Experimental Studies on Effect of Coil Wire Insert On Heat Transfer Enhancement and Friction Factor of Double Pipe Heat Exchanger

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ABSTRACT:
In the present study heat transfer characteristics and friction factor of horizontal double pipe heat exchanger with coil wire inserts made up of different materials are investigated. The Reynolds numbers are in the range of 4000-13000. The inner and outer diameters of tubes are 17 mm and 21.4 mm respectively. Hot water and cold water are used as working fluid on tube side and annulus side, respectively. The hot water and cold water flow rates are maintained same and in range of .033 to .1 kg/s. Three different materials as copper, aluminum, and stainless steel and different pitches are used. Aluminum, copper, and stainless steel inserts are of pitches 5, 10, and 15 mm respectively. Effect of these coil wire inserts material on enhancement of heat transfer and friction factor are considered. The experimental data obtained from plain tube were verified with the standard correlation to ensure the validation of experimental results. Coil wire has significant effect on heat transfer and friction factor. Cu insert has higher heat transfer enhancement of 1.58 times as compared to plane tube. On other hand Aluminum and stainless steel insert has heat transfer enhancement of 1.41 and 1.31as compared to plane tube respectively. The friction factor found to be increasing with decreasing coil wire pitch.

Keywords: coil wire, insert, enhancement, friction factor, heat exchanger

I. INTRODUCTION:

Heat transfer enhancement techniques are frequently used in a heat exchanger system in order to enhance heat transfer and increase in thermal performance of the system [6, 16]. Heat transfer enhancement techniques are divided in to two categories: active and passive methods. In active method, heat transfer is improved by supplying extra energy to the fluid or equipment. Active method include: use of mechanical auxiliary elements, rotating the surface, mixing fluid with mechanical accessories and constituting electrostatic in flow area. In contrast, the passive enhancement can be acquired without any external energy. The passive method include: the rough surfaces, extended surfaces, coated surfaces, and turbulator/ swirl generator devices. Coiled wire and twisted tape inserts are most commonly used swirl flow devices in order to enhance heat transfer in heat exchangers. These inserts causes redevelopment of boundary layer and increase in heat transfer surface area and cause enhancement of convective heat transfer by increasing turbulence.

To date, numerous researches have been carried out concerning the effect of coiled wire/ twisted tape inserts on heat transfer and friction factor. Effect of coil pitch, coil wire thickness for coil wire inserts and twist ratio and tape thickness for twisted tape inserts on heat transfer and friction factor are considered [1-11]. Effect of coil pitch and other corresponding parameters on heat transfer enhancement and friction factor of the horizontal concentric tubes with coiled wire inserts are proposed by Naphon[2] and it was found that coiled wire inserts are specially effective on laminar flow region in terms of heat transfer enhancement. Yakut and Sahin[12] experimentally investigated the heat transfer and pressure drop in a coiled wire inserted tube besides the properties of vortices generated by coiled wire insert and relation between entropy generation and vortex characteristics. A Garcia et al. [1] study effect of coil wire insert inside a horizontal tube in a laminar, transition and turbulent region with different pitch and wire diameter. At low Reynolds number coil wire found to be behaves as a smooth tube but accelerates critical Reynolds number down to 700. In turbulence region coil wire increase heat transfer rate up to four times compared to smooth tube. Y Shoji [5] study effect of length and segmentation of coil wire insert on heat transfer enhancement. It was found that increase with increase of coil wire length.

In heat transfer enhancement studies it was found that coil wire inserts provided much more heat transfer rate when they are used in combination with twisted tapes. S.Eiamsa-ard [4] used coiled wire and twisted tape inserts together. The obtained result revealed that dual combination of twisted tape and coiled wire provide higher heat transfer rate than that of single use of twisted tape and coiled wire. Sibel Gunes et al. [17] studies heat transfer enhancement in a tube with equilateral triangle cross-section wire inserts. Akhavan-Behabaddi et al. [8] studies pressure drop and heat transfer augmentation due to coiled wire inserts during laminar flow of oil inside a horizontal tube. Akhavan-Behabaddi et al [9] also concluded experimental work to determine heat transfer and pressure drop during flow boiling of R-134a in a coil wire inserted horizontal evaporator.

