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Comparison of Overall Heat Transfer Coefficient between Shell and Tube and Spiral Coil Heat Exchangers

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ABSTRACT

Heat exchangers are used in many industries and power generation applications. The performance of heat exchangers depends on the operating parameters and the types of flow. The sudden pressure drop is one of the major problems encountered in heat exchanger, and this would significantly affect the efficiency and the overall heat transfer coefficient of the heat exchanger. Therefore, this study is aimed at investigating and analyzing the effects of operating parameters that cause pressure fluctuation and affect the overall heat transfer coefficient. Experimental study was carried out for two types of flows: co-current and counter concurrent flows. Comparisons of the overall heat transfer coefficients between shell and tube and spiral coil heat exchangers were made. It was observed that mass flow rate affected the overall heat transfer coefficient. Besides, the counter current flow was more efficient compared to the co-current flow with enhanced overall heat transfer coefficient. The maximum overall heat transfer coefficient for spiral coil heat exchanger counter flow was 2702.78 W/m^2.K, showing a higher heat transfer efficiency when compared to the shell and tube heat exchanger. Moreover, the spiral coil heat exchanger occupied less space as opposed to the shell and tube heat exchanger.

Keywords: Co-current, counter current, overall heat transfer coefficient, pressure drop, shell and tube heat exchanger, spiral coil heat exchanger

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INTRODUCTION

Heat exchangers have been used in different engineering applications since the beginning of civilization (Zohuri, 2017). Its wide variety of applications include heat recovery systems, food industries, natural gas processing, space heating, sewage treatment, power stations, chemical plants, petrochemical plants refrigeration and air conditioning (Mohanraj et al., 2015; Ma'arof et al., 2019). There have been many techniques used for heat transfer enhancement in industrial applications, among which active and passive techniques were the two major enhancement techniques (Seyed, 2013). The heat transfer enhancement enables the size of the heat exchanger to be small, and improves the performance of heat exchanger. Faramarz (2013) compared active and passive enhancement methods. Extended inserts, surface, coiled or twisted tubes and additives could be utilized in passive methods to enhance the efficiency while electrostatic fields, surface vibration, injection and suction could be considered in active method to increase the performance of heat exchanger. Shah and Sekulic (2007) studied temperature profiles in two different heat exchangers, and highlighted two major disadvantages in the parallel flow design. The large temperature difference at the ends caused large thermal stresses. The contraction of the construction materials and opposing expansion due to different fluid temperatures could eventually result in material failure. Besides, the temperature of the cold fluid exiting the heat exchanger remains lower than the lowest temperature of the hot fluid, and this can be improved by optimizing the operating parameters.

A counter flow heat exchanger has the most effective flow patterns (Bergman and Incropera, 2011). Moreover, it has the lowest heat exchanger surface area because of the highest log mean temperature differences (LMTD). Based on comparable conditions, more heat is transferred in a counter flow than in a parallel flow heat exchanger. Ghias et al. (2016) stated that LMTD method could be used to determine the overall heat transfer coefficient U from experimental values using inlet and outlet temperatures and the fluid flow rates. With the inlet temperatures and U known, this method is not useful in predicting the outlet temperatures. In this case, the effectiveness NTU method is convenient to predict the outlet temperature. Moran et al. (2003) discussed that the convective heat transfer coefficient relied on fluid properties, flow geometry, and the flow rate. It is appropriate to describe this dependence using several dimensionless numbers called the Reynold number, which determines the flow regime. Naphon (2007) stated that heat transfer occured because of conduction between the layers of the fluid under laminar regime. In the transition and turbulent regimes, heat transfer happens mainly by forced convection. Higher turbulence could result in enhanced heat transfer.

