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Experimental Investigation of Heat Transfer Enhancement with Different Square Jagged Twisted Tapes and CuO/water Nano fluid

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Abstract: *Heat transfer & friction factor characteristics of CuO/water nano fluid have been experimentally investigated. The nano fluid was employed in circular tube equipped with square jagged copper twisted tape. The twist ratios of square jagged twisted tape was varied between 4, 6 and 7 by keeping the concentration of nano fluid constant at 0.1% volume concentration. The experiments were performed in turbulent regime with Reynolds number spanned between 5400 and 27000. To evaluate heat transfer enhancement and the increase of friction factor, the Nusselt number and friction factor of base fluid in the plain tube were employed as reference data. The obtained results reveal that Nusselt number increases with increase in Reynolds number and decrease in twist ratio. The simultaneous use of nano fluid and square jagged twisted tape with twist ratio 4 shows increase in Nusselt number value by 87% however there is increase in friction factor by only 23.4% as compared to the smooth tube values.*

Keywords: *heat transfer enhancement, nano fluid, pressure drop, square jagged twisted tapes, turbulent regime, twist ratio.*

1. 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 m^2/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.

2. HEAT TRANSFER ENHANCEMENT SING VARIOUS SQUARE JAGGED TWISTED TAPE INSERTS AND NANO FLUID

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-

Fig1: *Photographic view of experimental set up for forced convection*

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.

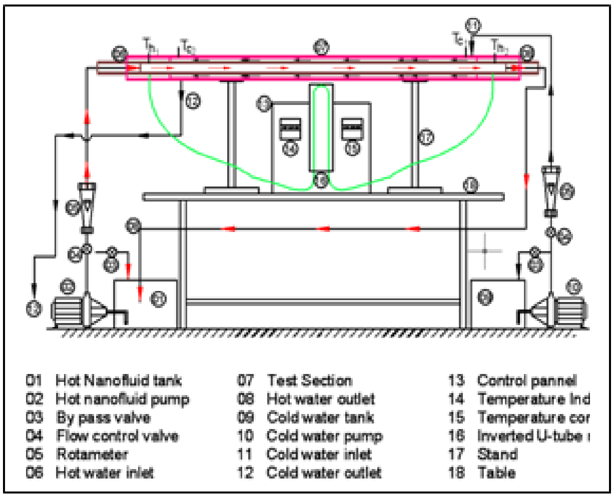

Fig 2: Schematic diagram of forced convection set up

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 70°C
3. Switch on temperature display
4. Start cold water pump
5. Adjust flow rate of cold water at 100 LPH
6. Start hot water pump
7. Adjust flow rate of hot water at 200 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.
14. Start nano fluid pump.
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 = 7, 6, 4

iii. Length of insert = 100cm

iv. Thickness of inserts = 3mm

E. Specifications of CuO Nano Particle

i. Average particle size =<80nm

ii. Purity =>99%

iii. Content of CuO =>99%

iv. Appearance = Black powder.

Fig 3: *Photographic view of CuO nanoparticles.*

Fig 4: *Copper square jagged Twisted tape (y/w=7)*

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Fig 5: *Copper square jagged Twisted tape (y/w=6).*

Fig 6: *Copper square jagged Twisted tape (y/w=4).*

3. DATA REDUCTION

1) Properties of water

a) Properties of hot water – calculated at mean bulk temperature.

$$T_{bh} = \frac{Th_1 + Th_2}{2}$$

b) Properties of cold water

$$T_{bc} = \frac{Tc_1 + Tc_2}{2}$$

2) Heat given by hot water

$$Q_h = m_h \ C_{ph} \ (T_{h1} - T_{h2})$$

3) Heat given by cold water

$$Q_c = m_c \ C_{pc} \ (T_{c2} - T_{c1})$$

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

$$A_s = \pi d_i L$$

b) Logarithmic mean temperature difference

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$\Delta T_1 = T_{h1} - T_{c2}$

$\Delta T_2 = T_{h2} - T_{c1}$

6) Nusselt Number of cold water flowing through the annular space.

$Nu_o = 0.023(R_{eo})^{0.8} \, (P_r)^{0.3}$

$$Re_o = \frac{\rho U_o D_h}{\mu}$$

$D_h = D_i - d_o$

Continuity equation

$m_c = \rho A_o U_o$

7) Heat transfer coefficient of cold water flowing through the annular space.

$$Nu_o = \frac{h_o D_h}{K}$$

$$h_o = \frac{Nu_o K}{D_h}$$

8) Heat transfer coefficient of hot water flowing through the tube.

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

$$h_i = \frac{1}{\left(\frac{1}{U} - \frac{1}{ho}\right)}$$

9) 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).

$Nu_i = 0.023(R_{ei})^{0.8} \, (P_r)^{0.3}$

11) Experimental Friction Factor

(i) $\Delta P = \varrho g h$

(ii) $\Delta P = \frac{f L \rho U_i^2}{2 d_i}$

$$f = \frac{2 g d_i h}{L U_i^2}$$

12) Theoretical Friction Factor

$$f = 0.0055\left(1 + \left(50 + \left(\frac{10^6}{Re_i}\right)\right)^{0.33}\right)$$

13) Performance evaluation criteria

$$PEC = \eta = \left(Nu) \frac{\frac{Nu}{p_i}}{\frac{f_3}{f_p}} \right)$$

4. RESULTS AND DISCUSSION

I. The accuracy with which the Nusselt number and friction factor could be evaluated experimentally with the use of present experimental set up was determined by conducting preliminary experiments with plain tube. The results are compared with standard empirical relationships and previous research work for turbulent flow. The purpose was to check the reliability of the apparatus.