Till date, published paper in a archival journal include only effect of coil wire geometry as coil pitch, coil wire diameter on heat transfer enhancement and pressure drop. The effect of coil wire insert material has not been mentioned yet. The present paper is experimental investigation of effect of coil wire insert made up of three different materials as Aluminum, stainless steel, and copper with different pitches on heat transfer enhancement and friction factor of double pipe heat exchanger. Aluminum, stainless steel and copper coil wire inserts of pitches 5, 10, and 15mm respectively are used. The Reynolds number used in a range of 4000-13000. The effect of these inserts on Nusselt number and friction factor are investigated experimentally.

II. EXPERIMENTAL SETUP

Schematic diagram of experimental apparatus is as shown in figure (1). Experiments were conducted in a double pipe heat exchanger. The hot water flows through inner tube (M.S. tube of d_i=17 mm) and cold water flows in counter flow through annulus. To measure pressure drop across test section two pressure taps are provided at inlet and of test section. Two calibrated rotameters were provided to indicate flow rate of test liquid. Two 3 kW geysers were used for providing hot water. Cold water and hot water flow rate were maintained equal and in range of .033 to .1 kg/s. Three coil wire inserts made up of copper, aluminum, and stainless steel were used in inner tube of double pipe heat exchanger. Four thermocouples were provided to measure inlet and outlet temperature of hot and cold waters. The test section is horizontal double pipe heat exchanger. The inner and outer diameters of inner tube are 17 and 21.4 mm respectively and that of outer tube are 42 and 48 mm respectively. The dimensions of tube with coil wire insert is shown table --.

Table 1: Range/values of parameters.

Parameter	Range/values		
The flow rates of water	2, 3,4,5,6 (Lit/min)		
ID of inner tube (di)	0.017 m	OD of inner tube (do)	0.0214 m
ID of outer tube (Di)	0.042 m		
Pitches of coil wire insert			
Copper insert	5 mm		
Aluminum inserts	10 mm		
Stainless steel insert	15 mm		
Test length of heat exchanger:			
For heat transfer	1.5m		
For pressure drop	1.6m		

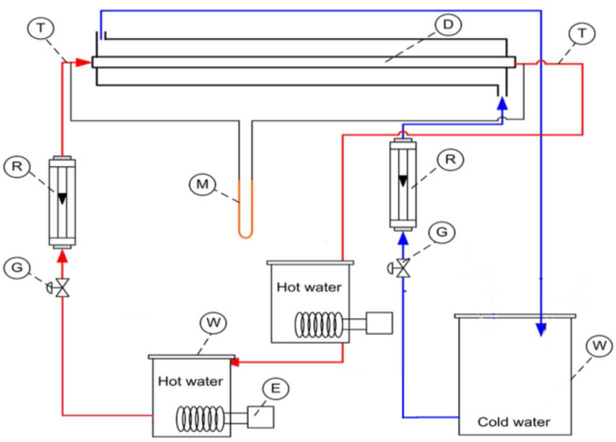

Fig. 1. Schematic diagram of the test apparatus: (B) Ball valve, , (D) Double pipe heat exchanger, (E) Ele ctrical heater,(M) Manometer, (G) Globe valve, (R) Rotameter, (T) RTD, and (W) Water tank.

