ICMIEE18-164

Study of Heat Transfer Enhancement in Tubular Heat Exchanger with Twisted Tape Inserts

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ABSTRACT

In the present work an experimental investigation has been carried out to study the convective heat transfer augmentation in a double pipe counter flow heat exchanger (HE) with twisted tape insert. Also, the results are compared with a basic heat exchanger (BHE) of similar length, diameter and flow rate. The HE consists of a 140 inches long copper tube with diameter of 1inch which is concentered in a PVC pipe having a diameter of 2inch. Hot fluid is allowed to flow through the inner copper tube and the cold fluid was allowed to flow through the annular passage between copper tube and the PVC pipe. Experiments were conducted at different mass flow rates of the hot fluid for both the BHE and MHEs. The effects of inserted twisted tapes and twist ratio on heat transfer rate, pressure drop and thermal performance factor characteristics have been investigated extensively. A twist ratio is defined as the ratio of twist length (y) to twisted tape width at the large end (W). The experiments were carried out by using twisted tapes with three different twist ratios (y/W) of 4.5, 6.0 and 7.5. All cases were tested under turbulent flow regime for Reynolds number between 20000 and 50000. The thermal performance indicators, i.e. heat loss from hot fluid, overall heat transfer coefficient, effectiveness, Nusselt Number etc. have been found to be enhanced for the modified HEs compared to that for the basic one. Also, the thermal performance factor tended to increase with decreasing tape twist ratio. The effectiveness of HEs is found to be increased with modifications with twisted tapes. However, after a certain limit of the mass flow rate of the hot fluid the variation in HE's effectiveness becomes less significant compared to that found up to that limiting mass flow rate.

Keywords: Basic Heat Exchanger, Modified Heat Exchanger, Twisted Tapes, Twist Ratio, Turbulent Flow.

1. Introduction

Heat exchangers are widely used device working as heating and cooling system in different industries like oil refineries, power plants and even residential areas [1-2]. Thermal performance improvement of many heat exchangers are needed for energy saving, lower operating cost moreover for better efficiency. Heat transfer augmentation methods are used in the heat exchanger systems to enhance the heat transfer rate and improve the thermal performances [1-13]. Bergles [1] categorized 13 heat transfer enhancement techniques in 'active' and 'passive' methods. External power is required for surface vibration, fluid vibration, injection, suction and electric or acoustic fields which are active methods of heat transfer enhancement. Passive techniques employ different surface geometry for heat transfer enhancement. Treated surface, rough surface, swirling flow devices, coiled tubes and surface tension devices are included in passive techniques of improving thermal performance of heat exchangers [2].

Heat transfer enhancement in heat exchanger has been subjected of many experimental and analytical investigation. Generally turbulent promotor which is called 'turbulator', one of the passive techniques widely used in heat transfer enhancement in the form of vortex flow or swirl flow devices such as rib, fin, baffle, winglet, propeller, grove roughened surfaces [3-9]. These turbulators are inserted in pipe flow to increase heat transfer surface area, to provide an interruption of thermal boundary layer development and to cause increased heat transfer by increasing turbulence intensity or fast fluid mixing. A number of investigations have been made using various turbulators with different configurations to heat transfer enhancement in the heated tube of heat transfer, such as twisted tube [10], wire-coils [11], grooved tubes [12], compound turbulators [13].

Guo at el [14] numerically studied the contribution to thermal performance of the conventional, short-width and center cleared twisted tapes. Configuration optimization of regularly spaced short-length twisted tapes in a circular tube for turbulent heat transfer was carried out by Wang et al. [15] by using computational fluid dynamics (CFDs) modeling. Eiamsa-ard et al. [16] presented experimental study on convective heat transfer in a circular tube with short-length twisted tapes inserted under uniform heat flux. Eiamsa-ard et al. [17] performed experimental works on heat transfer and friction factor characteristics in a heat exchanger fitted with twisted tape elements. They made their analysis for both continuously placed twisted tape and twisted tape placed with various free spaced in circular tube. Jaisankar et al. [18] experimentally examined the heat transfer, friction factor and thermal performance caused by twisted tape for solar water heater. The tape width, rod-diameter effects, and phase angle effects on heat transfer and pressure drop were analyzed experimentally in a circular tube fitted with regularly spaced twisted

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tape elements by Saha at el [19]. But they did not compare their studies with a basic heat exchanger.

