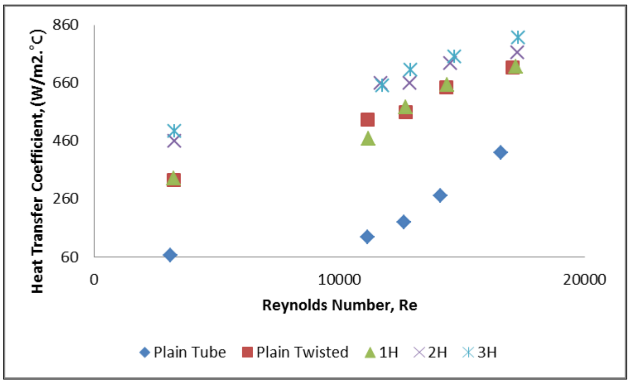

Figure-5. Local heat transfer coefficients.

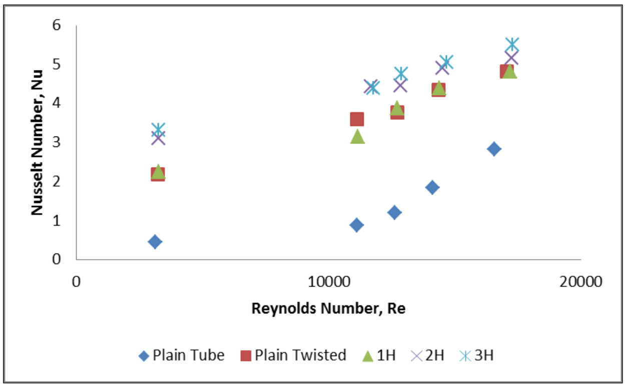

Figure-6. Variation of Nusselt number for different Reynolds number.

Figure-6 shows variation of Nusselt number with Reynolds number for porous twisted plate, plain twisted plate and plain tube without any inserts. Porous twisted plate with 3 holes obtained highest Nusselt number following by twisted plain without hole and plain tube. The strong turbulence intensity generated by holes on inserts increased the flow mixing and leads to enhancement of heat transfer.

CONCLUSIONS

The temperature distribution and heat transfer characteristic of the porous surface twisted plate as inserts in fitted tube are presented in this article. The result obtained was discussed and proved that porous surface twisted plate enhanced the heat transfer rate inside the tube. The selection on surface geometry of twisted plate plays a vital role in enhancing the heat transfer rate. In conclusion, twisted plate with porous surface area provides higher heat transfer compare to plain twisted plate and plain tube without any insert. It was observed that twisted tape with porous surface area are more dominant in providing a longer path for fluid mixing which led to enhance heat transfer rate. The main conclusion is summarizes as below:

a) Twisted plate with porous surface area has higher surface temperatures at all axial locations along the tube.

b) The bulk temperatures distribution indicates the overall of heat that took away is increased linearly for both inserts and without insert.

c) The heat transfer coefficient was higher for porous surface area, followed by plain twisted plate and plain tube without insert.

d) Porous twisted plate enhanced better heat transfer rate by developing better heat transfer characteristics without significantly changing effective surface area.

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ARPN Journal of Engineering and Applied Sciences

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