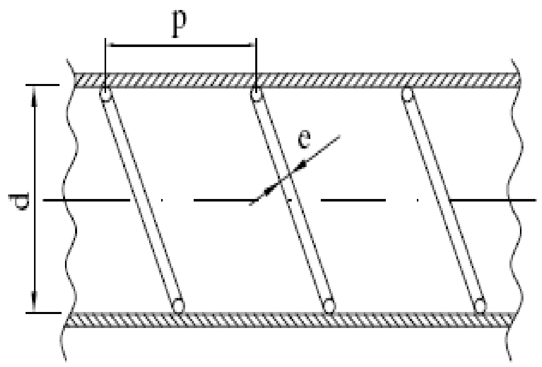

Fig. 2 Sketch of a coil wire fitted inside a smooth tube

III. DATA REDUCTION

The average Nusselt number and the friction factor are based on the inner diameter of the test tube. Heat absorbed by the cold water in the annulus, Qw,c can be written by

$$Q_{w,c} = m_c \, Cp_{,w} \, (T_{c,\,out} - T_{c,\,in}) \quad (1)$$

where m_c is the mass flow rate of cold water; Cp,w is the specific heat of water; Tc,in and Tc,out are the inlet and outlet cold water temperatures, respectively. The heat supplied from the hot water, Qh can be determined by

$$Q_h = m_h \, Cp_{,h} \, (T_{h,\,out} - T_{h,\,in}) \quad (2)$$

where m_h is the hot water mass flow rate; $T_{h,\ in}$ and $T_{h,\ out}$ are the inlet and outlet hot water temperatures, respectively.

The heat supplied by the hot fluid into the test tube is found to be 3% to 8% different than the heat absorbed by the cold fluid for thermal equilibrium due to convection and radiation heat losses from the test section to surroundings. Thus, the average value of heat transfer rate, supplied and absorbed by both fluids, is taken for internal convective heat transfer coefficient calculation.

$$Qavg = (Q_c+Q_h)/2 \quad (3)$$

For fluid flows in a concentric tube heat exchanger, the heat transfer coefficient, h_i is calculated from

$$Q_{ave} = U_i \, A_i \, \Delta T_{LMTD} \quad (4)$$

Where

$$Ai = \pi \, d_i \, L$$

The tube-side heat transfer coefficient hi is then determined using

$$\frac{1}{Ui} = \frac{1}{hi} + d_i \ln\frac{do}{di} + \frac{di}{do}\frac{1}{ho} \quad (5)$$

When the last three tirm on right side of equation (5) are kept constant and set to C_1 then equation (5) can be written as

$$\frac{1}{Ui} = \frac{1}{hi} + C_1 \quad (6)$$

Then heat transfer coefficient is related to Reynolds as

$$h_i = C \, Re^{\,m} \quad (7)$$

Where C and m stands for constant and power index values substituting equation (7) in equation (6)

$$\frac{1}{Ui} = \frac{1}{C} Re^{-m} + C1 = a\, Re^{-m} + C_1 \quad (8)$$

Eq. 8 implies that plot between $\frac{1}{Ui}$ and Re^{-m} is a straight line with its slope of a and intercept at C_1 in Y- axis ($\frac{1}{Ui}$). Rearranging equation (8) yields

$$h_i = \frac{1}{(\frac{1}{Ui} - 1)} \quad (9)$$

Then Nusselt number is calculated as

$$Nu = \frac{hi\ di}{k} \quad (10)$$

Friction factor f is calculated as

$$f = \frac{\Delta p}{{}^{L}/_{D}\,\rho U^2/_{2}} \quad (11)$$

IV. RESULT AND DISCUSSION

4.1 Verification of Experimental Result

First of all, the result obtained from experiment on heat transfer and friction factor characteristics in plane tube are verified in terms of Nusselt number, and friction factor. The Nusselt number and friction factor obtained from present plain tube compared with those from the proposed correlation by Gnienlinski for Nusselt number and proposed correlation by Blausius for friction factor.

$$Nu = 0.012(Re^{.87} - 280)\, Pr^{.4} \quad (12)$$

$$f = .316\, Re^{-.25} \quad (13)$$

Fig.3and 4 shows comparison of Nu number and friction factor of plain tube obtained from present study with those from proposed correlation. The data obtained from the experiments for the plain tube are reasonable agreement with predicted result from proposed correlation with discrepancy of ± 20% and ± 5% for Nusselt number and friction factor respectively.