In the light of above circumstances, the present study is focused to an extensive investigation of the thermal performance enhancement in double pipe heat exchanger with twisted tapes. For this, first of all, thermal performance study has been conducted in a basic double pipe heat exchanger (BHE). Then, twisted tape of copper with different twist ratios of 7.5, 6 and 4.5 have been inserted, and the thermal performance of the modified heat exchangers (MHEs) has been explored in a range of Reynolds number from 20000 to 50000. Finally, a comparative study has been conducted among the BHE and MHEs to explore the degree of the heat transfer augmentation.

2. EXPERIMENTAL SETUP

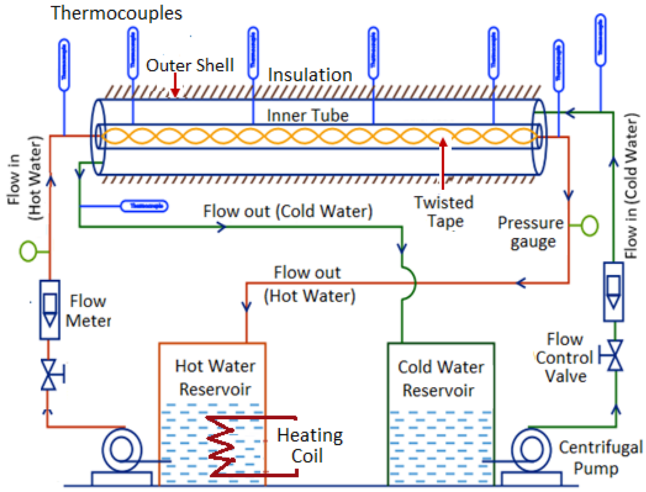

Fig. 1 Schematic of the Experimental Setup (The setup is installed at the Project Lab of Dept. of Mechanical and Production Engineering, AUST)

A detail of the experimental setup is displayed schematically in Fig. 1. This experimental setup is installed at the project lab under the Dept. of Mechanical and Production Engineering, AUST. In this setup, both hot and cold stream is water and it is supplied by two 0.5 hp power pumps. The flow rate of hot and cold both fluids are controlled by ball valve and the flow rate is measured by means of volumetric flow meter. In double pipe heat exchanger copper pipe of 1inch external diameter is used as tube and PVC pipe of 2inch internal diameter is used as shell. There are total eight pen type thermocouples used in the apparatus to measure the temperature of both hot and cold fluids at different points. The hot fluid is heated by a 1 kW portable water heater. Twisted tape made of copper used as turbulator to investigate the thermal performance improvement of the heat exchanger. Positioning of twisted tapes inside the copper tube and the thermocouples on the upper surface of the copper tube attached by solid seal are shown in Fig. 2. The twisted tapes with the length of 25 cm, width of 2 cm and 0.3 cm thick are shown in Fig. 3. Total number of 13 twisted taped are inserted in copper tube. Twisted tapes having twist ratio (y/W) of 7.5, 6 and 4 are inserted to study the thermal performance of the heat exchanger for different twist ratio.

