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Thermal hydraulic characteristics of turbulent single-phase flow in an enhanced tube using louvered strip insert with various slant angles

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ABSTRACT

Effect of slant angle (α) of louvered strip insert on single-phase forced convection heat transfer and friction factor of internal flow was investigated experimentally. The parameter of slant angles (α) 15°, 20° and 25° was examined at the Reynolds number (*Re*) of 5300–17,500. The plain tube was also performed for comparison. The results show that the louvered strip insert provided the increases in heat transfer and friction factor up to 77.02% and 3.35 times above the plain tube. The results also indicate that heat transfer and friction factor increased with increasing slant angle. The highest slant angle yielded the highest thermal performance factor in the value of 1.12. Empirical correlations were also developed for Nusselt number and friction factor based on experimental data.

1. Introduction

The investigation of heat transfer and fluid flow characteristics has played an important role in theory and application of the equipment with heat exchange process such as tube heat exchanger. The main purposes are to improve the convection heat transfer coefficients, reduce the pumping power and give the more effective heat exchange equipment. There are several methods employed for enhancing heat transfer in a tube, and passive methods are the mostly implemented. One of the most passive methods that were used in the application of smooth-tube heat exchanger was insert devices [1–21]. Insert devices involve geometric forms that are inserted into a circular tube as a turbulator. Turbulator elements expect to increase turbulence of the flow and also reduce the thermal boundary layer thickness and reveal on enhancing heat transfer coefficient of the surface of the flow. In general, the main mechanism of heat transfer augmentation by insertion offered (1) the reduction of a hydraulic diameter of heat transfer tube causes an increase of flow velocity and curvature, which in turn increases the shear stress near the wall and drives secondary motion, (2) the velocity near the tube wall increases due to the blockage of the insertion which reduces the thickness of the boundary layer, (3) the induced swirling flow makes a better fluid mixing between the core and the near-wall flow regions, and (4) the extra heat transfer through thermal contact [3,4].

Many turbulator forms are available to intensify the laminar and turbulent flow heat transfer in a tube such as twisted tape, strip tape, coil wire, helical wire, helical screw-tape, and so on. Recently, most researchers have been experimentally and numerically studied the use of louvered strip inserts on the heat transfer augmentation of the heat exchanger [11–18]. Louvered strip insert is a kind of turbulator, which shaped like flat-leaf made from thin metals and mounted on the wire. Pethkoll et al. [11] found that louvered strip insert in a parallel-flow concentric tube heat exchanger gives better performance compared with without insertion (plain tube). The tube installed with louvered turbulators created the high recirculation flow, disturbing the growth of the boundary layer, leading to the better heat transfer by slighting the boundary layer thickness. The experimental results showed that the average of Nusselt number and friction factor was increased compare with the plain tube. Eiamsa-ard et al. [12] experimentally investigated heat transfer and friction characteristics of a concentric tube heat

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exchanger with louvered strip elements with a backward and forward arrangement with various inclined angles (θ = 15°, 25° and 30°). The results indicate that the presence of louvered strips conducts a higher heat transfer rate over the plain tube. The Nusselt number increases with the increase of inclined angle. Louvered strip generates a strong turbulence intensity guiding to rapid mixing of the flow especially at higher inclined angles. Fan et al. [13] evaluated trough numerical simulation the characteristics of heat transfer, flow resistance, and overall thermo-hydraulic performance of turbulent airflow in a circular tube installed with louvered strip inserts. The parameters were different slant angles and pitch of the louvered strip. The numerical results revealed that combination of these two parameters affected the heat transfer rate and flow resistance. Larger slant angle and small pitch effectively not only enhance the heat transfer rate but also increase the flow resistance. The effect of slant angles is more significant than inserts pitch, due to slant angle can create a higher radial flow velocity.

Mohammed et al. [14] studied numerically the effect of louvered strip insert installed in a circular double heat exchanger on thermal and flow characteristics using various types of nanofluids. The combination of various slant angle and pitch was investigated in this study. The results show that combination of the highest slant angle (α) of 30° and lowest pitch (S) of 30 mm can promote the heat transfer by approximately 367%–411% over the plain tube. The higher slant angle generates a strong turbulence intensity leading to rapid mixing of the flow. The effects of the louver and delta winglet geometry on the thermal-hydraulic performance of such a compound heat exchanger were performed by Huisseune et al. [15]. A small fin pitch and large louvered angle promote a strong flow deflection and thus has a large contribution of the louvers. The influences of a modification of small pipe insert with various spacer lengths and arc radii with different slant angle on heat transfer enhancement, flow resistance and thermal-hydraulic performance were experimentally studied by Wenbin et al. [16]. A small pipe was formed into an S-shape and installed on a core rode. Tubes fitted with pipe inserts affect the heat transfer coefficient and friction factor. Review article on heat transfer enhancement by using various types of inserts was developed by Tabatabaeikia et al. [17]. The review revealed that among the types of insert devices in various conditions and arrangements, louvered strip insert had better function in backward flow compared to forward flow. Compared to all kind of insertions, the utilization of louvered strip insert can significantly improve the heat transfer coefficient with providing a more reasonable friction factor. Park et al. [18] carried out experiments using a louvered fin heat exchanger to study the effect of inclination angles on thermal performance of the repeated frosting/defrosting cycles. They reported that the heat transfer rate and pressure drop varied less during repeated cycling for bigger inclination angles.