4.2 Effect of coil wire insert on heat transfer enhancement

Fig.5 shows variation of Nusselt number with Reynolds number for tube fitted with coil wire inserts of different materials (copper, aluminum, and stainless steel). From fig.(5) it can be seen that Nusselt number for the tube fitted with coil wire insert are higher than that of plain tube for given Reynolds number. This is because coil wire insert interrupts the development of boundary layer of the fluid flow near the wall of test section hence it increases fluid temperature in the radial direction. Due to larger contact surface area the heat transfer rate increases. Also it creates the turbulence and whirling motion to the water when is flowing inside the test section. The whirling makes flow to be highly turbulent, which leads to improved convection heat transfer.

As a Reynolds number increases for a given coil wire inserts, the Nusselt number also increases indicating enhanced heat transfer. It is also observed from fig. (5) that Nusselt number for a given Reynolds number is higher for copper insert than aluminum and stainless steel inserts. Cu tube causes higher heat transfer enhancement about 1.58, and aluminum and stainless steel causes heat transfer rate enhancement up to 1.41 and 1.31 respectively.

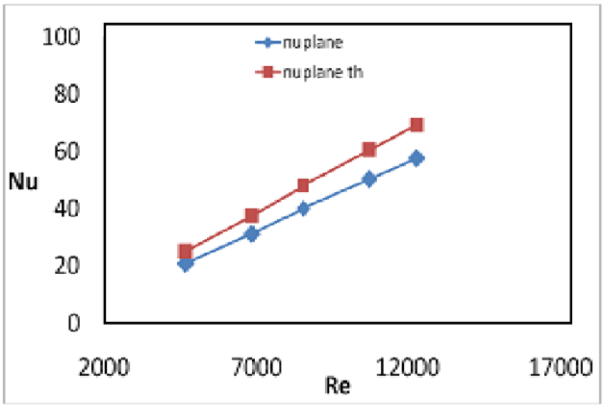

Fig. 3 Comparison of Nusselt number–plain tube.

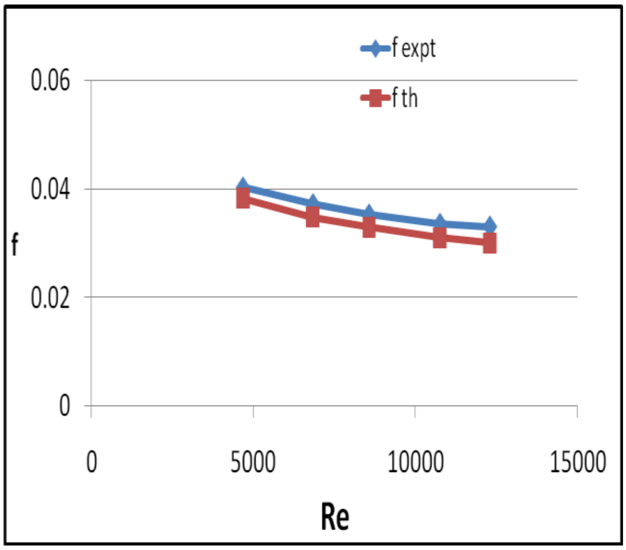

Fig. 4 Comparison of friction factor - plain tube

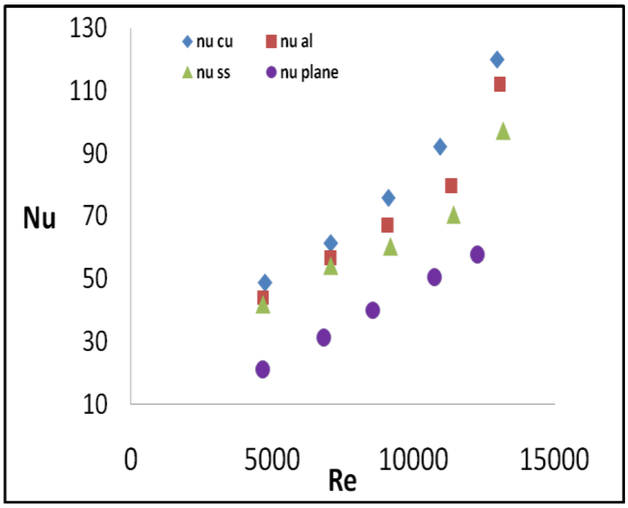

Fig. 5 Comparison of Nusselt number Vs Reynolds number with various coil wire inserts