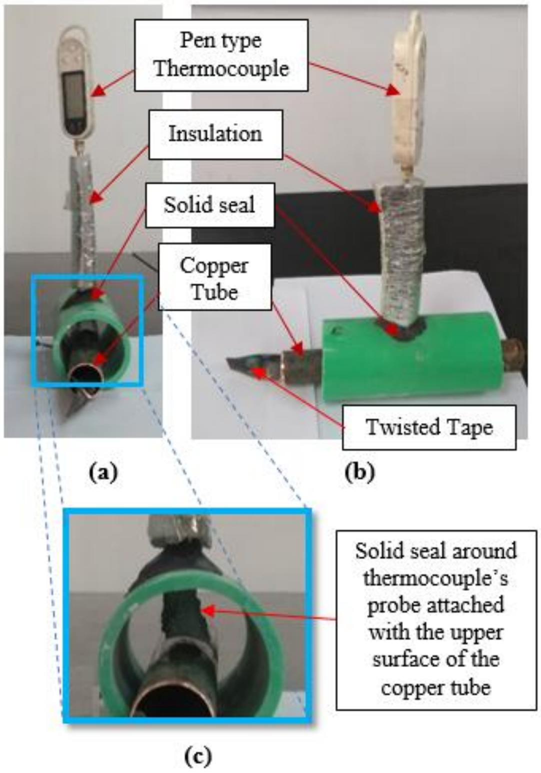

Fig. 2 Positioning of twisted tape and the thermocouple in heat exchanger: (a) & (b) truncated portion of the heat exchanger to show fittings, and (c) a magnified view to show the thermocouple probe's fitting with the outer wall of copper tube to measure the wall temperature.

Two pressure gauges are used to measure the pressure drop in both shell and tube explicitly, due to insertion of twisted tapes in the pipes which interrupts normal flow of fluid. The experiments are conducted by varying flow rate in terms of Reynolds numbers ranging from 20000 to 50000. First hot water and cold water are brought into desired temperature. Temperature of cold water is generally room temperature. The hot water temperature is about 30˚C more than cold water. Heater connection is turned off before starting the procedure. Ball valves are regulated to get desired flow. Ball valve for cold water pipeline is always fixed. Two pumps are started at the same time. Data is taken from eight (8) thermocouples. Two for cold water inlet and outlet temperature, two for hot water inlet and outlet temperature and another four for wall temperature of the hot water tube. Data is also taken from two pressure gauges mounted on the hot water pipe at inlet and outlet. The setup runs for 30 minutes for every data collection session. Data is taken after 1minute of interval. For modified heat exchanger 13 twisted tapes are inserted inside the copper tube. Rests of the procedures are all the same for varying twisted tapes with various twist ratios.

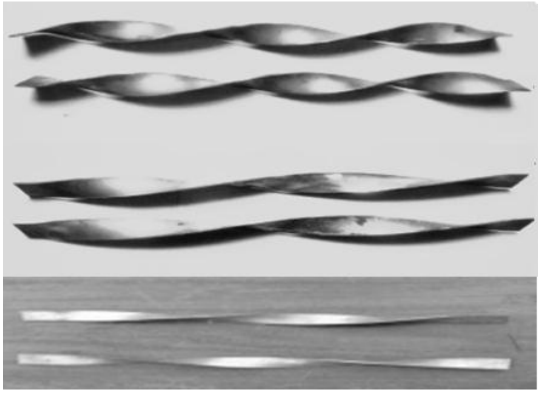

Fig.3 Twisted tapes with different twist ratios (y/W = 4.5, 6, 7.5 (from top to bottom))

3. DATA ANALYSIS

The purpose of the current work is to determine the effect of using twisted tapes in heat transfer rate of the heat exchanger. For investigation all calculations have to done for basic heat exchanger and modified heat exchanger with different twisted ratios.

The steady state of the heat transfer rate is assumed to be equal to the heat loss from the hot fluid in tube can be expressed as follows:

$$Q_H = Q_{conv.} \tag{1}$$

where,

$$Q_H = mC_{p,H}(T_o - T_i) \tag{2}$$

The convection heat transfer from tube can be written by

$$Q_{conv.} = hA(T_w - T_b) \tag{3}$$

in which the bulk temperature is found by

$$T_b = (T_o + T_i)/2 \tag{4}$$

and, the average wall temperature is calculated as:

$$T_w = \Sigma t_w/4 \tag{5}$$

where, t_w local wall temperature maintaining equal distance along the length of the hot tube. The average wall temperature T_w is computed by using 4 points of local wall temperatures.

