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Experimental Study on Effect of Heat Transfer Characteristics in a Corrugated Tube Pipe Having Different Pitch Length

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Abstract- Heat transfer augmentation is a technique needed to increase the thermal performance of heat exchangers effecting energy, material & cost savings. This heat transfer augmentation technique lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, analysis of heat transfer rate and pressure drop are the major parameter which are to be taken care of during design of heat exchanger using any of this techniques. One such technique is the use of corrugated tube instead of smooth tube. Corrugated tubes can enhance heat transfer coefficient on both the outer and inner heat transfer surface area without a significant increase in pressure drop. Experimental study is carried out on corrugated double pipe heat exchanger, in which comparison of heat transfer is carried out on smooth pipe and corrugated pipe having different pitch length. Pitch length of 0.045, 0.055 and 0.065 meter were taken and comparison of results were done with smooth pipe.

Index Terms- Corrugated tube, Heat exchanger, Corrugated pitch

I. INTRODUCTION

Heat exchangers are used in different purposes ranging from conversions, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some common examples include condensation and steam generation in power plants, sensible cooling & heating in chemical processing, agricultural and pharmaceutical products, fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchangers performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to heat exchange process. Heat transfer augmentation is a technique needed to increase the thermal performance of heat exchangers effecting energy, material & cost savings. These techniques are also referred as “heat transfer enhancement techniques” or “heat transfer intensification techniques”. Convective heat transfer is improved by reducing the thermal resistance in the heat exchanger is what augmentation techniques do. This heat transfer augmentation technique lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, analysis of heat transfer rate and pressure drop are the major parameter which are to be taken care of during design of heat exchanger using any of this techniques. Work pertaining to heat transfer enhancement using corrugated tube in two phase flow are limited. However, little information is now available for some cases on two phase heat transfer enhancement by using corrugated tube. There are no suitable correlations for heat transfer coefficient, pressure drop characteristics and other important relevant parameters yet available. Typically, corrugated tubes can improve the heat transfer performance on the heat exchanger in order to reduce the size of the heat exchangers. Heat transfer enhancement is achieved not only by employing corrugation on tubes but recently few more techniques have been developed which are using wire loop structures inside a pipe, by introducing some obstruction at inlet of flow creating swirl motion, by controlling the velocity of flow, by using twisted tape inserts etc. By employing all such means to increase the heat transfer phenomena care must be taken that it must not be at the cost of pressure drop caused. Because increase in pressure drop may lead to increase in pumping energy, ultimately results in increase of energy consumed. Hence, enhancement of heat transfer must be economical and not at the cost of any other waste of energy.

Heat exchangers are used in different purposes ranging from conversions, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some common examples include condensation and steam generation in power plants, sensible cooling & heating in chemical processing, products, fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchangers performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to heat exchange process. One such technique is the use of corrugated tube instead of smooth tube. Corrugated tubes can enhance heat transfer coefficient on both the outer and inner heat transfer surface area without a significant increase in

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pressure drop. Increase in fluid mixing, unsteadiness, turbulence flow or by limiting the growth of fluid boundary layers close to the heat transfer surface is done by corrugation on the surface of pipe. To understand the phenomena of heat transfer augmentation due to corrugation in pipe an experimental study is carried out. On corrugated double pipe heat exchanger, comparison of heat transfer will be carried out on smooth pipe and corrugated pipe having different pitch length. Pitch length of 0.045, 0.055 and 0.065 meter will be taken and comparison of results will be done with smooth pipe. Results will enable to predict the performance of heat transfer due to corrugation in a pipe and enable us to correlate with different correlation established by various researchers in past.

II. EXPERIMENTAL SETUP

1. Experimental Setup

Experimental setup has been constructed as shown with schematic diagram in figure 1. It consists of double pipe heat exchanger in which tube inserted inside shell.

