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Study of Heat Transfer and Flow Friction in a Concentric Double Pipe Heat Exchanger Fitted with Twisted Tape Elements

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Abstract—*An experimental study has been carried out to investigate the heat transfer and flow friction in a concentric double pipe heat exchanger with twisted tape made of aluminum inserted inside the inner tube using water as a working fluid in both side for a range of Reynolds number, 4000-12000. Results are presented for different twist ratios, viz. 3, 4, and 5 under steady state condition. The friction factor, convective Nusselt number and overall enhancement ratio have been presented for different Reynolds number and twist ratio. The results obtained are compared with that of plain tube. The maximum increase in Nusselt number is 45% and that in friction factor is 210% for tube fitted with twisted tape of twist ratio, 3.*

Keywords*: Heat exchanger, twisted tape, Twist Ratio, Nusselt number, friction factor*

1. INTODUCTION

Double pipe heat exchanger are most widely used heat exchangers has got wide range of applications like power generation, refrigeration plants and household applications like domestic refrigerator and air conditioner. The great amount of energy required to run these devices has always been a concern. Therefore heat transfer enhancement is a popular area of research with an intention to come out with techniques to make heat exchangers more efficient. such techniques have been found very effective in increasing the rate of heat transfer and can help in optimum performance of heat exchangers leading to lower power consumption and reduced size of the equipment. These techniques are generally categorized into two categories. These are active methods and passive methods. In active method of heat transfer enhancement we have an external source of heat transfer such as fluid vibration, injection and suction of the fluid, jet impingement and electrostatic fields. The other method is passive method which requires no external source of power. It includes geometrical medication of the flow path or insertion of external tabulators which generate additional turbulence leading to an increased rate of heat transfer. Twisted tapes are a kind of external tabulator that is inserted inside the tube. It is passive method of heat transfer enhancement.

Experimental study of Sarada et al. [1] showed that the enhancement of heat transfer with twisted tape insert as compared to plain tube varied from 36% to 48% for full width (26 mm) and 33 % to 39% for reduced width (22 mm) insert. Murugesan et al. [2] investigated heat transfer and friction factor characteristics in circular tube fitted with twisted tape consisting of wire nails for twist ratio 2.0, 4.4 and 6.0 and found that that the Nusselt number, friction factor and thermal enhancement factor for tube fitted with twisted tape consisting of wire nails is greater than those fitted with plain twisted tape. Saha et. al. [3] investigated laminar flow heat transfer and pressure drop in a circular tube having wire coil and helical screw-tape Inserts and found that the helical-screw tape inserts in combination with wire coil inserts perform better than wire coil or Helical-screw tape insert acting alone but also increased pressure drop. Dhamane et. al. [4] experimentally investigated heat transfer and friction factor characteristics for circular tube fitted with wavy twisted tape and found that the enhancement of heat transfer with wavy twisted tape inserts as compared to plain tube varied from 9% to 43% for various inserts. Murugesan et. al. [5] studied u-cut twisted tape insert in a circular tube whose results revealed that heat transfer rate, friction factor and thermal enhancement factor in the tube fitted with u-cut twisted tape is significantly higher than those in the tube fitted with Plain twisted tape and plain tube. Various other researchers have performed similar experiments using twisted tape with v-cut, rectangular-cut, peripherally cut twisted tape etc. and have found similar results. Eiamsa-ard et. al. [6] investigated heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements and showed that that by using regularly spaced twisted tape inserts increase in heat transfer is achieved with comparatively lesser increase in friction factor as compared to plain to tube. Saha et. al. [7] also performed similar experiments using regularly spaced twisted tapes and obtained similar kind of results. Patil et. al. [8] performed experimental investigation of heat transfer and friction factor characteristics in tubular heat exchanger using twisted tape with straight delta winglets as inserts and observed that with decrease in twist ratio, heat transfer coefficient increases, but pressure drop also increases whereas increase in depth of cut (d/w) ratio improved both heat transfer coefficient and friction factor. Patel et. al [9] performed experimental investigation and comparative Study with twisted tape Flat Type Rectangular section, Simply Twisted Tape and Twisted Tape insert with Wiry Metallic Sponge. Mulla et. al [10] performed experimental investigation for heat transfer enhancement using simple twisted tape insert and twisted tape with baffles for laminar flow conditions and found Nusselt number to increase by 110 to 120% and 130 to 140% respectively than that of plain tube. Eiamsa-ard et. al. [15] showed that twisted tape with peripheral cut generate additional turbulence in the vicinity of the tube and Nu and f increase with increase in tape depth ratio (d/W) and decrease in width ratio (w/W).