The average heat transfer coefficient (h) and Nusselt number (Nu) are estimated as follows:

$$h = mC_{p,H}(T_o - T_i)/A(T_w - T_b) \tag{6}$$

the heat transfer is calculated from the average Nu which can be obtained by

$$Nu = hD/k \tag{7}$$

Reynolds number (Re) is estimated by

$$Re = VD/\vartheta \tag{8}$$

where, V is the velocity of hot fluid inside the tube.

Effectiveness and overall heat transfer coefficient is obtained as follows:

$$\epsilon = \Delta T\,(\text{of fluid with minimum heat rate}) / \Delta T_{max} \tag{9}$$

and, the overall heat transfer coefficient is found by

$$U = Q_H / A\,\Delta T_m \tag{10}$$

where, ΔT_m is logarithmic mean temperature difference (LMTD) and it expressed as

$$\Delta T_m = \frac{(T_{H\ out} - T_{C\ in}) - (T_{H\ in} - T_{C\ out})}{ln[(T_{H\ out} - T_{C\ in})/(T_{H\ in} - T_{C\ out})]} \tag{11}$$

All of thermo-physical properties of water are determined at the overall bulk water temperature T_b , Eq. (4).

4. RESULTS AND DISCUSSION

4.1 Validation of Experiments on Basic Heat Exchanger

In this study, the experimentally obtained Nusselt number values for the basic heat exchanger (BHE) are compared with the correlation of Dittus-Boelter as given below:

$$Nu = 0.023\,Re^{0.8}\,Pr^{0.4} \tag{12}$$

Fig. 4 shows the variation of Nusselt number as function of Reynolds number for experimental study and that for the Dittus-Boelter correlation. For both cases, with the increase of flow velocity in terms of Reynolds number, the heat transfer in terms of Nusselt number also increases. This occurs due to the fact that the heat transfer rate enhances with higher flow velocity of the working fluid. The experimental results display a good agreement with the results obtained from Dittus-Boelter correlation.

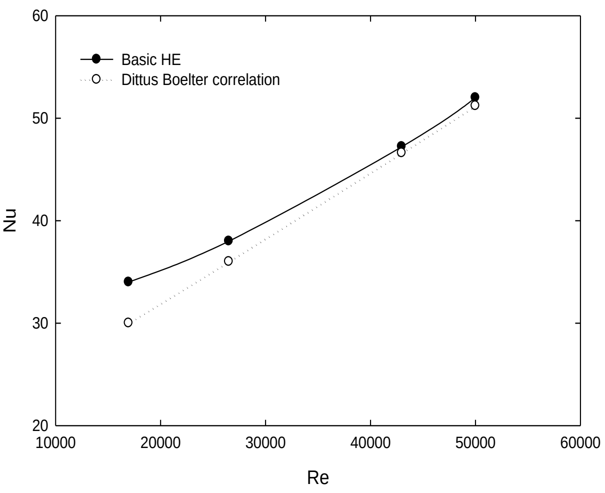

Fig.4 Variation of Nusselt number as a function of Reynolds number for Basic Heat Exchanger (BHE).

