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RESEARCH ARTICLE

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Experimental Investigations of Heat Transfer Enhancement in a Double Tube Heat Exchanger with Rectangular Grooved

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This study was performed to investigate experimentally the enhanced of heat transfer in a double tube heat exchanger system with rectangular grooves in turbulent flow regime. The shell side diameter is 28 mm which is made of acrylic. While the tube diameter is 20 mm which is made of aluminium. Grooves were incised in annulus room/outer surface of tube side, with grooves space (s) = 2 mm, distance between groove (t) = 8 mm, and the grooves height (h) = 0.3 mm. The experiments consist of temperature measurement of inlet and outlet heat exchanger with k-type themocouples. Throughout the investigation, hot fluid and cold fluid flowed in the inner pipe (tube side) and the space between pipes (annulus), respectively. The Reynold number of cold fluid have been varied from 31981 to 43601 in a parallel flow condition. The mass flow rate of hot fluid remains constant with Reynold number 30904. Water is used as the working fluid. Result showed the considerable effect of grooves which is applied in double tube heat exchanger. The total heat transfer enhancement of 7.8% and the ratio of heat transfer enhancement is larger for higher Reynold number. Finally, the use of grooves in the heat exchanger give benefit of heat transfer process.

Keywords: Heat Transfer, Rectangular Grooves, Annulus, Double Pipe Heat Exchanger.

1. INTRODUCTION

Heat exchanger is a device which is used to transfer thermal energy between fluid at different thermal condition.[1] The heat exchanger takes the main role of many industries application such as food processing, petrochemical, automotive, power plant, RHVAC and many other applications. According to the heat exchanger construction, double pipe is the simplest and maintenance easily. Many studies have been done to enhance the heat transfer process and controlling the fluid flow through on it. Passive technique developed widely for the application because does not require additional energy. Groove is a form of passive technique.

Groove incised into heat exchanger, increase surface area with little change in diameter and potentially improve not only heat transfer but also pressure drop. Many investigation have been done to improve pressure drop and friction on grooves.[2] controlling near wall turbulent flow to reducing pressure drop. Grooves prevent the flow structure transformation into turbulent spot.[3] Reference [4] formulated a correlation to predict frictional pressure drop of R410A-oil mixture inside internal spiral grooved tube.[5–8] studied grooved pipe flow characteristics and their correlation on pressure drop, radial velocity and friction. Investigation into various shape of groove has been done to improve the flow and flow structure details. Reference [9] investigated on transverse square grooves at turbulent boundary layers; Reference [10] investigated on V shaped riblets; Reference [11] investigated on helical grooves; and Reference [12] studied on semi-circular riblet surfaces.

Over the years, a great deal of investigation has done into fluid flow through grooves as well as their relationship to heat transfer characteristics. Reference [13] investigated the approach temperature of grooved double pipe heat exchanger. Reference [14] investigated the heat transfer coefficient in a channel with periodic transverse grooves. Heat transfer and flow characteristics of water flowing through horizontal internally grooved pipes studied by Ref. [15] and found the thermal enhancement about 1.4 to 2.2. A significant effect on heat transfer enhancement due to surface roughness in turbulent flow investigated by Ref. [16]. Studied by Ref. [17], found the increase of heat transfer coefficient 10% on triangular-profiled riblet surface in wind tunnels. Numerical study of turbulent flow characteristics and heat transfer performance has been done by Ref. [18]. This investigation is to enhance heat transfer without causing increase pressure drop by modified the swirl flow.[19] Using a numerical method to study heat transfer of

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nanofluid in turbulent flow regime through groove channel; the result shows very potential increase of heat transfer and great candidates for the next development of heat exchanger efficiency. A validation between experimental data and numerical simulation has been developed[20] in a rectangular channel with cylindrical groove to enhance heat transfer with minimum pressure drop; the groove formation reduced and reattachment recirculating flows inside the groove and improve overall thermal performance.

Although many investigations has centered on grooves shape, flow structure correlated on heat transfer enhancement on various applications, very little have been done on the annulus of heat exchanger. In grooved annulus, the heat transfers are unique because of the grooves position between pipes. Thus, this study concentrated on observing heat transfer through the grooved annulus in double pipe heat exchanger.

2. EXPERIMENTAL APPARATUS AND METHOD

The sketch of the apparatus for this study is shown in Figure 1. This study used parallel flow in flow direction. In parallel flow heat exchanger, the hot side inlet temperature is in contact with the cold side inlet temperature. The experiment installation consisted two centrifugal pump which was stabilized by electric stabilizer to circulate hot and cold water through a pipe system. Water used as a working fluid. Rotameter was installed to control volume flowrate through the test section. The Reynold number (Re) of the annulus room investigated were 31981, 34888, 37796, 40703, 43610 respectively. Meanwhile the Re for hot fluid were maintain constant at 30904. The hot water temperature was 50 ± 0.5 °C and the cold water was 30 ± 0.5 °C.