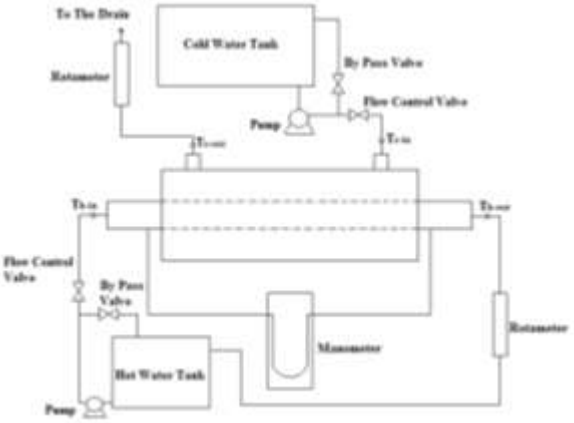


Fig.1. Schematic diagram of experimental set up

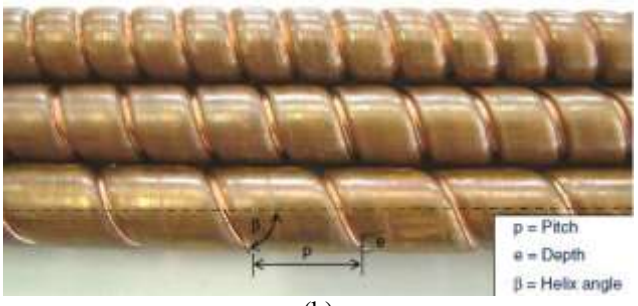
Table 1: Dimensions of tube and cell

Dimensions	Smooth Tube	Corrugated Tube	Shell
Length of tube (L) mm	2450	2450	2350
Inside diameter (Di) mm	26	23, 24, 25	48
Outside diameter (Do) mm	28.5	28.5	50
Pitch (p) mm	-	4.5,5.5, 6.5	-
Corrugated height (e) mm	-	0.5	-
Pitch to Diameter ration (P/Di)	-	0.18, 0.22, 0.27	-
Corrugated height to Diameter ratio(e/Di)	-	0.02	-

Experimental setup also include rota meters, Thermocouples, cold water tank, hot water tank, water heater, pump, the flow control valve, by pass valve, U tube manometer etc. The shell is well insulated by using asbestos to reduce heat losses to the atmosphere.

Corrugated tube as shown in figure with rib height 0.5mm, with this rib height internal diameter reduced to 25mm, it is made of copper material. Shell as shown in figure 2 fabricated with inside inserted concentric tube.

(a)



(b)

Fig.2. Experimental Test Facility used for experimentation

2. Instruments Used

Rotameter

Two rotameters are used to measure mass flow rate of both side cold water side and hot water side. Mass flow rate measuring capacity of rotameter is about up to 4LPM

Resistant Temperature Detector (RTD)

RTD is used to measure four temperature inlet and outlet temperature of cold water side, inlet and outlet temperature of

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hot water side. Used RTD can measure temperature in 0 to 200 °C.

Pump
Two pumps are used in this experimental setup. One pump for circulating hot water through tube and another one is used for circulating cold water through shell. It can work up to mass flow rate 2300LPH and height up to 9ft

Water Tanks
Two Water tanks are used for storing hot and cold water respectively in each. 50 litre tank for hot water and 100 litre for cold water.

Flow Control Valve & Water Heater
Flow control valves are used to change mass flow rate of water at both side. 1000Watt Water heater is used to raise temperature of water inside hot water tank.

Fig.3RTD

Fig.4Flow Control Valve

3. Experimental Procedure
Measuring instruments are calibrated first, Calibration of rota-meter is done in which water filled in one bucket. The readings are taken to calculate mass flow rate of water, measuring parameters are weight of water collected & time taken for it. Number of reading is taken and average flow rate used for calculations. For calibrating RTD, all the RTDs are dipped in a constant water bath & readings shown by each RTD are noted. Temperature shown by one of the RTD (T1) was taken as reference & corrections were made to other RTDs values. For determining friction factor: Pressure drop is measured for each flow rate with the help of manometer at room temperature. Carbon tetrachloride used as a manometric liquid in U- tube manometer. Air bubbles are removed from the manometer so that the liquid levels in both the limbs were equal when the flow is stopped.