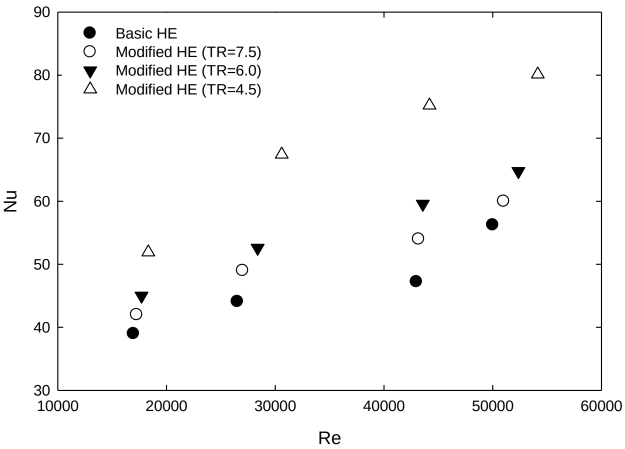

Fig.5 Variation of Nusselt number with Reynolds number for BHE and MHEs

4.2 Effect of inserting Twisted Tape and Twist ratio

Insertion of twisted tape in the copper tube causes smaller annular flow area for the hot fluid than in basic heat exchanger. With the decrease of flow area, the flow velocity increases. Twisted tape generates secondary flow inside the copper tube along with the interruption of normal fluid flow. Turbulence caused by higher flow velocity and twisted tapes, accompanying with secondary fluid flow causes increase in the heat transfer. Twisted tapes with lower twist ratio has more twist than the twisted tapes with higher twist ratio. With higher twists the tapes generate rapid secondary flow and turbulence which results higher heat transfer than other twisted tapes with high twist ratio. The variations of Nusselt number with Reynolds for modified HEs with three different twist ratio along with basic HE is shown in Fig. 5. Reynolds number is a function of velocity and velocity itself is a function of mass flow rate and Nusselt number is also proportional to the flow velocity. Both Reynolds number and Nusselt number are higher in the MHE with TR = 4.5, than both the BHE and the other MHEs with TR = 6.0, 7.5, for different mass flow rate of hot water. Fig. 5 displays that, the insertion of twisted tape increases turbulence of the flow and thus increases the velocity of the flow which increases heat transfer in terms of Nusselt number. It also shows the linear behavior of Nusselt number variation along Reynolds number for both BHE and MHEs. The rate of heat loss from the hot fluid of the inner tube with mass flow rate of hot fluid for both the BHE and MHEs is displayed in Fig. 6. Insertion of twisted tape in copper tube causes swirl flow of hot fluid as well as turbulence. For these reasons heat loss increases with the increase of mass flow rate of hot fluid which indicates augmentation of heat transfer rate due to twisted tape insertions. The heat loss is found to be the highest in MHE with TR = 4.5 and the least in the BHE. Nusselt number is related to the heat transfer rate. Higher the Nusselt number means there is more convective heat transfer rate. With the increase in mass flowrate, Nusselt number increases in terms of heat transfer rate. Variation