4.3 Effect of coil wire insert on overall heat transfer coefficient

Fig.(6) shows variation of overall heat transfer coefficient (Ui) with Reynolds number. It can seen that Ui increases with Reynolds number for all cases. Overall heat transfer coefficient is higher for copper coil wire insert than aluminum, stainless steel inserts and plain tube.

4.4 Effect of coil wire insert on friction factor Generally the friction factor decreases with the increasing Reynolds Number for different pitches. From fig. 7 it can be seen that friction factor for the tube fitted with coil wire inserts are significantly higher than plane tube for a given Reynolds. It indicates that friction factor for a given Reynolds number increases with decreasing pitch due to swirl flow generated by coil wire inserts and reaches a maximum for pitch of 5 mm. From fig it can be seen that friction factor of Stainless steel insert of 10 mm pitch is less when compared with turbulator of aluminum pitch of 5mm. This is due to less contact surface of turbulator, so more area is available for water to flow in the test section. The friction factor of aluminum coil wire insert of 5 mm pitch is 5.4 to 6.7 times of the plane tube. Stainless steel tube insert cause friction factor of 4.8 to 5.9 times to plane tube and copper insert has friction factor of 4.3 to 5.4 times plane tube.

4.5 Effect of coil wire insert on heat transfer ratio The heat transfer ratio (Nu_a/Nu_o) is ratio of Nusselt number obtained from tube with coil wire insert to that of plane tube. The heat transfer ratio is shown in fig.(8). It is clear that for a net energy gain, that is, for an effective heat transfer, the heat transfer ratio must be greater than unity. It can be seen that from fig. (8) heat transfer increase introduced by coiled wire insert is remarkable. The Nusselt number ratio value tends to decrease with the increase of Reynolds number from 4000 to 12000 for all cases. The heat transfer ratio is higher for copper than aluminum and stainless steel coil inserts irrespective of higher pitch. The copper coil wire insert has (Nu_a/Nu_o) ratio of 1.53 to 1.68, aluminum has 1.35 to 1.53 and stainless steel has 1.2 to 1.46.

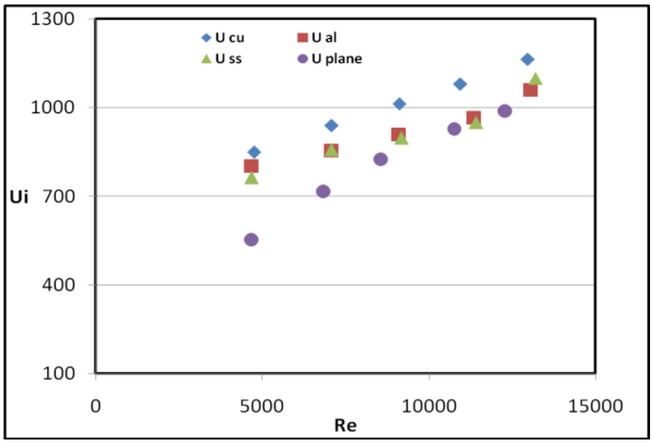

Fig. 6 Comparison of Overall heat transfer coefficient Vs Reynolds number with various coil inserts