Hot water side tank is filled with water. To raise the temperature of water, heating of water has been carried out with use of heater provided in hot water tank. Heating of water should be at required constant temperature. For circulating hot water through the tube centrifugal pump is provided and for controlling mass flow rate of hot water, flow control & by pass valve is provided.

After reaching sufficient temperature it allow to flow through tube of heat exchanger at particular flow rate. Similarly cold water also allowed pass through shell in counter current direction at atmospheric temperature and particular mass flow rate.

Inlet- outlet temperature of both hot water side and cold water side are noted after it attains steady value. Similar process repeated for different cold water side mass flow rate.

4. Design of Experiments

- Mass flow rate of hot water (mh) side kept constant at 16 LPM for all case and mass flow rate of cold water (mc) side is varied such as 6.25, 10, 12.5, 15, 16, 18.5 LPM.
- At given mass flow rate mh = 16 LPM & mc = 6.25 LPM the temperature of hot water inlet (Th-in), hot water outlet (Th-out), the temperature at cold water inlet (Tc-in), cold water outlet (Tc-out) are noticed
- Similar process is carried out by changing cold water side mass flow rate (mc) such as 6.25, 10, 12.5, 15, 16, 18.5 LPM, all four temperature noticed for all cases.
- At given mass flow rate mh & mc, pressure drop is measured by manometer as h1 & h2 the net fluid height at section1 and section 2 respectively. The difference of h1 & h2 gives Δh which used to obtain pressure drop Δp.
- Based on above observations Reynold number (Re), Nusselt number (Nu) & Friction factor (f) are obtained.
- Re, Nu and f are also obtained by correlations established by scientists for given conditions.
- This procedure is adopted for all sets of readings.

III. RESULTS AND DISCUSSION

Main objective of this experimental study is to improve thermal performance of double pipe heat exchanger. Experiment has been carried out with corrugated surface tube

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& compared with conventional smooth tube. Experimental results compared with available correlations for smooth and corrugated tube. Entire study divided in to following cases:

- **Case 0**: Smooth tube
- **Case 1**: Corrugated tube with pitch (p) =0.045mm
- **Case 2**: Corrugated tube with pitch (p) =0.055mm
- **Case 3**: Corrugated tube with pitch (p) =0.065mm

Friction factor (f) & Nusselt number (Nu) has been experimentally calculated with different Reynolds number (Re).

1. Friction Factor Calculation

Experimentally friction factor calculated with the help of following equations for all cases. Friction factor is given by:

$$f_{\exp} = \frac{\Delta P}{\frac{1}{2}\rho V^2\left(\frac{L}{D_h}\right)}$$

Where pressure drop calculated with:

$$\Delta P = \left(\rho_{ccl4} - \rho_w\right) g \Delta h$$

Where ρ_{ccl4}= Density of carbon tetrachloride,
ρ_w= Density of Water,
Δh= Manometer reading
Empirical correlation to find friction factor for smooth pipe is given by Naphon et.al as below:

$$f = 0.66\,\mathrm{Re}^{-0.33}, (5000 \le \mathrm{Re} \le 25000)$$

Empirical correlation to find friction factor for corrugated tube is given by Pethkool et.al as below:

$$f = 1.15\,\mathrm{Re}^{-0.239}\left(\frac{e}{D}\right)^{0.179}\left(\frac{p}{D}\right)^{0.164}$$

U-tube manometer used to calculate pressure drop. Once pressure drop is known, friction factor can be calculated with the help of equation 1.

It is compared with available correlation for smooth & corrugated tube. Rotameter used to obtained mass flow rate value & Reynolds number. It is observed that Friction factor slowly decrease with Reynolds number shown in Figure 5.