After careful observation of the above literatures the objective of the present work is to study the effect of twisted tape elements made of aluminum of twist ratio 3, 4 and 5 on heat transfer and friction factor characteristics of concentric double pipe heat exchanger. Most of works have used twisted tapes of stainless steel and copper. Aluminum is used because it can be twisted to desired shape easily and has better conductivity than stainless steel and cheaper as compared to copper. Eiamsa-ard et. al. [6] used stainless steel twisted tapes of high twist ratio i(i.e. 6 and 7) and hot water was allowed to flow in the inner tube but in the present work, cold water is allowed to flow in the inner tube. Sarada et al. [1] used twist ratios 3, 4 and 5 with air as working fluid but in the present work water is used as the working fluid.

2. EXPERIMENTAL SETUP AND DESCRIPTION

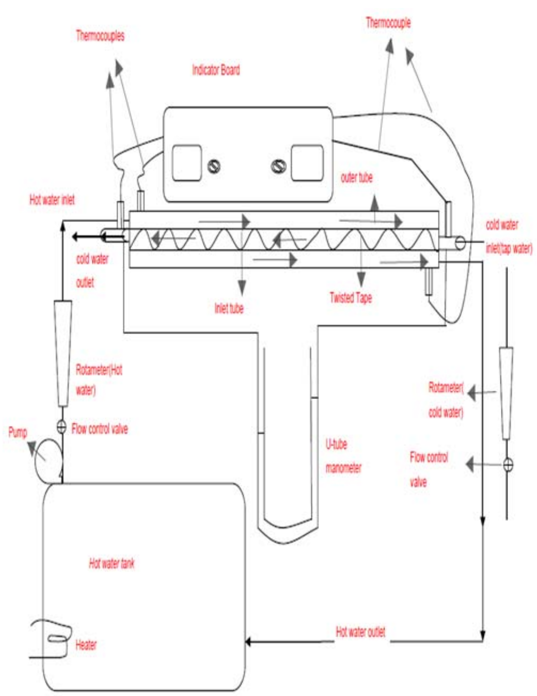

Fig. 1: Experimental Setup

Experiments are carried out in a double-pipe concentric heat exchanger in parallel mode of operation. The working fluid is water. Cold water flows in the inner tube while hot water flows in the annulus. Hot water is stored in hot a water tank heated up to 60℃. The hot water from the hot water tank is circulated through a pump. Two separate rotameters are used to determine the mass flow rate of hot and cold water respectively. Four thermocouples indicate the temperatures at inlet and outlet of hot and cold water. Control valves are used to control the flow hot water and cold water. The pressure difference across the test section is measured by using U-tube manometers.

The material of outer tube is stainless steel having inner diameter of 42mm. The material of the inner tube is copper having inner diameter of 28 mm and and outer diameter of 32 mm. The length of the tube is 1.6 m. The twisted tape is made of aluminum of length 1.6-1.7 m of 18 mm. The twisted tape has a thickness of 1 mm. Hot water flow rate is fixed at 500LPH and cold water flow rate is varied from 300 LPH to 700 LPH.

Fig. 2: Twisted tapes

3. DATA REDUCTION

Reynolds number is given by

$$\mathrm{Re} = \frac{4\overset{o}{m}}{\pi(d_o + D_i)\mu} \tag{1}$$

Heat gained by cold water is given by $Q_{cw} = m_c c_{pw}(T_{co} - T_{ci})$ (2)

And heat given by the hot water is given by $Q_{hw} = m_h c_{pw}(T_{ho} - T_{hi})$ (3)

The average heat transfer rate Q_{avg} used in the calculation is estimated by

$$Q_{avg} = \frac{Q_{wc} + Q_{wh}}{2} \quad (4)$$

Also, $Q_{avg} = U_i A_i \Delta T_{lmtd}$ (5)

Overall heat transfer coefficient is given by $\frac{1}{U_i} = \frac{1}{h_i} + \frac{1}{h_o}$ (6)

The annulus side heat transfer coefficient h_o is estimated by using the correlation of Dittus and Boelter given by

$$Nu_o = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3} \quad (7)$$

Then, h_o Can be obtained from

$$h_o = \frac{kNu_o}{d_h} \quad (8)$$

Nusselt number for tube side can be obtained from

$$Nu_i = \frac{h_i d_i}{k} \quad (9)$$

Friction factor can be obtained experimentally from pressure drop calculations using

U-manometer given by

$$\Delta p = f \frac{L}{d_i} \frac{\rho v 2}{2} \quad (10)$$

This gives, $f = \dfrac{\Delta p}{(\frac{L}{d_i})(\rho \frac{v^2}{2})}$ (11)

Overall Enhancement ratio = $\dfrac{Nu/Nu_o}{(f/f_o)^{1/3}}$ (12)

The uncertainty calculation for Reynolds number was ±5%, for Nusselt number was ±10% and for friction factor was ±14%.The uncertainty in velocity measurement was less than ±5% .The uncertainty in pressure measurement was 10%.The uncertainty in temperature measurement was ±0.25 ℃.

