Heat Transfer Enhancement with Different Square Jagged Twisted Tapes and CuO Nano fluid

1Krishna S. Borate, 2A.V. Gawandare, 3P.M. Khanwalkar

1,2,3Department of Mechanical Engineering, Sinhgad College of Engineering, Pune, India

Email: 1krishnaborate@sinhgad.edu, 3pmkhanwalkar.scoe@sinhgad.edu

Abstract— The present experimental work is carried out with copper twisted tape inserts 3mm thick with5.2, 4.2 twist ratios and nano fluid. The inserts when placed in the path of the flow of the fluid, create a high degree of turbulence resulting in an increase in the heat transfer rate and the pressure drop. Apart from the basic reason of improvement in thermal conductivity in nano fluids, the suspension of nano particles alters the flow behaviour in general. The work includes the determination of friction factor and heat transfer coefficient for various twisted tape inserts with varying twists and CuO nano fluid. The Reynolds number is varied from 5000 to 16000. Correlations for Nusselt number and friction factor are developed for the twisted tape inserts from the obtained results. The results of varying twists in square jagged tape with different pitches and CuO nano fluid have been compared with the values for the smooth tube. The 3mm thick with 4.2 twist copper insert and nano fluid shows increase in Nusselt number values by 81% however there is increase in friction factor by only 21.5% as compared to the smooth tube values.

Index Terms— Enhancement efficiency, heat transfer, square jagged twisted tapes, turbulent; swirling, pressure drop, nano fluid.

I. INTRODUCTION

Heat exchangers are widely used in various industrial processes for heating and cooling applications such as air conditioning and refrigeration systems, heat recovery processes food and dairy processes, chemical process plants etc. The major challenge in designing a heat exchanger is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Furthermore, sometimes there is a need for miniaturization of a heat exchanger in specific applications, such as space application, through an augmentation of heat transfer. For example, a heat exchanger for an ocean thermal energy conversion (OTEC) plant requires a heat transfer surface area of the order of 10000 m2 /MW [1]. Therefore, an increase in the efficiency of the heat exchanger through an augmentation technique may result in a considerable saving in the material cost. Furthermore, as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more common for heat exchangers used in marine applications and in chemical industries. In some specific applications, such as heat exchangers dealing with fluids of low thermal conductivity (gases and oils) and desalination plants, there is a need to increase the heat transfer rate. The heat transfer rate can be improved by introducing a disturbance in the fluid flow thereby breaking the viscous and thermal boundary layer. However, in the process pumping power may increase significantly and ultimately the pumping cost becomes high. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years and are discussed under the classification section.

II. HEAT TRANSFER ENHANCEMENT USING VARIOUS SQUARE JAGGED TWISTED TAPE

A. Present experimental work

The experimental study on passive heat transfer augmentation using square jagged copper twisted tape inserts for no. of twists with nano fluid were carried on in a single phase flow heat exchanger having the specifications as listed below:

![Experimental setup for forced convection](image)
B. Experimental Set up

Experimental set up consists of test section having tube in tube heat exchanger. Inside tube is of Copper and outside tube is of Stainless Steel. Four thermocouples are connected to the test section, two at the inlet and two at the outlet of hot and cold water respectively. Two rotameters are connected at inlet of cold and hot water to measure the flow rates. Also control valves and bypass valves are provided at inlet of both the rotameters. Two centrifugal pumps are used to circulate the cold and hot water. Two tanks are used for storing the hot water and cold water. Electric heater is attached to the hot water tank having capacity of 1500watt. To measure the pressure difference between inlet and outlet of test section of hot fluid inverted U-tube manometer is used. Different twisted tape inserts are used along with CuO nano fluid.

Figure 2 Schematic diagram of forced convection setup

C. Experimental Procedure

1. Refer to the Fig 1 and make all the cable connection carefully.
2. Switch ON the water heater wait until water temperature reaches 80.
3. Switch on temperature display.
4. Start cold water pump.
5. Adjust flow rate of cold water at 100 LPH.
7. Adjust flow rate of hot water at 100 LPH and keep it constant.
8. The temperatures will keep on rising continuously. When steady state is reached, note all the temperatures (T1 to T4).
9. Now adjust flow rate of hot water at 200 LPH.
10. The temperatures will keep on rising continuously. When steady state is reached, note all the temperatures (T1 to T4).
11. Repeat step 9 and 10 for hot water flow rates at 300, 400, 500, 600, 700, 800 and 900 LPH.
12. Now use the nano fluid with inserts.
13. Fill the hot water tank with prepared CuO nano fluid.
15. Repeat step nos. 7, 8, 9, 10.
16. Switch off pumps, water heater and temperature display.