Experimental result shows similar trend of Naphon's equation. Value of friction factor is higher in case of corrugated tube as compared to smooth tube shown in Figure 6.

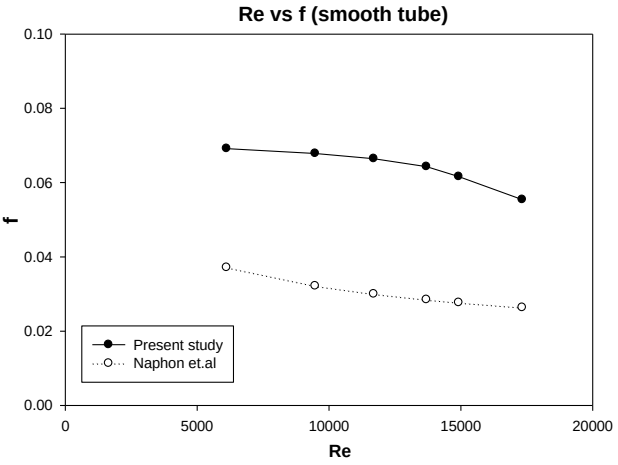

Fig.5 (a) Effect of Reynolds number on Friction factor Smooth tube

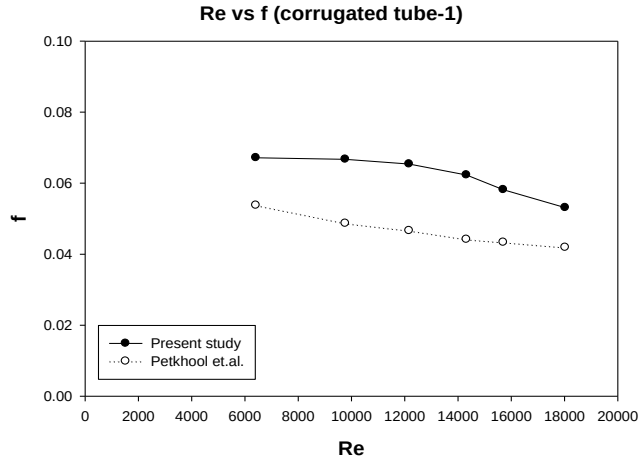

Fig.5(b) Effect of Reynolds number on Friction factor Corrugated tube

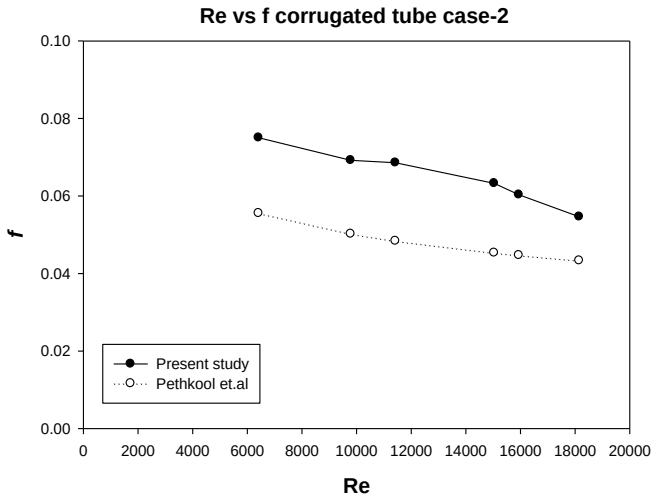

Fig.6 (a) Effect of corrugated pitch (a) p=0.055m

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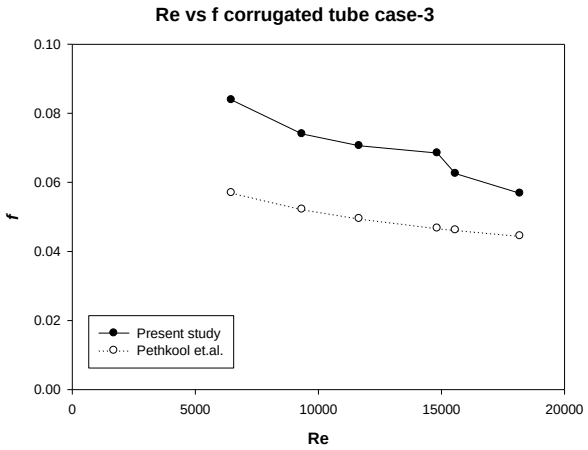