4. RESULT AND DISCUSSION

4.1. Validation of plain tube

The experimental Nusselt number friction factor obtained for plain tube is validated with Dittus-Bolter and Blassius correlation:

$$Nu_o = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3} \quad (13)$$

$$f = \frac{0.314}{\mathrm{Re}^{1/4}} \quad (14)$$

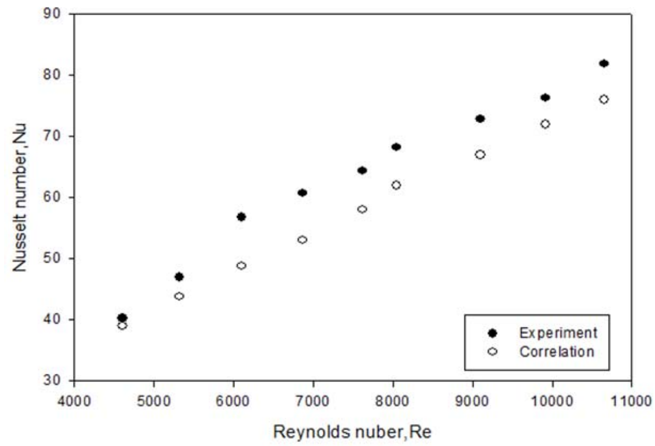

Fig. 3: Validation curve of Nusselt number for plain tube

It is found that the results obtained for the plain tube is in good agreement with those obtained from the correlations.

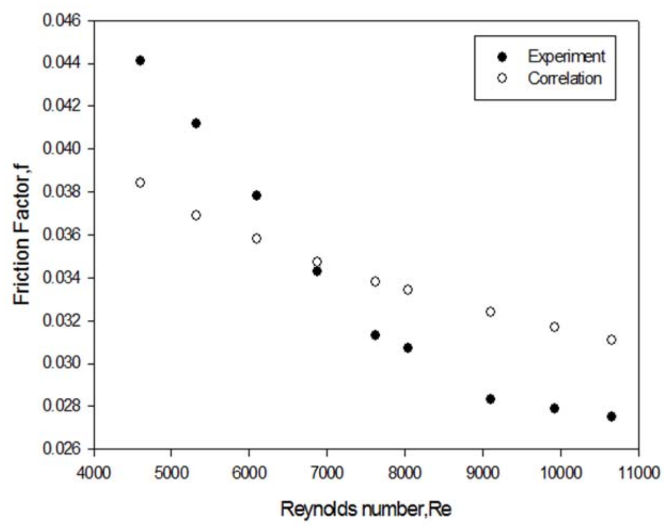

Fig. 4: Validation curve of Friction(f) for plain tube

4.2 Effect of twist Ratio on Nusselt number

Variation of Nusselt number with Reynolds number by inserting twisted tapes of different twist ratios (y =3,4 and 5) is shown in the graphs below. It is noticed that that tubular heat exchanger equipped with twisted tape shows considerable increase in Nusselt number resulting in increased heat transfer as compared to plain tube. The reason behind the enhanced heat transfer of inserted tubes is attributed to the swirl motion generated due to the due the geometrical shape of the twisted tape. This increases the turbulence which leads to higher convection heat transfer and ultimately larger Nusselt number. More number of twists generates more intense swirl leading to larger Nusselt number. Thus, more number of twist i.e lower the twist ratio higher is the Nusselt number corresponding to a particular Reynolds number. The increase in Nusselt number for the tube fitted with twist ratio 3 over plain tube with varies from 30% to 45%. The increase in Nusselt number is 20%-35% for twist ratio 4 and 10%-25% for twist ratio 5. The percentage increase in Nusselt number for tube fitted with twisted tape over plane tube is larger at lower Reynolds number and decreases with increase in Reynolds number.