The heat exchanger test section was a 20 mm diameter of tube side and 28 mm diameter of shell side and 50 cm long. The tube was made by aluminium meanwhile the shell side was made by acrylic tube. The annulus room internally etched grooves on outer surface of tube side. The groove were formed by using a conventional etching technique and the detail image of rectangular groove shown if Figure 2. Thermocouples were used to measure the temperature of inlet and outlet of hot and cold fluid in the test section. The signal from thermocouple digitalized using data logger before being recorded in a computer memory for 600 s. The heat transfer enhancement from groove to that of the smooth annulus define as,

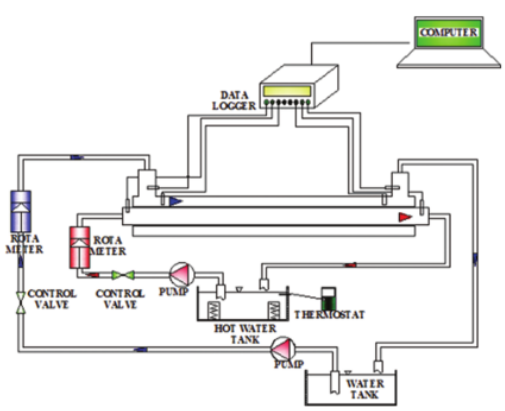

Fig. 1. The schematic representation of the experiment apparatus set-up.

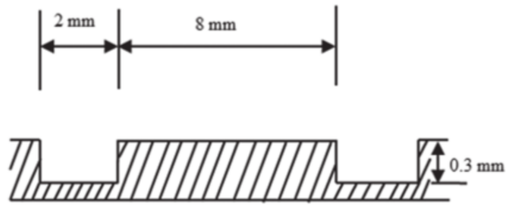

Fig. 2. Detail image of rectangular groove.

$$E_h = \frac{Q_{\text{groove}} - Q_{\text{smooth}}}{Q_{\text{smooth}}} \times 100\% \tag{1}$$

2.1. Data Processing

The aim of this investigation is to determine the heat transfer enhancement in grooved annulus of double pipe heat exchanger. The parameters of interest are Reynold number (Re), heat transfer (Q), NTU, effectiveness (e). The Re is given by

$$Re = uD/uRe = uD/v \tag{2}$$

NTU and Effectiveness follow the equation as,

$$\text{NTU} = \frac{UA}{C_{\min}} \tag{3}$$

$$\varepsilon = \frac{1 - \exp[-\text{NTU}(1-c)]}{1 - c\exp[-\text{NTU}(1-c)]} \tag{4}$$

3. RESULTS AND DISCUSSION

Heat transfer data for the smooth annulus was collected first. This data was then used as a comparison to the data from the grooved annulus. Figure 3 shows the total heat transfer of the heat exchanger. It is found that, the heat transfer increased with the increased of Reynold number and the annulus room with groove gave higher values of heat transfer than those of smooth annulus.

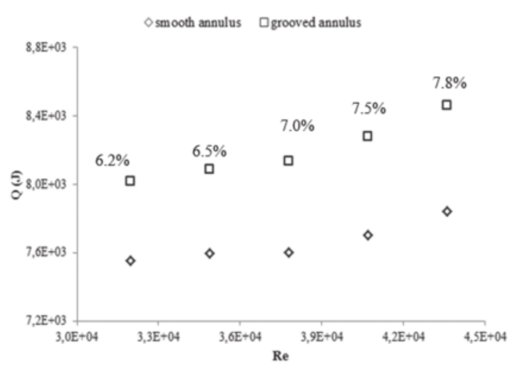

Fig. 3. The variation of heat transfer with Reynold number.