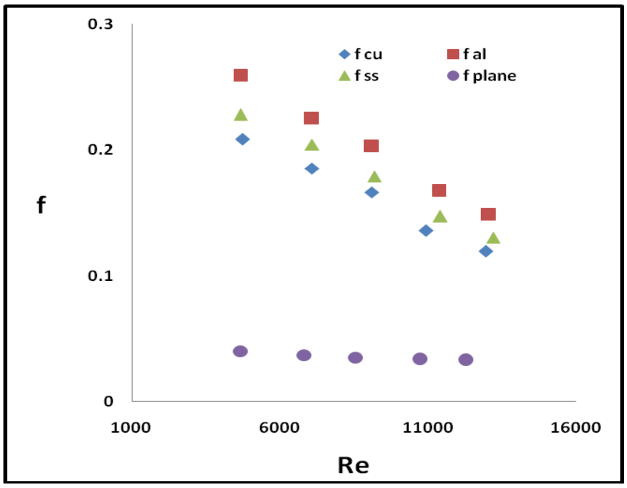

Fig. 7 Comparison of friction factor Vs Reynolds number with various coil wire inserts

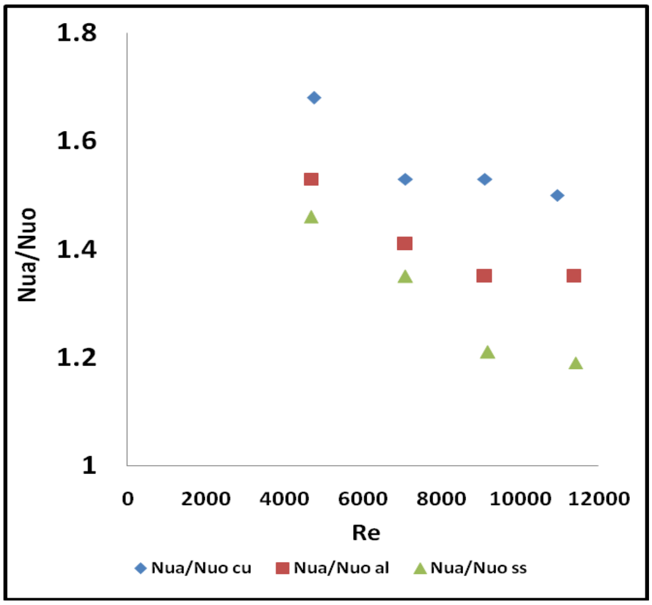

Fig. 8 Comparison of Nu_a/Nu_o Vs Reynolds number with various coil wire inserts

V. CONCLUSIONS.

Experimental investigation of the heat transfer an**d** friction factor characteristics of a double pipe heat exchanger fitted with coil wire insert made up of three different material as copper, aluminum and stainless steel and different pitches have been studied for Reynolds number in range of 4000-13000 and following conclusion are drawn.

1. Experimental data obtained for plane tube were compared with those from theoretical correlations. The data obtained is in good agreement with the theoretical correlation with the discrepancy of ±20% for Nusselt number and ±05% for friction factor.
2. The maximum Nusselt number is obtained for copper coil wire insert than aluminum and stainless steel coil wire insert .The copper, aluminum, and stainless steel coil wire insert cause heat transfer enhancement up to 1.58, 1.41, and 1.31 respectively as compared to plane tube.
3. Friction factor found to be increasing with the decreasing pitch of coil wire insert. It is higher for aluminum insert of 5 mm pitch than stainless steel and copper coil wire insert of 10 and 15 mm pitch respectively.
4. The above finding indicates that copper can be used as coil wire insert material for higher heat transfer enhancement than aluminum and stainless steel.
5. The above finding also indicates that coil wire insert in double pipe heat exchanger enhances heat transfer with considerable pressure drop.

Nomenclature.

A	Area
d	Tube diameter, m
L	Length of test section, m
h	Heat transfer coefficient, kW/(m^2 °C)
k	Thermal conductivity, kW/(m °C)
Nu	Nusselt number
Q	Heat transfer rate, kW
T	Temperature, °C
C_p	Specific heat, kJ/(kg °C)
f	Friction factor
p	Coil pitch, m
m	Mass flow rate, kg/s
Pr	Prandtl number
Re	Reynolds number
V	Velocity, m/s

Subscripts
ave Average
h Hot
in Inlet
out Outlet
w Water
c Coil
i Inside
o Outside

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