A. *Experimental and theoretical heat transfer results for smooth tube*

Fig. 7 shows the relation between Reynolds number v/s. Nusselt 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 %

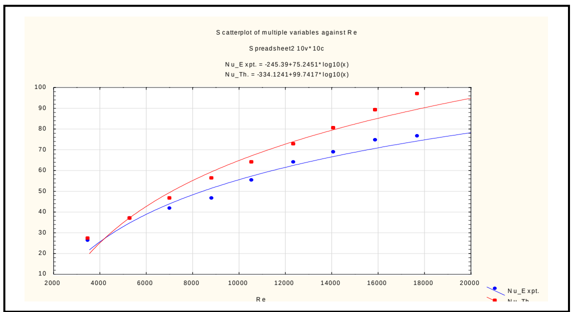

Fig 7: *Reynolds number v/s. Nusselt number for plain tube*

B. *Experimental and Theoretical Friction Factor Results for Smooth Tube.*

Fig. 8 shows the relation between Reynolds number v/s. friction factors for turbulent flow in a plain tube. The results obtained are in close with theoretical values. This proves that the experimental test rig is validated and further experimentation can be carried out.

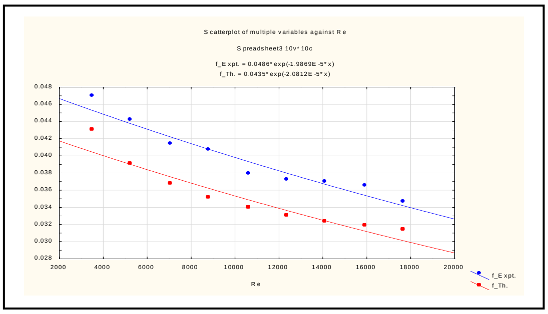

Fig 8: *Reynolds number v/s. Friction factor plot for plain tube*

C. *Comparison of "Plain Tube" and "Tubes with various twisted tapes"*

Fig. 9 shows the relation between Nussult 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 lower twist ratio gives highest Nusselt number for a particular Reynolds number. Heat transfer rate is better with twisted tapes of lower twist ratio.

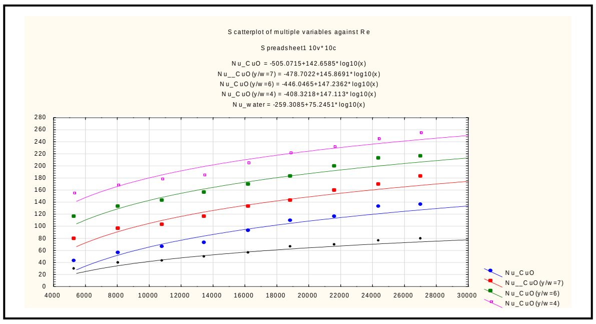

Fig 9: *Reynolds number v/s. Nussult number plot for Y=7,6,4, CuO, water.*

Fig. 10 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 for a plain tube. With decrease in twist ratio, the friction factor goes on increasing for a particular Reynolds number.

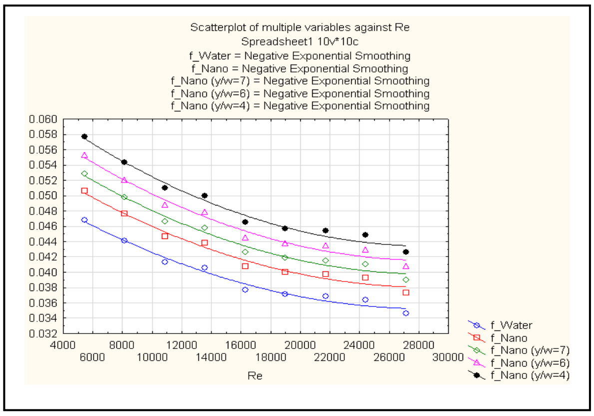

Fig 10: *Reynolds number v/s. Friction factor plot for Y=7,6,4,CuO, water*

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 6000, the curves are more leaning and the friction factor is comparatively high.

5. CONCLUSIONS

Experimental investigation of heat transfer and friction factor characteristics of circular tube fitted with full-length square jagged twisted tape inserts and CuO nano fluid of different twist ratios have 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 43 %.
- Maximum increase in Nu for twisted tape with y/w = 7 and nano fluid was found to be 66 %.
- Maximum increase in Nu for twisted tape with y/w = 6 and nano fluid was found to be 78%.
- Maximum increase in Nu for twisted tape with y/w = 4 and nano fluid was found to be 87%.
- Friction factor is increased by 9 % with nano fluid.
- Friction factor is increased by 14 % with y/w=7 & nano fluid.
- Friction factor is increased by 19 % with y/w=6 and nano fluid.
- Friction factor is increased by 23 % with y/w=4 and nano fluid.
- It is concluded that Nusselt number increased by 87% while friction factor increases by 23% so with less pumping power more heat transfer can achieved

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