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STUDY ON PARAMETERS IN COUNTER CURRENT DOUBLE PIPE HEAT EXCHANGER APPLYING CIRCULAR TURBULATOR

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Abstract
Many industries dealing with manufacturing and HVAC (heating, ventilation, and air cooling) are rely heavily on thermodynamics principles with respect to heat and mass transfer. The objective of this study is to do optimization to yield optimum heat transfer rate and minimized pressure drop with regard to number of circular turbulator (CT) and water debit on Nusselt number (Nu) in counter current double pipe heat exchanger. This work has applied the classical rule of thermal science dealing with Nusselt number in relation to convection and conduction of heat transfer rate due to temperature effect. The result shows the highest Nu found to be 835.3 at 5 CT and water debit of 9 L/min. The addition of CT number gives effect on fluid current due to vortex generation. This study also investigates the effect of CT number on friction coefficient that the friction coefficient of a heat exchanger in the absence of CT is lower than that in the presence of CT. For any CT number, the friction coefficient is reduced with increasing water debit. The study has also found that the thermal performance ratio has achieved higher values for heat exchanger in the absence of CT.

Keywords: circular turbulator, friction coefficient, heat exchanger, Nusselt number, thermal performance, water debit.

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1. Introduction

Double pipe heat exchanger has been used in many industries related to food processing, chemical industry, solar water heater, vegetable drying and air conditioning [1]. A good heat exchanger design should have compact dimension and need low power. There are two methods in order to enhance heat exchanger performance, i.e. the active and passive methods. The active method is in relation to increase extra power of the heat exchanger, while the passive method is related to modification of heat transfer surface or applying swirl device/turbulator in fluid current [1–3].

Moreover, an effective heat exchanger must have high thermal performance ratio (TPR). The thermal performance ratio of heat exchanger is defined as the ratio of heat transfer rate (h) to pressure drop (ΔP) [1]. This ratio gives useful information on heat transfer rate in relation to the power energy needed such as using pump or compressor.

The functions of a turbulator are (i) to reduce laminar flow, (ii) to enhance turbulent current, (iii) to increase area of heat transfer and (iv) to generate vortex or secondary flow. Besides to enhance Nusselt number and heat transfer rate, the turbulator gives impact on enhancement of friction coefficient and pressure drop [1,4,5,7]. Increasing number of turbulator may change flow pattern in area of heat transfer and accelerate fluid mixing between slow current and fast current [4,6,8]. According to Yadav and Sahu [1], Adem A et al [9] and Piroz Zamankhan [10] increasing number of turbulator may change current pattern and enhance fluid recirculation, increase contact area between fluid and heat surface, elevate fluid mixing and heat transfer rate.

There are various shapes and types of turbulator investigated in order to enhance heat transfer rate. Previous study reported that the geometrical of turbulator might affect heat transfer rate [4–8,11–14]. A given shape of turbulator may change fluid direction so that the fluid from hotter area and the fluid from colder are more easily mixed [2,4,15–17].

Although the study on the effect of circular turbulator in double pipe heat exchanger on fluid current and friction factor has already reported in previous investigations, however, this optimization study is still valuable for related industries until today. This study applies variation of CT numbers using CT free, 3 CT, 5 CT and 7 CT. Besides the varied CT numbers using in outer pipe, the cool water debits are varied at 3, 5, 7 and 9 L/min. The varied fluid debits reflect representative condition for all current as the 3 and 5 L/min. water debits represented laminar flow while the 7 and 9 L/min. represented turbulent flow.

Nevertheless, this investigation with regard to CT number and water debit is useful for optimization study to yield higher heat transfer and lower pressure drop. Therefore, the objective of this study is particularly emphasized on the optimization to achieve the target of a counter flow double pipe heat exchanger.

2. Experimental and Procedures

As it is known, input data can be conducted when the system has already gained a steady state. The input data of temperature have been done simultaneously for all temperature sensors. In order to know the pressure drop of cool water flow, it can be done by reading the difference of height of water surface of a manometer connected to a channel for input and output of cold water.

2.1 Material and Equipment

This study applies water as working fluid with temperature of hot water is managed to be 50°C with constant debit of 2.58 L/min. and temperature of cold water of 23.5°, with debit variation of 3, 5, 7 and 9 L/min. Hot water flows in inner pipe made of copper alloy with inner and outer pipe diameters of 7 mm and 9 mm, respectively. Cool water flows in outer pipe made of PVC (poly vinyl chloride) with inner and outer pipe diameters of 27 mm and 32 mm, respectively. Table 1 shows the equipment specification in detail.

Table 1. Equipment used in this study and its specification.