Fig.6 (b) Effect of corrugated pitch (b) p=0.065m

Heat Transfer Calculation

Performance of the heat exchanger is strongly depends on heat transfer capacity, which can directly reflected in terms of Nusselt number. Temperature at various location has been measured to obtained overall heat transfer coefficient & evaluate Nusselt number for all cases.

$$Nu_{\exp} = \frac{h_{\exp} D}{K}$$

Where heat transfer coefficient is calculated by:

$$h_{\exp} = \frac{Q_{avg}}{A_s \Delta T_{LMTD}}$$

$$Q_{avg} = \frac{Q_c + Q_h}{2}$$

$$Q_c = m_c C_p \left(T_{c,out} - T_{c,in}\right)$$

$$Q_h = m_h C_p (T_{h,in} - T_{h,out})$$

$$\Delta T_{LMTD} = \frac{\left(T_{h,out} - T_{c,out}\right) - \left(T_{h,in} - T_{c,in}\right)}{\ln\left(\frac{T_{h,out} - T_{c,out}}{T_{h,in} - T_{c,in}}\right)}$$

Empirical correlation to find out Nusselt number for smooth tube is given by Tam & Ghajar as below:

$$Nu = 0.023 \mathrm{Re}^{0.8} \mathrm{Pr}^{0.385} \left(\frac{L}{D}\right)^{-0.0054} \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

Empirical correlation to find out Nusselt number for corrugated tube is given by Pethkool et.el as below:

$$Nu = 1.579 \mathrm{Re}^{0.639} \mathrm{Pr}^{0.3} \left(\frac{e}{D}\right)^{0.46} \left(\frac{p}{D}\right)^{0.35}$$

It clearly shows Nusselt number increases with Reynolds number.

Experimental results indicate similar trend shown in Figure 7 And Figure 8 shows that with increases in corrugated pitch heat transfer enhancement will better.