D. Specifications of inserts

Material: Copper
i. Width of twisted tape = 12mm
ii. Twist ratio = 5.2, 4.2.
iii. Length of insert = 100cm
iv. Thickness of inserts = 3mm

E. Specifications of CuO Nano fluid

i. Average particle size = <80nm
ii. Purity = >99%
iii. Content of CuO = >99%
iv. Appearance = Black powder
v. Concentration = 0.4%
Methodology And Sample

III. CALCULATIONS

Properties of Water

a) Properties of hot water – calculated at mean bulk temperature
\[ T_{bh} = \frac{T_{h1} + T_{h2}}{2} \]

b) Properties of cold water
\[ T_{bc} = \frac{T_{c1} + T_{c2}}{2} \]

2) Heat given by hot water
\[ Q_h = m_h C_p (T_{h1} - T_{h2}) \]

3) Heat given by cold water
\[ Q_c = m_c C_p (T_{c2} - T_{c1}) \]

4) Average heat transfer
\[ Q_{avg} = \frac{Q_h + Q_c}{2} \]

5) Overall heat transfer coefficient
\[ Q_{avg} = U A_s \Delta T_m \]

a) Surface area of tube
\[ A_s = \pi d L \]

b) Logarithmic mean temperature difference
\[ \Delta T_m = \frac{(\Delta T_1 - \Delta T_2)\ln(\Delta T_1/\Delta T_2)}{\Delta T_1} \]
\[ \Delta T_1 = T_{h1} - T_{c2} \]
\[ \Delta T_2 = T_{h2} - T_{c1} \]

6) Nusselt Number of cold water flowing through the annular space.
\[ Nu_c = 0.023 \left( \frac{Re_c}{Pr} \right)^{0.8} \]

7) Heat transfer coefficient of cold water flowing through the annular space.
\[ h_c = \frac{Nu_c k}{D_h} \]

8) Heat transfer coefficient of hot water flowing through the tube.
\[ \frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} \]
\[ h_i = \frac{1}{(1/U - 1/h_o)} \]

Experimental Nusselt Number of hot water flowing through the tube.
\[ Nu_i = \frac{h_i D_i}{k} \]

10) Theoretical Nusselt Number of hot water flowing through the tube (Dittus Boelter equation).
\[ Nu_i = 0.023 \left( \frac{Re_{i0}}{Pr} \right)^{0.3} \]

11) Experimental Friction Factor
a) \[ \Delta p = \rho g h \]
b) \[ \Delta p = f L \rho U_i^2 / 2d_i \]
\[ f = 2g d_i h / L U_i^2 \]

12) Theoretical Friction Factor
\[ f = 0.0055 \left( 1+(50+(10^{6}/Re_i))^{0.33} \right) \]

13) Performance evaluation criteria
\[ \frac{Nu}{f} = \eta = \frac{P_f}{f_3} \]
\[ PEC = \frac{P_f}{f_3} \]

IV. RESULTS AND DISCUSSION

A. Validation Of The Experimental Programme

The accuracy with which the friction factor and Nusselt number could be evaluated experimentally with the use of present experimental rig was determined by conducting preliminary experiments with plain tube without insert, and results compared with standard empirical relationships and previous research work for laminar flow. The purpose was to check the reliability of the apparatus.

a. Heat transfer results for smooth tube:

Figure 6 shows the relation between Nusselt number v/s Reynolds number. The curve shows that Nusselt number is a function of Reynolds number. The values are in close agreement with the Dittus-Boelter equation with a maximum variation of 20 %.
b. Friction factor results for smooth tube:

Figure 7 shows the relation friction factor v/s Reynolds number for turbulent flow in the tube without twisted tape insert, that is smooth tube flow conditions. This proves that the experimental test rig is validated and further experimentation can be carried out.

B. Comparison Of Plain Tube and Tubes With Various Twisted Tapes

Figure 8 shows the relation between Nusselt number and Reynolds number for plain tube and tube with various inserts, the Figure concludes that the Nusselt number is function of Reynolds number. Nusselt number increases with increase in Reynolds number. Hence, convective heat transfer rate is more with higher Reynolds number. Further, it can be concluded that, twisted tapes with tighter twist (with lesser twist ratio) give increased Nusselt number for a particular Reynolds number. Heat transfer rate is better with twisted tapes of lower twist ratio. Perforated tapes shown greater Nusselt number compared with plain twisted tapes.

Figure 9 shows the relation between friction factor and Reynolds number for plain tube and tube with various inserts, the Figure concludes that the friction is minimum when the twisted tape is not inserted. Further, with the increase in twist, i.e. with the decrease in twist ratio, the friction factor goes on increasing for a particular Reynolds number. Perforated tapes show lesser friction factor compared with plain twisted tapes.

The curves are very steep for lesser values of Reynolds number. This is due to the fact that, for lower values of Reynolds number, the viscous force dominates the inertia force. For lower Reynolds number, less than 550, the curves are more leaning and the friction factor is comparatively high.

V. CONCLUSION

Experimental investigation of heat transfer and friction factor characteristics of circular tube fitted with full-length square jagged twisted tape inserts of different twist ratio has been presented. Calculations and curve fitting is done and correlations are obtained. The results showed that there was an appreciable enhancement in heat transfer and that the heat transfer is more with lesser twist ratio.
Maximum increase in Nu for nano fluid was found to be 31 %

Maximum increase in Nu for twisted tape with $y = 5.2$ and nano fluid was found to be 90 %

Maximum increase in Nu for twisted tape with $y = 4.2$ and nano fluid was found to be 151 %

Friction factor is increased by 30 % with nano fluid

Friction factor is increased by 50 % with $y = 5.2$ & nano fluid

Friction factor is increased by 89 % with $y = 4.2$ and nano fluid

It is concluded that heat transfer increase by 151% while friction factor increases by 89% so with less pumping power more heat transfer can achieved

REFERENCES