There are various types of shell and tube heat exchangers (Kakac et al., 2012). Baffles in the shell are used to enhance the rate of heat transfer. The quantity of shell side and the tube side flow arrangement would depend on the pressure drop, heat duty, fouling factor, manufacturing techniques, cost, corrosion control and the cleaning purpose. Lebele-Alawa and Egwanwo (2012) performed extensive numerical analysis on heat transfer in the shell and tube heat exchanger using basic governing equation and based on three parameters: outlet temperature, the heat exchanger effectiveness and heat transfers coefficient. Helical baffle was used to enhance the heat transfer rate as it forced the shell side to access the plug flow condition attaining higher efficiency. The types of baffles also affect the efficiency of the heat exchangers. Kirubadurai et al. (2014) found that modified baffle had a higher enhancement performance than segmental baffle.

Kondhalkar and Kapatkat (2012) carried out experimental study on the performance analysis of a spiral tube heat exchanger. They found that spiral tube heat exchanger had 15-20% lower cost than shell and tube type heat exchanger. The low velocity with more turbulence could reduce fouling and increase the heat transfer rate in the spiral tube heat exchanger, making it preferable than other types of heat exchanger. Hossain et al. (2012) analyzed the heat transfer coefficient and effectiveness of the spiral coil heat exchanger operating with water. It was found that heat transfer rate increased nearly with straight line with increased Reynolds number, and this was considered acceptable for the spiral coil heat exchanger. In addition, Nusselt number also increased with increasing Reynolds number for all three cold water flow rates tested. The work of Guha and Unde (2014) also showed the attainment of these requirements in the most optimal way along with achieving safety, operability, maintainability, sustainability and profitability. Bhavsar et al. (2013) focused on performance analysis of spiral tube heat exchanger and stated that heat transfer with a spiral tube was higher than that of a straight tube.

In counter flow arrangement, centrifugal force created by the spiral shape enhances the heat transfer of both tube and shell sides. Shirgire and Kumar (2013) also found that the heat transfer in helical coil heat exchanger was higher than that of straight tube heat exchanger due to compactness. Reddy et al. (2016) discussed that the contact time had influence on the heat transfer rate of heat exchangers. Shell and tube heat exchanger have a low contact time compared to other types of heat exchangers. As a result, increasing contact time would play a role in enhancing heat transfer rate. The sudden pressure drop is one of the major problems encountered in heat exchanger, affecting the efficiency and the overall heat transfer coefficient of the heat exchangers significantly. The objective of this study was, therefore, to investigate and compare the overall heat transfer coefficient between a single-pass shell and tube and spiral coil heat exchangers under co-current and counter current flows. The effects of process variables, such as temperature distribution, overall heat transfer coefficient, effectiveness, flow rate and pressure drop through hot testing under balanced flow condition are also investigated, which would benefit in designing and optimizing the performance of the two heat exchangers.

EXPERIMENTAL SET UP AND TECHNIQUES

Figure 1 shows the experimental setup utilized for the current study. It consists of storage tank, centrifugal pump, digital hydraulic pressure gauge, and infrared temperature sensor. Heater and pump were mounted so that hot water can be pumped and passes through the Shell. The electric heater of capacity 2 kW mounted in the hot reservoir was used to raise the temperature of water to 60-70^{o}C prior to pumping to the heat exchanger. The valves mounted at different locaton in the setup were used to have cocurrent and counter current flows in the two heat exchangers. Dimensions of the shell and tube and spiral coil are depicted in Table 1 and 2, respectively. The heat exchanger shell is made of IS2606 steel and has an internal diameter of 100 mm and thickness of 10 mm whereas the spiral coils has internal and outside diameters of 34 mm and 44 mm, respectively.