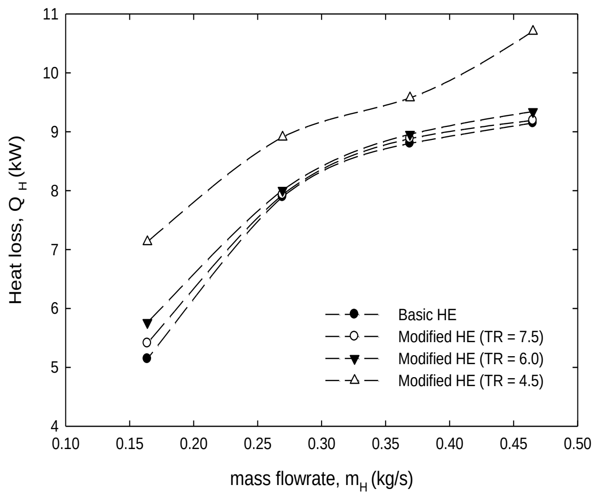

Fig. 6 Variation of heat loss from hot fluid with its mass flowrate

of Nusselt number as function of mass flowrate is shown in Fig. 7. From Fig. 7, Nusselt number is higher in the MHE with TR = 4.5 than the BHE and the other MHEs (TR = 6.0, 7.5). As the mass flow rate increases, the Nusselt number increases for all types of the heat exchangers. Fig. 8 shows the variation of Reynolds number with mass flow rate of hot fluid. Reynolds number increases for constant mass flowrates and is the highest for the MHE with lowest twist ratio than the MHEs and the BHE. Twisted tape with lowest twist ratio has denser twists than other which help the tape to generate more turbulence. This results in higher Reynolds numbers for the MHEs compared to that for BHE. The variation of overall heat transfer coefficient as function of mass flow rate of hot fluid for BHE and MHEs is displayed in the Fig.9. The overall heat transfer coefficient increases with the increase of mass flow rate of hot fluid for all types of heat exchangers. As heat transfer enhancement method (insertion of twisted tape) applied, the overall heat transfer coefficient increases with constant mass flow rate of hot fluid. The overall heat transfer co-efficient is found to be higher in the MHEs than the BHE. The overall heat transfer co-efficient depends on the surface area. Twisted tape with low twist ratio has more twist that tends to more surface area. So the overall heat transfer coefficient is the minimum in the BHE and the maximum in the MHE with twisted tape having twist ratio of 4.5. The variation of effectiveness with mass flowrate of hot fluid for all heat exchangers is shown in Fig. 10. The comparison of effectiveness among the BHE and the MHEs displays that the effectiveness increases along with the increase in mass flow rate of hot fluid for all cases. The effectiveness of the MHE with TR = 7.5 is higher than the BHE, and the effectiveness of the MHE with TR = 6.0 is higher than both the BHE and the MHE with TR = 7.5. For the MHE with TR = 4.5, the effectiveness is found to be the maximum. In the present study, for different mass flow rate of hot fluid and for both basic and modified heat exchangers effectiveness is computed from the recorded data. The lines of effectiveness of the BHE and that of the MHEs (with TR = 7.5, 6.0, 4.5) nearly follow the same trend. But it is found that as the mass flow rate increases the difference in effectiveness decreases between the heat exchangers. This means, the effectiveness achieved by applying twisted tape inserts is limited to the mass flowrate of the fluid. Hence, it can be inferred that beyond a limit of the mass flow rate, in terms of effectiveness, the achievement in MHEs becomes insignificant compared to that achieved in the BHE.