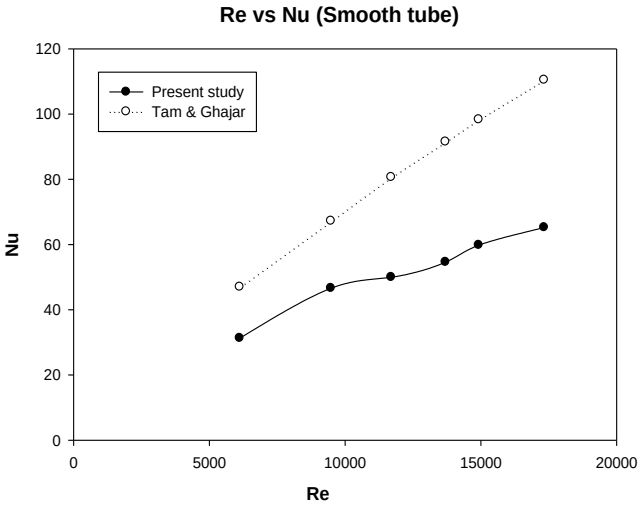

Fig.7 (a) Effect of Reynolds number on Nusselt Number smooth tube

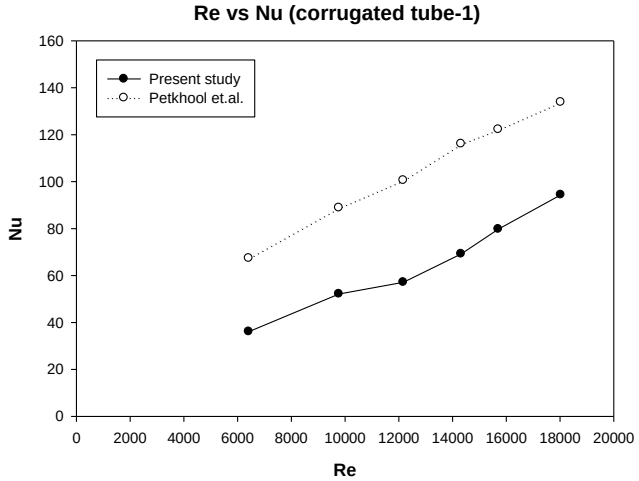

Fig.7 (b) Effect of Reynolds number on Nusselt Number corrugated tube

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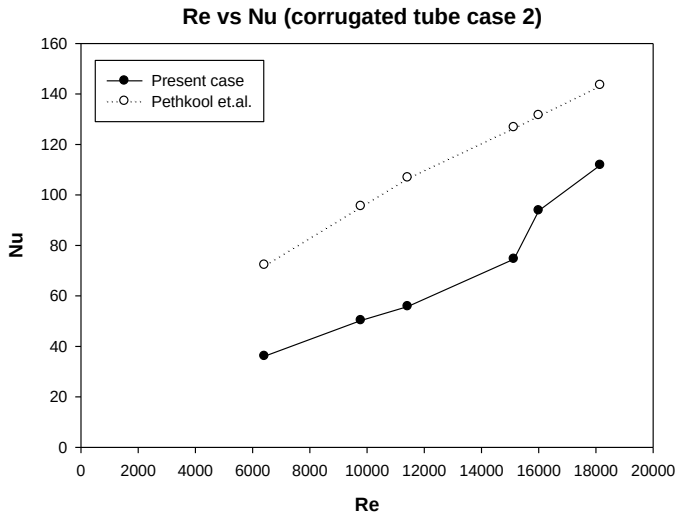

Fig.8 (a) Effect of corrugated pitch on Nusselt number (a) p=0.055 m

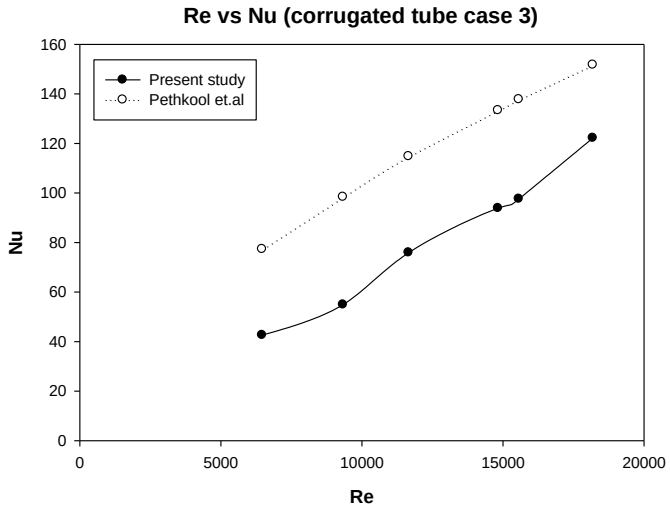

Fig.8 (b) Effect of corrugated pitch on Nusselt number p= 0.065m

IV. CONCLUSION

- Friction factor decreases with Reynolds number
- Corrugated tube having higher value of friction factor.
- Friction factor increases with corrugated pitch value.
- Heat transfer coefficient increases with Reynolds number in all cases.
- Nusselt number rise with Reynolds number.
- Corrugated tube help to enhanced heat transfer & hence Nusselt number is more in case of corrugated tube as compared to smooth tube for given Reynolds number.
- It is observed that effect of with corrugated pitch of 0.065m heat transfer enhancement is significant.

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