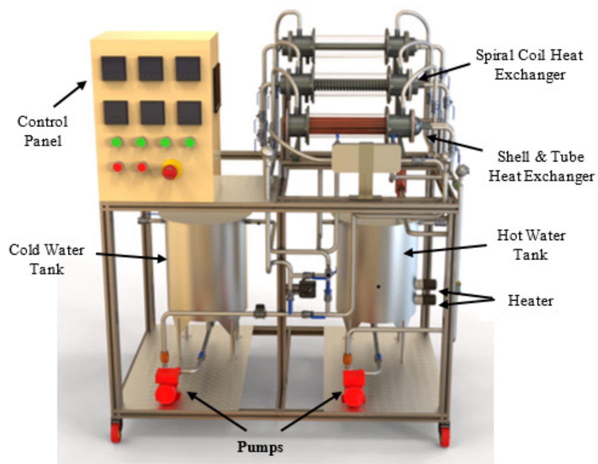

Figure 1. Experimental set-up

Table 1
Dimensions of shell and tube

Item	Dimension
Tube O.D. (do)	6 mm
Tube I.D. (di)	4 mm
Tube Length (L)	Approx. 440 mm at one pass
Tube Count (Nt)	16 (Two passes)
Tube Pitch (pt)	18 mm
Tube arrangement	Triangle
Shell O.D.	110 mm
Shell I.D. (Ds)	100 mm
Baffle Count	5
Baffle Distance (lB)	50 mm
Material of Construction	Stainless Steel/ Copper/ Borosilicate

Table 2
Dimensions of spiral coil

Item	Dimensions
Coil Tubing O.D.	9.53 mm
Coil Tubing I.D.	7.05 mm
Coil Length (L)	5.00 m
Coil I.D.	34 mm
Coil O.D.	44 mm
Shell O.D.	110 mm
Shell I.D. (Ds)	100 mm
Material of Construction	Stainless Steel/ Borosilicate

The mathematical equations were used to analyze the raw experimental data to evaluate the heat transfer rate, heat lost, logarithmic mean temperature difference and overall heat transfer coefficient. Heat absorbed or released was calculated by using the following expression:

$$Q = m\ Cp\ \Delta\ T \tag{1}$$

Where,
Q is heat transfer rate for hot or cold water (w/m^2K)
m is mass flow rate (kg/s)
Cp is specific heat of water (J/kg.K)
ΔT is temperature difference (^oC)

Heat lost was calculated as follows:

$$\text{Heat lost} = Qhot - Qcold \tag{2}$$

Efficiency was then calculated as:

$$Efficiency = \left(\frac{Qcold}{Qhot}\right) X\ 100\% \tag{3}$$

Overall heat transfer coefficient was calculated as follows:

$$U = \frac{Q}{A\ \Delta T_{lm}} \tag{4}$$

Where,
U = overall heat transfer coefficient
Q = heat transfer rate for hot or cold water
A = total contact area
ΔT_{tm}= logarithmic mean temperature difference (LMTD)

LMTD was calculated as follows:

$$\Delta T_{lm} = \frac{\Delta T1 - \Delta T2}{\ln(\Delta T1/\Delta T2)} \quad (5)$$

The temperature gradient for co-current flow was calculated as in Equations (6) and (7):

$$T_{hot\ in} - T_{cold\ in} = \Delta T_1 \quad (6)$$
$$T_{hot\ out} - T_{cold\ out} = \Delta T_2 \quad (7)$$

The temperature gradient for counter-current flow was given as:

$$T_{hot\ in} - T_{cold\ out} = \Delta T_1 \quad (8)$$
$$T_{hot\ out} - T_{cold\ in} = \Delta T_2 \quad (9)$$

The heat transfer effectiveness, ε, was calculated as follows:

$$\varepsilon = \frac{Q}{Q_{max}} \quad (10)$$

Where,
Q is the actual heat transfer rate
Q_{max} is the maximum possible heat transfer rate

The maximum possible heat transfer rate was calculated as follows:

$$Q_{max}=C_{min}\,(T_{hot\ in} - T_{cold\ in}) \quad (11)$$

C_{min} is the smaller heat capacity rate of hot water (C_{hot}) and cold water (C_{cold}).

RESULTS AND DISCUSSION

Comparative analysis between Shell tube heat exchanger and Spiral coil heat exchangers
Figure 2 and 3 show the overall heat transfer coefficients of the spiral coil and shell and tube heat exchangers with co-current and counter current flow patterns, respectively. As the mass flow rate through the spiral coil and shell tube heat exchangers increased the overall heat transfer coefficient also increased. The overall heat transfer coefficient was much higher for the spiral coil heat exchanger than that of shell tube heat exchangers. The effectiveness of heat exchanger was greatly affected by hot water mass flow rate and cold water flow rates. When hot water mass flow rate increased, the effectiveness decreased. Spiral coil counter current flow was most effective in all these conditions and shell tube parallel flow heat exchanger was least effective.