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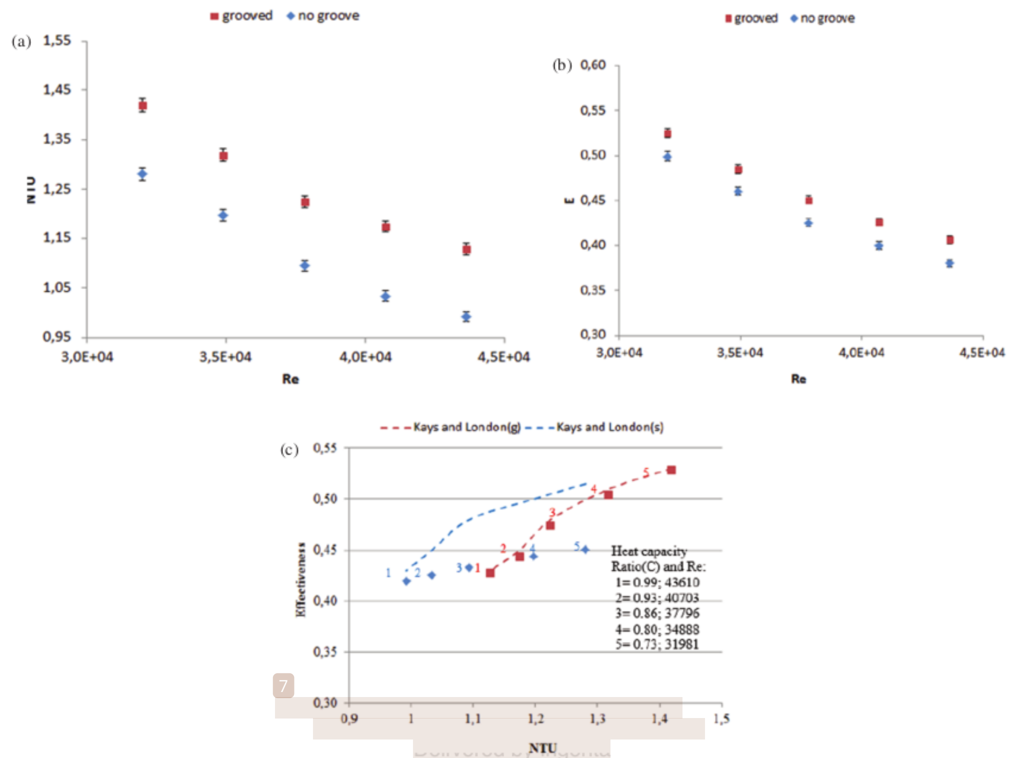

Fig. 4. Relations of effectiveness, NTU and *Re*. (a) *Re* and NTU; (b) *Re* and effectiveness; (c) NTU and effectiveness.

For smooth annulus, Q, increased from 7550 to 7840 J with the increase of Reynold number from 31981 to 43610 respectively. Using Eq. (1) at comparable Reynold number, the heat transfer in a grooved annulus were enhanced (E_h) 6.2% to 7.8% compared to those of smooth annulus. Swirl flow on the fluid near pipe wall generated by the groove was responsible for thinning the thermal boundary layer. Groove also increase the mixing fluid in annulus room. This phenomenon made heat transfer higher through the fluid.

The effectiveness, NTU and *Re* relationship of the smooth and grooved annulus were presented in Figure 4. Figures 4(a), (b) shows the NTU and effectiveness as a function of *Re*. The decrease of effectiveness indicates the decrease of the rate of actual heat transfer. The increase of NTU indicates an enlargement of surface area and overall heat transfer coefficient (UA) value. The NTU and effectiveness value of grooved heat exchanger is higher than smooth heat exchanger. This indicates the grooved heat exchanger have more surface area and more actual heat to transfer through the surface. Figure 4(c) also shows the NTU and effectiveness (E) obtain from Ref. [21] relations. Number of 1 to 5 represent the heat capacity ratio (C) on specific experiment Reynold number. NTU and effectiveness (E) were compared to that of Ref. [21]. It is found that with the decrease of heat capacity ratio gave increased NTU and effectiveness. At the same heat capacity ratio, the effectiveness and NTU of grooved annulus was higher than those for smooth annulus. The grooves lead to an increase of turbulence so that the fluid interaction and momentum also increases. Figure 4(c) also provides a descriptions that the NTU and effectiveness of this experiment approaching the value obtained from Ref. [21] for double tube heat exchanger.

4. CONCLUSIONS

An experimental investigation was carried out for heat transfer enhancement, NTU, effectiveness (ε) of grooved annulus from double pipe heat exchanger. The result can be summarized as,

(a) The heat transfer increased with increase of *Re*. At a specified Re, the heat transfer increase 6.2% to 7.8% compared to that of smooth annulus.

(b) The effectiveness increased with decrease heat capacity ratio and increase NTU value.

LIST OF SYMBOLS

u fluid velocity [m/s^2]
D diameter [m]
υ kinematic viscosity [m^2/s]
ρ fluid density [kg/m^3]
E_h heat transfer enhancement
E effectiveness

A	surface area [m^2]
U	overall heat transfer coefficient [W/m$^2 \cdot$°C]
$C_{\min}$	heat capacity rate [W/°C]
C	heat capacity ratio
NTU	number of transfer unit.

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