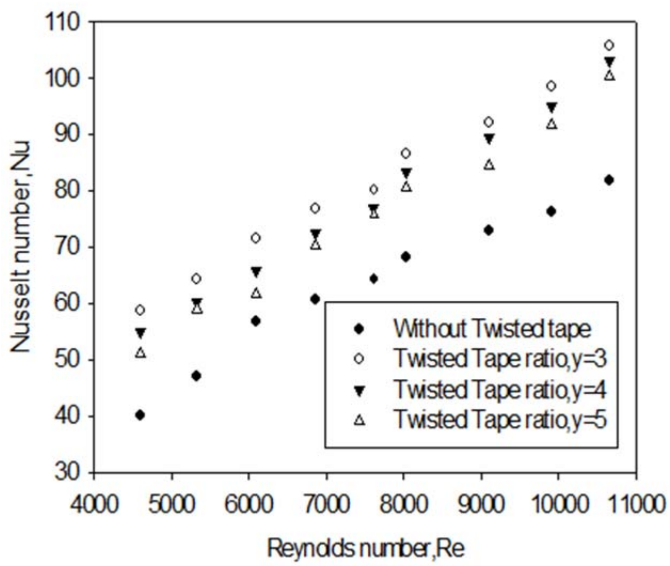

Fig. 5: Variation of Nusselt number (nu) with Reynolds number(Re) for the twisted tape(y =3,4 and 5)

4.3 Effect of twist Ratio on Friction factor

The friction factor for inserted tubes is also higher compared to the plain tube. The geometry of the twisted tape offers higher obstruction to the flow leading to greater pressure drop. Like, the Nusselt number friction factor also increases with decrease in twist ratio. The increase in friction factor for the tube fitted with twist ratio 3 over plain tube varies from 160%-210%. The increase in friction factor is 110%-160% for twist ratio 4 and 80%-120% for twist ratio 5. The percentage increase in friction factor for tube fitted with twisted tape over plane tube is larger at lower Reynolds number and decreases with increase in Reynolds number.

Fig. 5: Variation of friction factor (f) with Reynolds number (Re) for the twisted tape(y =3,4 and 5)

4.4 Correlations

The following correlation have been developed from the experimental data

Correlation for Nusselt number

$$Nu = 0.0963\mathrm{Re}^{0.73}\,\mathrm{Pr}^{0.33}\,y^{-0.25} \tag{15}$$

Correlation for friction factor

$$f = 3.62\,\mathrm{Re}^{-0.3}\,y^{-0.67} \tag{16}$$

The correlation coefficient of the above correlations is 0.97 and 0.92 for Nusselt number and Friction factor respectively which signifies the excellent agreement between the correlated data and the experimental data.

5. CONCLUSION

The present work clearly indicates that twisted tapes are highly effective in increasing the heat transfer. Although it is accompanied by substantial increase in friction factor, this technique can be highly useful to reduce the size of heat exchangers where heat transfer is the primary requirement. A maximum heat transfer enhancement of 46% over and above plain tube is obtained with the twisted tape of twist ratio 3 at Reynolds number 4600.The increase in heat transfer is attributed to swirl flow generated due to the shape of the twisted tape which leads to increased turbulence and better mixing of the fluid.

6. NOMENCLATURE

Y=Twist Ratio=H/W

$H\ twist\ pitch$, mm

$W\ width\ of\ the\ twisted\ tape$, mm

Re Reynolds number

d_i Diameter of inner tube, m

$d_o\ diamenter\ of\ outer\ tube, mm$

$d_h\ Hydraullic\ diameter$

$= d_o - d_o$,mm

$v\ velocity\ of\ flow\ in\ iner\ tube$, mm

$\vartheta\ kinematic\ viscosity\ of\ the\ fluid, {}^{m^2}/_{sec}$

$Q_{cw}\ \ heat\ gained\ by\ cold\ water, watt$

m_{cw} $mass\ flow\ rate\ of\ cold\ water, {}^{kg}/_{sec}$

C_{pw} $specific\ heat\ of\ cold\ water, {}^{J}/_{kgK}$

T_{co} $outlet\ tempreture\ of\ cold\ water, ℃$

T_{ci} $inlet\ tempreture\ of\ cold\ water, ℃$

U_i $overall\ heat\ transfer\ coifficient\ based\ on$

$inner\ diameter.$

ΔT_{lmtd} $\log mean\ tempreture\ difference, ℃$

A_i $cross\ sectional\ area\ of\ inner\ tube$

$= \pi d_i L, m^2$

A_o $cross\ sectional\ area\ of\ outer\ tube$

$= \pi d_o L, m^2$

h_i $tube\ side\ heat\ transfer\ coifficient, {}^{w}/_{m^2K}$

h_o $annulus\ side\ heat\ tranfer\ coefficient, {}^{w}/_{m^2K}$

Nu_o $nusselt\ number\ for\ annulus\ side$

Nu_i $nusselt\ number\ for\ flow\ in\ inner\ tube$

K thermal conductivity,${}^{w}/_{mk}$

pr $prandtl\ number$

ΔP $pressure\ drop\ across\ the\ test\ section, {}^{N}/_{m^2}$

f $friction\ factor$

V mean velocity of flow,${}^{m}/_{sec}$

ρ $density\ of\ the\ liquid, {}^{kg}/_{m^3}$

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