Pressure drops in the spiral coil and shell and tube heat exchangers for the co-current and counter current flows are depicted in Figure 4 and 5, respectively. Pressure drop in the

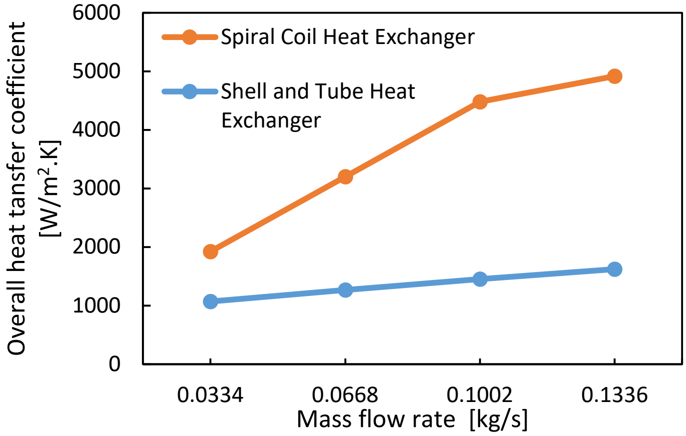

Figure 2. Comparison of overall heat transfer coefficient between the Spiral coil and Shell tube heat exchangers (co-current)

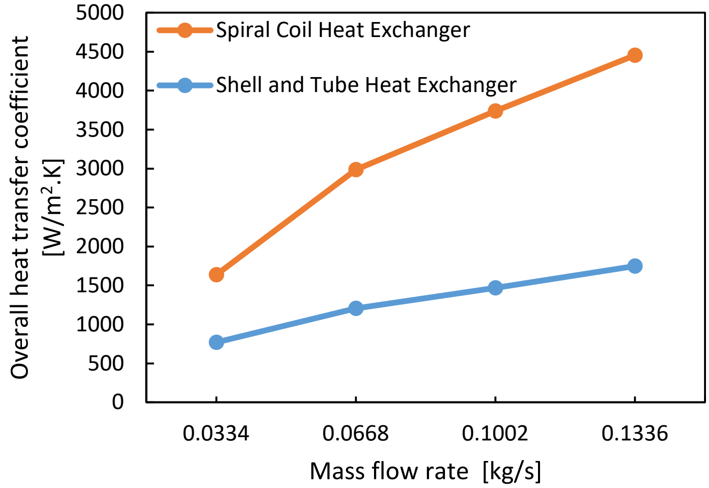

Figure 3. Overall heat transfer coefficient in the Spiral coil and Shell tube heat exchanger (counter current)

spiral coil was higher than that of the shell tube heat exchanger. Moreover, the spiral coil heat exchanger occupies less space (Andrzejczyk & Muszynski, 2018).

Comparative Analysis between Co-current Flow and Counter Current Flow

Figure 6 shows the difference in overall heat transfer coefficient between co current and counter current flows for the shell and tube heat exchanger. The overall heat transfer coefficient increased with an increase in the mass flow rate. However, the heat transferred for counter current flow was higher compared to the co-current flow with maximum overall heat transfer coefficient of 1750.34 W/m^2.k calculated in a laminar regime.

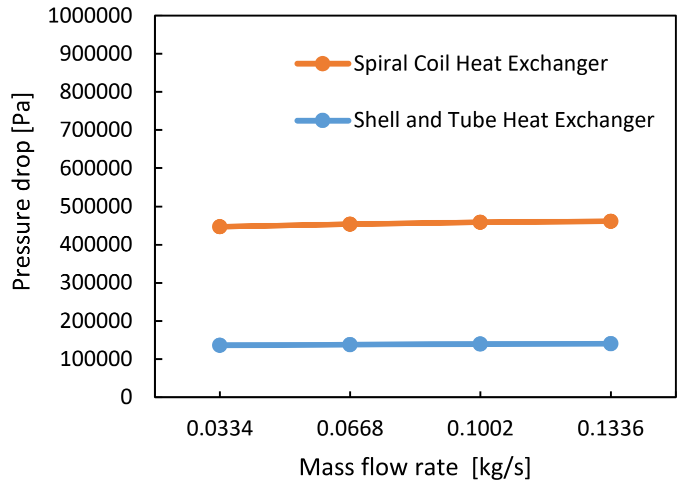

Figure 4. Comparison of pressure drop between the Spiral coil and Shell tube heat exchangers (co-current)