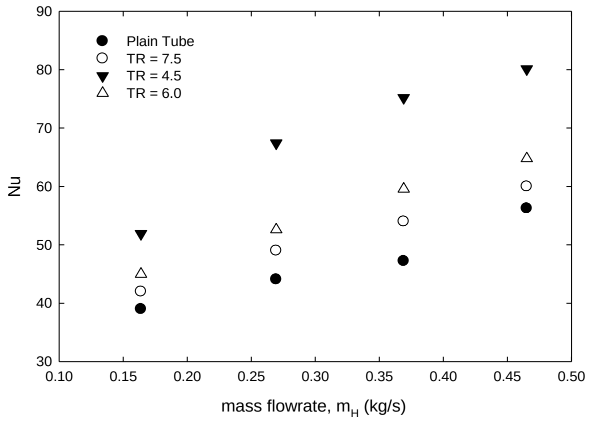

Fig. 7 Variation of Nusselt number with mass flowrate of hot fluid

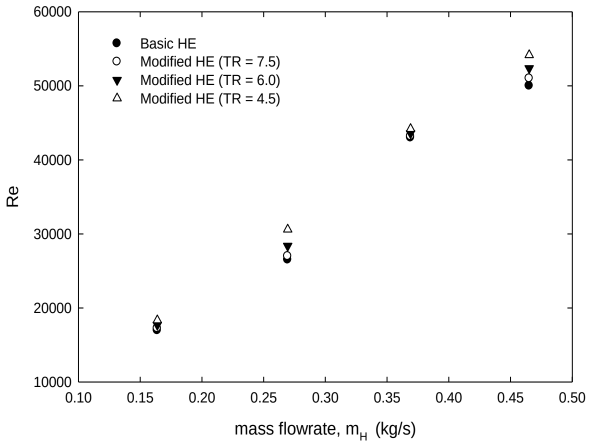

Fig. 8 Variation of Reynolds number with mass flowrate of hot fluid

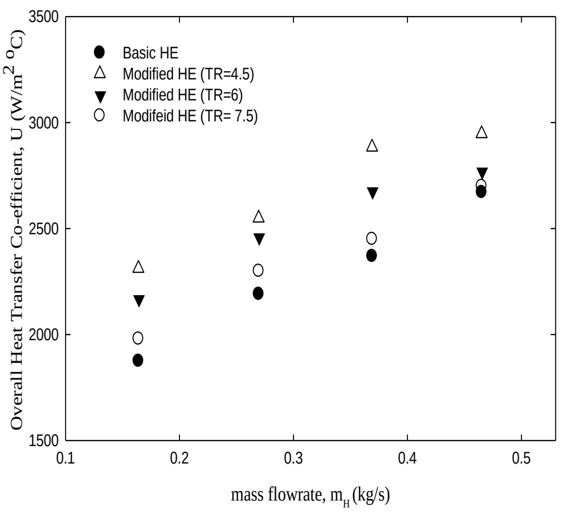

Fig. 9 Variation of Overall heat transfer coefficient with mass flowrate of hot fluid

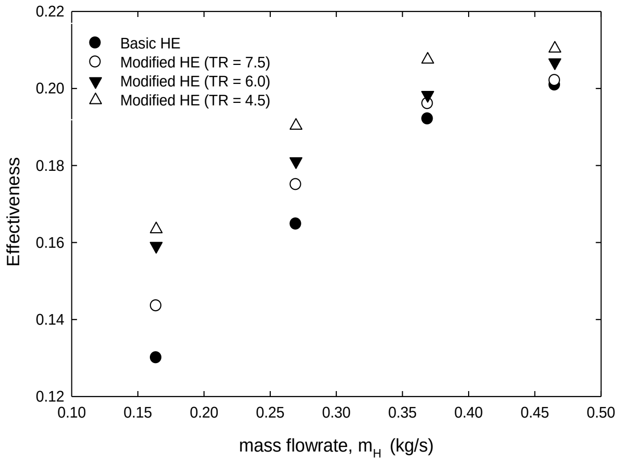

Fig. 10 Variation of Effectiveness with mass flowrate of hot fluid

5. Conclusion

In this study, an experimental investigation on different performance indicators in a tubular heat exchanger (HE) of basic and modified with twisted tape inserts has been carried out following variable flow of hot fluid and constant flow of cold fluid in a closed circuit. According to the experiments, the major findings can be summarized as follows:

(i) Heat transfer rate was found to be enhanced in modified heat exchangers compared to that of basic heat exchanger. The rate of heat transfer enhancement was ~14.1% for HE with TR of 4.5, ~6% for HE with TR of 6.0, and ~2.5% for HE with TR of 7.5 in the modified heat exchangers(MHEs) compared to that of the basic heat exchanger (MHE).

(ii) Reynolds number increases for the MHEs as twisted tape generate turbulence in the fluid flow.

(iii) Nusselt number is found to be increased in the MHEs due to the augmentation in the heat transfer rate through the inner copper tube wall.

(iv) The effectiveness of the MHEs is limited to the mass flow rate of the fluid through the inner tube. After a limit of mass flow rate, the effectiveness becomes less significant compared to that occurs at lower mass rates.

6. NOMENCLATURE

c_p : specific heat at constant pressure, $kJ \cdot kg^{-1} \cdot K^{-1}$
Re : Reynolds number
Pr : Prandtl number
h : specific enthalpy, $kJ \cdot kg^{-1}$
U : overall heat transfer coefficient, $W/m^2\,^oC$
T : temperature, K
t : Celsius temperature, ^oC
k : Thermal conductivity, W/mK
ϑ : Kinematic viscosity, m^2/s

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