No	Name	Specification
1	Thermocouple	K – type
2	Pump for cool water	100 L/min.debit; 23 m head
3	Pump for hot water	15 L/min.debit; 0.9 m head
4	Heater	To arrange water temperature until 50°C
5	Circular turbulator	Fiberglass; 27 mm outer diameter; 22 mm inner diameter

2.2 Design and Size of Circular Turbulator

This work applies ring type circular turbulator installed in inner diameter of outer pipe with outer and inner diameters of 27 mm and 22 mm, respectively, and with its thickness of 2 mm. The design is illustrated in Fig. 1, wherein Fig. 2 shows the scheme of this work.

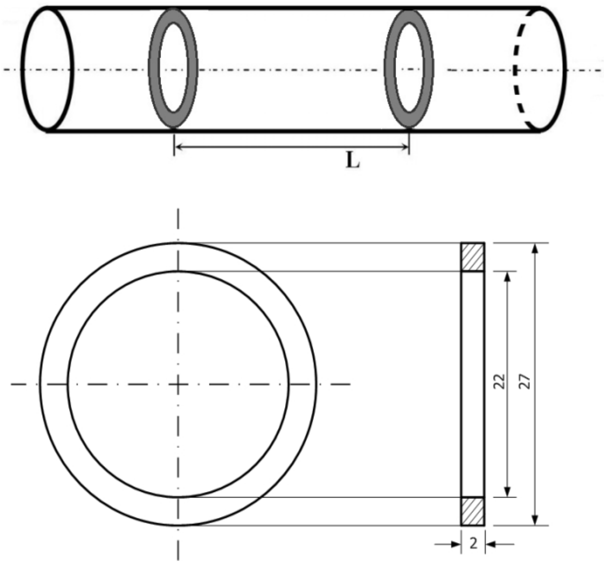

Fig. 1. The illustrated design and size of circular turbulator.

2.3 Design of Double Pipe Heat Exchanger

For comparison, Sheikholeslami applied helical turbulator that its shape similar to leaning circulator turbulator as shown in Fig. 2 [13,19].

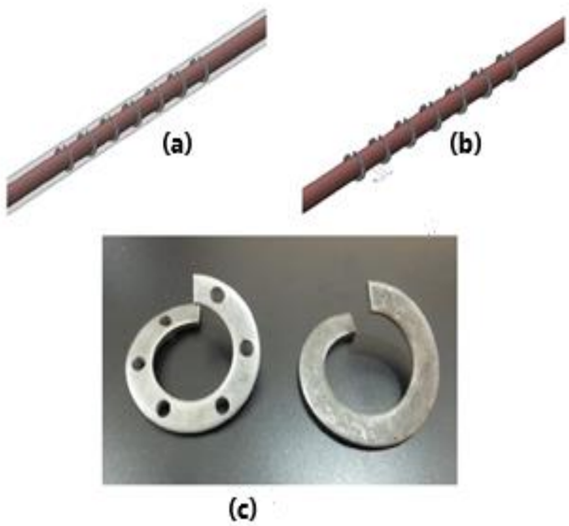

Fig. 2. Discontinuous helical turbulators (a) typical; (b) perforated; (c) samples of helical turbulator [13]

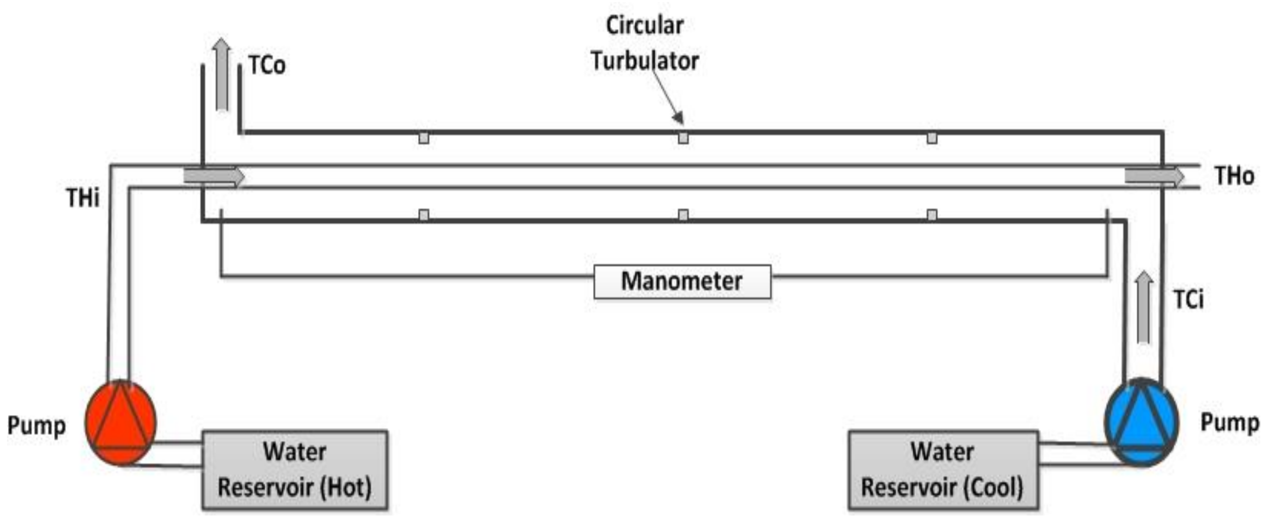

Fig. 3. Design of counter current double pipe heat exchanger.