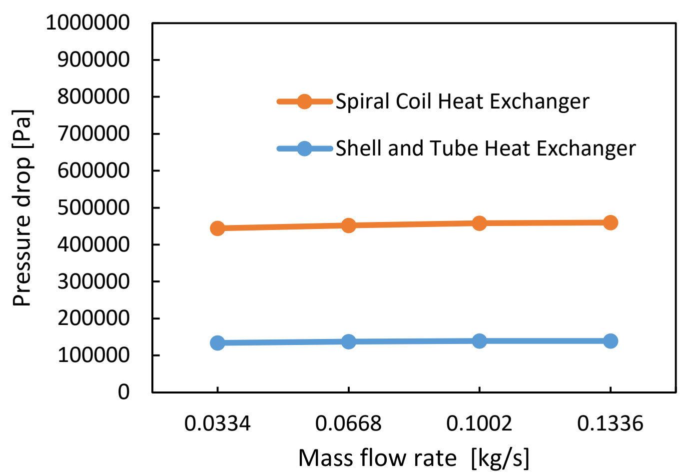

Figure 5. Pressure drop in the Spiral coil and Shell and tube heat exchangers (counter current)

Figure 7 shows the overall heat transfer coefficient between co current and counter current flow for the spiral coil heat exchanger. The overall heat transfer coefficient increased with an increase in the mass flow rate (Tapre & Kaware, 2015). However, the amount of the heat transfer for counter current flow was greater than that of the co-current flow with the maximum coefficient of 3295.67 W/m^2.k at a mass flow rate of 0.1336 kg/s.

Figure 8 shows pressure drop in the co-current and counter current flows of the shell and tube heat exchanger. It can be shown that the pressure drop in the shell and tube heat exchager for counter current flow increased with the mass flow rate. The amount of pressure

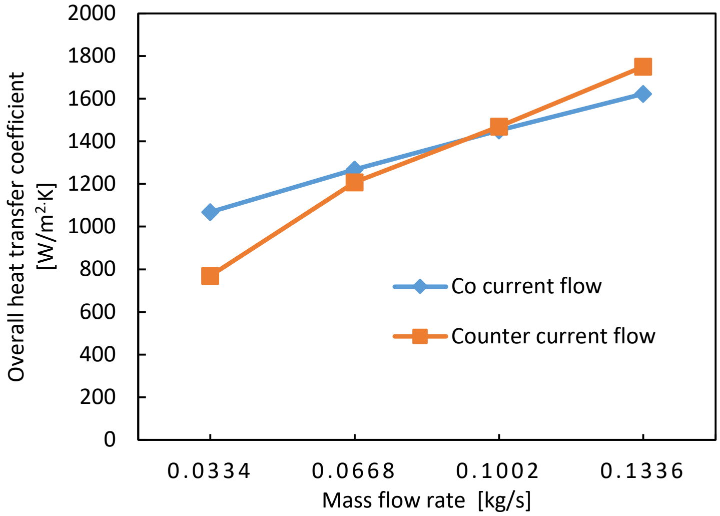

Figure 6. Comparison of overall heat transfer coefficient between co-current and counter current flows in the shell and tube heat exchanger