A summary of the related experimental investigations of heat transfer enhancement performed at our laboratory [22–25] reveals that both heat transfer coefficient and friction factor of internal flow equipped with insertion were consistently higher than those of plain tube. Yaningsih et al. [22] carried out an experimental study on the convective heat transfer enhancement in a concentric tube heat exchanger with a different axial pitch ratio of perforated twisted tape inserts. Continuing the experimental investigation for twisted tape insert, the effect of various wings with alternate axis on thermal performance was studied [23]. The experimental results provided that heat transfer rate and friction factor of the heat exchanger equipped with our proposed twisted tape inserts provided significantly higher than those of the plain tube and with typical twisted tape insert. Experimental investigation of heat transfer enhancement using V-down continuous rib roughened plate with attack angles of 30–80° in a solar air heater for turbulent flow with uniform heat flux was reported [24]. The use of artificial roughness was compared with the smooth duct. The result showed that the maximum value of enhancement Nusselt number and friction factor was for an angle of attack of 60°. Moreover, effect of punched delta winglet vortex generator inserts (PDWVGs) on turbulent convective flow inside a circular tube was experimentally investigated [25]. The heat transfer rate showed uptrend with increasing of the attack angle and Reynolds number. The friction factor revealed uptrend with increasing attack angle but yields the downtrend with increasing Reynolds number.

According to the literature review above, the application of louvered strip inserts has been shown more attractive than other insert devices due to a significant improved pressure loss. Hence, to achieve the ideal thermal performance factor some parameters of the louvered strip inserts are to be considered. The parameters that affect the performance of the louvered strip inserts are louvered strip geometry (elliptical shaped leaves, diamond shaped leaves, square shaped leaves), the angle of the installation of louvered strip against the wire (slant angle or inclination angle), the arrangements of louvered strip insert against the fluid flow direction (forward or backward arrangement). In the present work, a new design of louvered strip insert is developed. Compared to the previous reported works, the novel concept of the present study proposes the different slant angles and material of louvered strip insert. Effects of slant angle are examined to investigate the characteristics of heat transfer and friction factor. Empirical correlations are also proposed for predicting the heat transfer and friction factor based on experimental results.

2. Experimental method

2.1. Apparatus and procedure

Fig. 1 shows a schematic diagram of experimental apparatus. The experimental apparatus consists of three major components; the test section, fluid flow system, and data measurement system. The test section was a horizontal concentric tube heat exchanger, made from smooth aluminum tube. The outer diameter (d_o) and inner diameter (d_i) of the inner tube were, respectively, 15.8 mm and 14.3 mm with 2500 mm in length (L_i). Outer tube was 1950 mm in length (L_o). The inner diameter (D_i) and outer diameter (D_o) were 23.4 mm and 25.4 mm, respectively. The test section was insulated with glass wool to minimize heat losses to the atmosphere through convection and radiation. The insertion was installed inside of the inner tube. The experiments were conducted under two conditions both with louvered strip insert and without louvered strip insert (plain tube).

The fluid flow system consists of two working fluids, hot water passed through the inner tube, and cold water was at the outer tube in the counter-current direction. Hot water flow was a closed loop system. After passing through the test section, the fluid flowed through the hot water tank and recirculated to the experimental setup. The hot water was heated by the 4000 W electric heater, which was controlled by temperature to maintain a constant temperature in the hot-water tank.

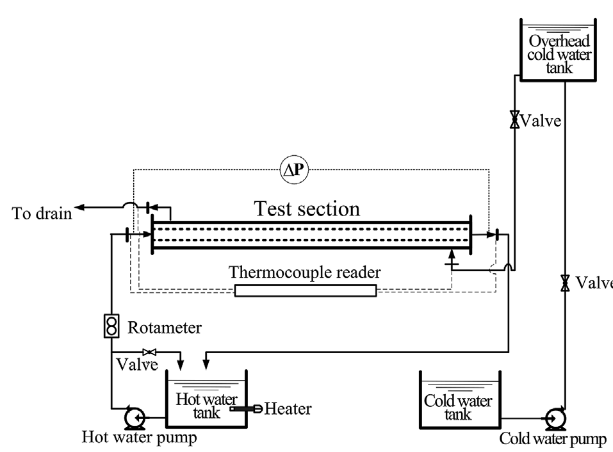

Fig. 1. Schematic diagram of experimental apparatus.