3. Results and Discussion

The results show the increasing CT number causing increased Nusselt number and friction coefficient under the influence of varied water debit.

3.1 The Effect of CT Number and Water Debit on Nusselt Number

Fig. 4 shows increasing water debit yielded increased Nusselt number (Nu) since increasing fluid debit is in line proportional with increased Reynolds number (Re). Reynolds number is about linear proportional with Nu. This finding is in agreement with previous investigations reported by Yadav and Sahu [1] and other researcher [7–9] that increased Re yielded increased Nu as Re proportionally correlated with fluid debit.

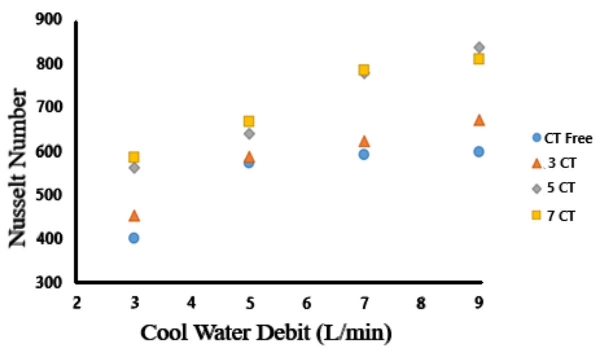

Fig. 4. The effect of cool water debit on Nusselt number at varied CT. Fiberglass CT. Copper alloy inner pipe. PVC outer pipe.

Moreover, increasing number of CT causes increased Nu, this phenomenon is corresponding with CT installment in flow pipe generating faster mixing between water with high temperature around pipe center (fast fluid) and water with low temperature near pipe wall (slow fluid) [4,8,15-17]. The fluid mixing yields more heat energy transferred as convective current. This matter is in consistency with the definition of Nu related to ratio of convective heat transfer toward conductive heat transfer. This understanding is in concordance to investigation by Kumar et al. [5] that fluid flow patterns of different inserts reveals that the swirl motion induced by twisted surface of tape disrupts the boundary layer near pipe wall and thus enhances the heat transfer rate.

Sheikholeslami [19] reported that the addition of a twist turbulator increased Nusselt number (Nu) by 1.5–1.7 times of the Nu of a heat exchanger without applying twist turbulator. Similar finding reported by Nemat Mashoofi [15] justified that addition of a turbulator in outer pipe filled by hot water increased Nu by 8–32% and applying turbulator in inner pipe filled by air increased Nu by 52–81%. This finding is due to the turbulator reduced obstacles related to temperature boundary layer [19].

In this study, it seems that installing of 7 CT in outer pipe yields lower effect on heat transfer rate compared to that of 3 CT and 5 CT. Applying of 7 CT in outer pipe makes the distance between CTs get closer and thus the development of fluid flow is not optimally achieved, or in other words, the fluid from pipe center is undergone retardation in movement to pipe wall as area of heat transfer. This implies the mixing effect between hot and cool water getting reduced and thus decreasing convective heat transfer.

This study shows that increased CT number and water debit resulting increased Reynold number leading to increased Nusselt number as defined in Dittus–Boelter equation below for turbulent flow

$$Nu = 0.023\ Re^{0.8}\ Pr^{n} \tag{1}$$

where n = 0.4 for hot fluid and n = 0.3 for cold fluid.

3.2 The Effect of CT Number and Water Debit on Friction Coefficient

The term of friction coefficient is often stated as friction factor based on the calculation process of Darcy Friction Factor that the friction factor is inversely proportional with square fluid velocity. The fluid velocity is about linear proportional with enhancement of fluid debit and thus the friction coefficient gets lower with enhancement of fluid debit. This phenomenon is illustrated in Fig. 5.