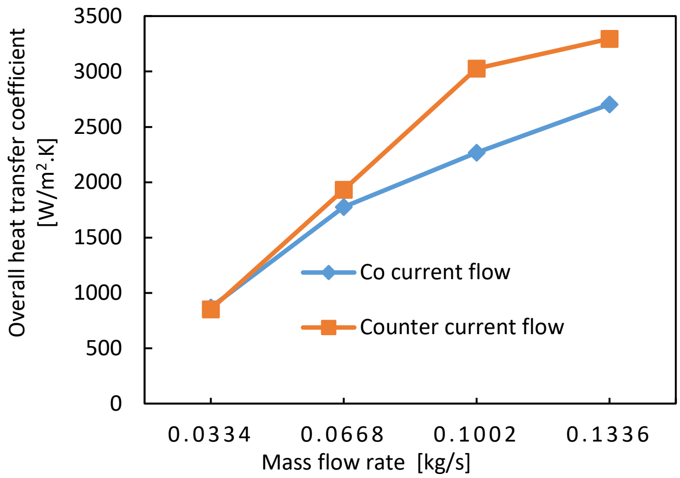

Figure 7. Overall heat transfer coefficient between co-current and counter current flows in the spiral coil heat exchanger

drop for the shell and tube in co-current flow also increased with the increase in mass flow rate and this was smaller than that of counter current flow.

Figure 9 shows pressure drop in cocurrent and counter current flows in the spiral coil heat exchanger. It can be seen that pressure drop in counter current flow of the shell and tube heat exchanger increased linearly with the mass flow rate. The pressure drop for the spiral coil in cocurrent flow also increased with an increase in mass flow rate.

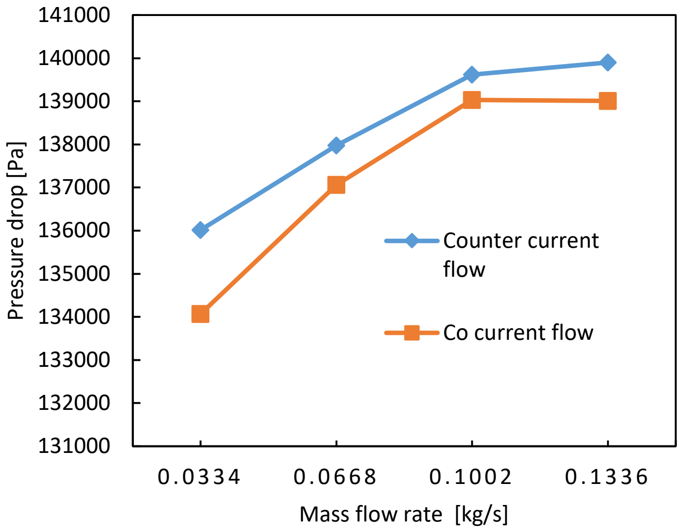

Figure 8. Pressure drop in the co-current and counter current flows in shell and tube heat exchanger

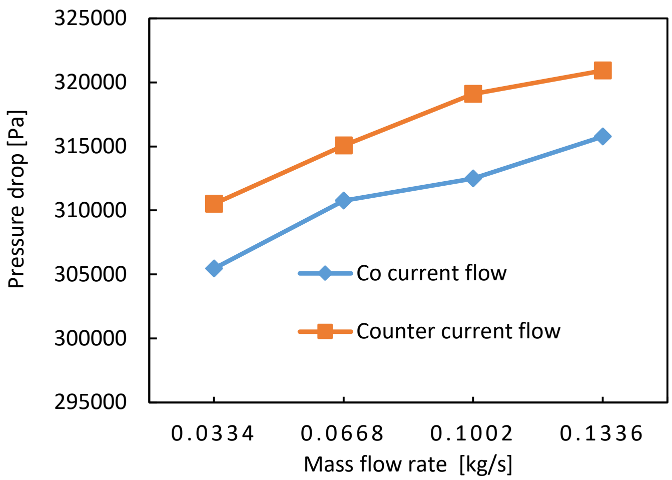

Figure 9. Pressure drop in the co-current and counter current flows in the spiral coil heat exchanger

Figure 10 shows the relationship between overall heat transfer coefficient against Reynold number for counter current and co-current shell and tube heat exchanger. It can be clearly seen that the overall heat transfer coefficient increased with an increase in the cold flow rates. Both flows were found laminar based on the Reynold number. Due to laminar flow, the velocity of the fluid flow through the shell is small and therefore the interaction among fluid particles is also low. When the velocity is low, the heat transfer among fluid particles occurs very slowly. This is why the overall heat transfer coefficient becomes quite similar at different Reynolds number.