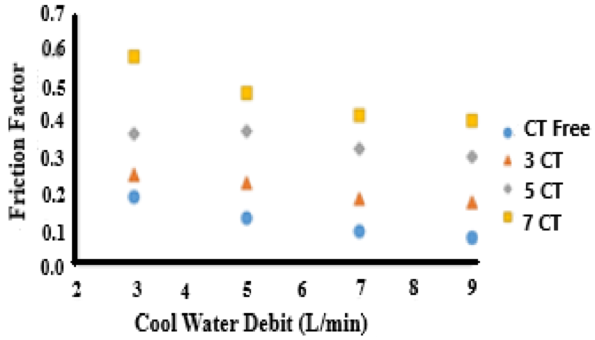

Fig. 5. The effect of cool water debit on friction coefficient at varied CT. Fiberglass CT. Copper alloy inner pipe. PVC outer pipe.

Double pipe heat exchanger without any CT has the lowest friction coefficient and with addition of any CT may impede fluid current, thus, it yields increased friction coefficient (Fig. 5). According to Ruengpayungsak [20] that a channel using a turbulator always has higher friction factor rather than a channel without using a turbulator. The existence of a turbulator in a channel yielded a friction factor by 2.7–15.5 times than a channel without using a turbulator.

This finding is consistent with the report of Sahin et al. [3] that increased Nu caused by increased Re and thus the friction factor reduced. The finding of this study is also supported by the investigation of Yadav and Sahu [1] that the gradually decreased friction factor was caused by increased Reynolds number.

The result of this work is also in agreement with the Darcy friction factor equation described as follows:

$$\Delta P = f\ \frac{L}{D}\ \frac{\mu V^2}{2} \tag{2}$$

Equation 2 defines that friction factor (f) inversely proportional with velocity of fluid (V), while the velocity of fluid is directly proportional with fluid debit. Therefore, the friction factor is inversely proportional with fluid debit as shown in Fig. 5.

3.3 The Effect of CT Number and Water Debit on Thermal Performance Ratio

Fig. 6 shows the effect of cool water debit and CT number on thermal performance ratio. It is seen that increased cool water debit and number of CT causing decreased thermal performance ratio. This phenomenon can be elucidated by increased CT number always followed by increased pressure drop that is more significant than increased heat transfer rate.

This concept is in agreement with previous work as reported by Yadav Sigh [8] that the study had showed thermal performance ratio found higher for 1–1.2 times for heat exchanger without the existence of CT compared to that using CT.

On other occasion, Eiamsa-ard et al reported similar finding that increased number of CT yielded decreased thermal performance ratio [11] According to this report, heat exchanger pipe without CT yielded TPR about 1.05–1.69 times higher than that pipe applying CT.

This finding shows that applying CT for a heat exchanger channel increasing heat transfer rate, however, it also needs power such as a pump or compressor provided in the heat exchanger device to produce heat transfer rate as desired.

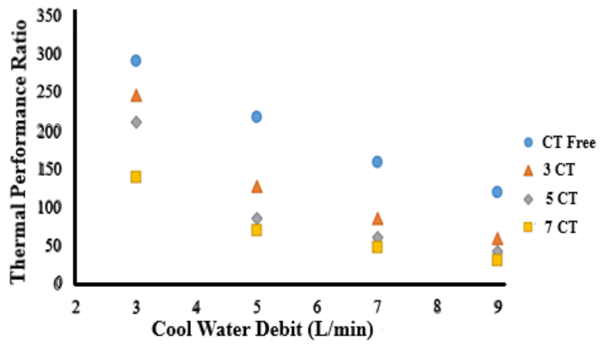

Fig. 6. The effect of cool water debit on thermal performance ratio at varied CT. Fiberglass CT. Copper alloy inner pipe. PVC outer pipe.

With regard to the Darcy friction factor equation mentioned above, the pressure drop (ΔP) is directly proportional to quadratic form of velocity of fluid (V^2). The velocity of fluid is directly proportional with water debit. The coefficient of convective heat transfer (h) is directly proportional to Reynold number (Re) leading to directly proportional to velocity of fluid (V) as described in equation (3) below.

$$\frac{h.L}{k} = C\, Re^{m}\, Pr^{n} \quad (3)$$

The thermal performance ratio (TP) is the ratio between coefficient convective heat transfer (h) to pressure drop (ΔP) as defined below.

$$TP = \frac{h}{\Delta P} \quad (4)$$

Therefore, with regard to equation (4) increased water debit yielding increased pressure drop (ΔP) resulting reduction of thermal performance ratio (TP) as justified in Fig. 6.

As seen from the analytical examinations above, the findings of this work are in good agreement with the classical thermal formulas.

4. Conclusion

This investigation shows the highest Nu found to be 835.3 at 5 CT and water debit of 9 L/min. The addition of CT number affected the fluid flow caused by vortex generation. The friction coefficient of a heat exchanger without CT is lower than that with CT. For any CT number, the friction coefficient is getting reduced with increasing water debit. At the moment, a conclusion can be withdrawn that better thermal performance ratio obtained for a heat exchanger in the absence of CT and at water debit produced turbulent current.

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