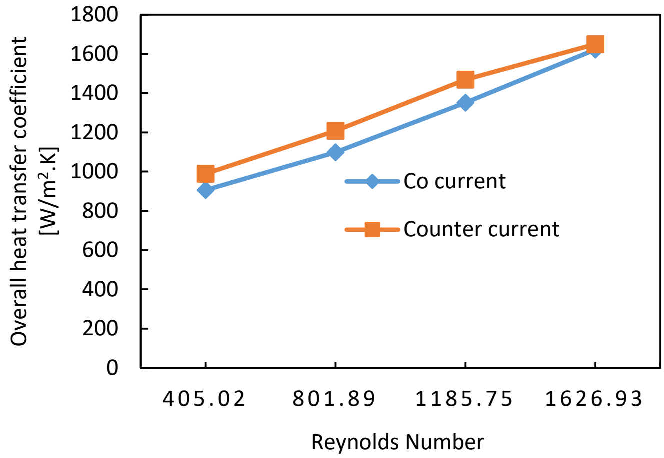

Figure 10. Overall heat transfer coefficient against Reynolds number for the shell and tube heat exchanger

Figure 11 shows the relationship between overall heat transfer coefficient, U and Reynold number for counter current and co-current spiral coil heat exchanger. It can be clearly seen that overall heat transfer coefficient increased with Reynolds number for both flow patterns. Besides, the overall heat transfer coefficients for counter current and co current flow were also quite similar since it works with the same variation of cold water flow rate. Overall heat transfer coefficient is also dependent on convective heat transfer coefficient, so an increase in Reynolds number resulted in higher heat transfer rates. It also shows that overall heat transfer coefficient for counter current is slightly higher than that of co-current flow patterns.

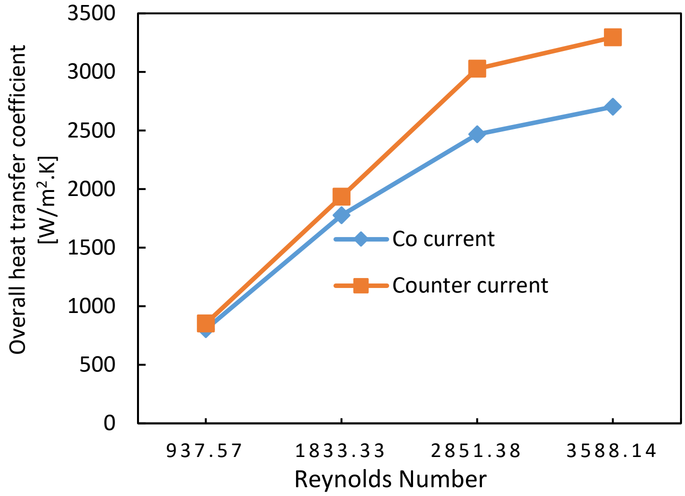

Figure 11. Overall heat transfer coefficient against Reynold number for the spiral coil heat exchanger

CONCLUSION

This paper presents a study on overall heat transfer coefficient of a single-pass shell and tube and spiral coil heat exchangers for better understanding of heat transfer coefficient and effectiveness of the two heat exchangers. The experiments were conducted on the shell and tube and spiral coil heat exchangers with different mass flow rates in cocurrent and counter current flow patterns. A comparison was made between cocurrent and counter current flows in the shell and tube and spiral coil heat exchangers with respect to the performance characteristics, such as overall heat transfer coefficient, heat transfer rate, temperature distributions, temperature difference and pressure drops. The overall heat transfer coefficient increased with an increase in mass flow rate. An increased mass flow rate induced an increase in pressure drop as expected. The counter current flow was more efficient compared to the co-current flow with enhanced overall heat transfer coefficient. Further research needs to be performed that include the experiment at low temperatures in order to check the performance of the present heat exchanger for various applications. Hence, the findings of this study would benefit the operator to design and optimize the best performance of heat exchangers.

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