Experimental Investigation of U-tube heat exchanger using Plain tube and Corrugated tube

Dhavalkumar Maheshwari[1], Kartik Trivedi[2]

[1] M.E. Student, Dept. of Thermal Engineering, L.J.I.E.T, Gujarat, India.
[2] Professor, Dept. of Thermal Engineering, L.J.I.E.T, Gujarat, India.

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Abstract - *U-tube heat exchangers [UTHX] have been commonly used in Industries over the year. The main objective in any design of heat exchanger is the estimation of the minimum heat transfer area required for a given heat duty (q), as it governs the overall cost of heat exchanger. U-tube heat exchanger [UTHX] in which u–shaped tube use and it is counter flow type heat exchanger. In this heat exchanger, tube side fluid is hot water as hot fluid and shell side fluid is cold water as cold fluid is used. In this work I do comparative study on Thermal designing and analysis of U-tube Heat Exchanger [UTHX] with Plain tube and Corrugated tube by doing firstly thermal designing calculation by TEMA [Tubular Exchanger Manufacturer Association] Standard of U-tube Heat Exchanger. And then this type of U-tube heat exchanger with Plain tube compare with Corrugated tube for different characteristics parameters like heat transfer rate, overall heat transfer coefficient, efficiency, effectiveness, pressure drop etc. in order to increase heat transfer rate, efficiency, heat transfer area and reduce pressure drop. Corrugated tubes have different characteristics parameters which are Height to Diameter ratio (e/D_H), Relative pitch ratio (p/e), Relative helix angle (β).*

***Key Words*: U-tube heat exchanger, heat transfer rate, corrugated tube, TEMA**

1. INTRODUCTION

A heat exchanger is a heat transfer device that is used for transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid available, at different temperatures. In most of heat exchanger available, the fluids separated by a heat transfer surface, and in which they ideally do not mix.

As the name implies, the tubes of a U-tube heat exchanger [UTHX] are bent in U shape. Evidently, there is only one tube sheet is available in a U-tube heat exchanger. However, the bending of tubes represents an additional cost. Further, the minimum U-bend diameter is usually three times the tube outside diameter so that the central pass-partition lane is considerably large in a U-tube heat exchanger [UTHX] than in one having straight tubes. Consequently, for a given number of tubes, a U-tube heat exchanger will have a larger shell diameter compared with straight tube. The additional

cost of the bending of U-tubes and large shell diameter more or less offset the saving in cost due to the elimination of one tube-sheet. Thus the cost of a U-tube heat exchanger is comparable to that of a fixed tube-sheet exchanger.
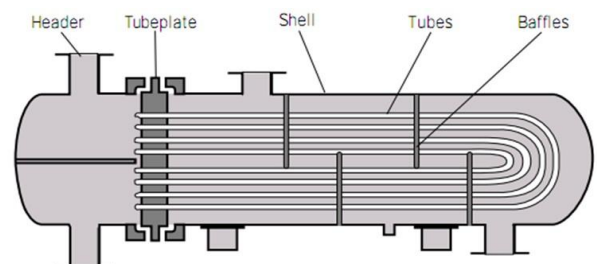

Fig -1: U-Tube Heat Exchanger [UTHX]

U-tube heat exchanger is classified based on construction of heat exchanger. U-tube heat exchanger is designed by Tubular Exchanger Manufactures Association [TEMA] Standards. In a double pass U-tube heat exchanger, the fluid enter at one side inside the u-tubes and out at same side. In U-tube heat exchanger, one fluid flow in tube and other fluid flow over the tube. The sets of u-tubes called tube-bundle.

1.1 Component of U-Tube Heat Exchanger:-
(1) Shell
(2) Shell Cover
(3) U-Tubes
(4) Tube bundle
(5) Baffles
(6) Nozzle
(7) Tie Rod

1.2 Application:-
(1) As domestic hot water, liquid and gas cooling and oil cooler.
(2) As condensers, steam generator, boiler feed water heater in Power Plant.
(3) They can also be used in swimming pool water heating.
(4) In waste heat recovery application with heat recovery from liquids.
(5) Glycol cooling, Water heating with steam.
(6) As action heat exchanger in the chemical industries and petroleum-refining.
(7) As instaneous water to water heat transfer with pumped boiler water circulation.

Vinous M. Hameed and Aliaa H. Akhbala, have experimentally investigated the augmentation of convective heat transfer in a single-phase turbulent flow by using corrugated tubes type has been investigated. Hot and cold water are used as working fluid in shell and tube side. Experiments are performed under various conditions of mass flow rates for cold water and hot water. They find the effect of pitch of corrugated tube and volumetric flow rate on the heat transfer coefficient is examined. Hot and cold water are used as working fluid in shell and tube side. They compared result obtain from corrugated tube heat exchanger with smooth tube heat exchanger. They found that corrugated tubes have a significant effect on the heat transfer augmentations. [1]

P. B. Borade, K. V. Mali had done comparative analysis made on CFD analysis and Thermal design of U-shaped heat exchanger tube. Kettle Re-boiler used u-shaped tubes in shell and tube heat exchanger. The construction of U-tube is done by SA 213 304 tubing. R22 and Chlorosilanes fluids flow across the shell and tube respectively. Thermal designing was done by Kern's method to investigate heat transfer rate and pressure drop. A CFD ANSYS Fluent v12.1 has been used to investigate the pressure and temperature variation across U-tube. Comparison between thermal designing and CFD analysis shows that less pressure drop occurs across the tube while Temperature at inlet and outlet is maintained. [2]

Lu Linping, Liang Ying had done various experiments has been done and found heat transfer coefficient, pressure drop and thermal stress for corrugated tubes and straight tubes. By comparing and analyzing the pressure drop, heat transfer in tube side and shell side and stress and axial forces, they found that the corrugated tube heat exchanger has better heat transfer coefficient; higher pressure drop and much lower stress caused by temperature difference and has advantages under circumstance of low Raynolds number and higher temperature difference. [3]

Gulsah Cakmak had been used U-tube heat exchanger for water heating storage. Water was used as heat transfer fluid and calcium-chloride hexa-hydrate with 29 °C melting temperature was used. In U-tube bundle heat exchangers, by designing a testing set with the purpose of storing in salt hydrates by using phase change method, some experiments are conducted. The diameter of outer body is 150mm and its length is 740 mm. In U-tube bundle, 6 copper tubes which have 19mm diameter each were used. Water passes in copper tubes and rest of area was filled with phase change material which is about 20 kg. They have confirm that heat energy and other waste energies can be stored with phase change material and the energy can taken back if necessary as useful. [4]

2. METHODOLOGY

2.1 Thermal Analysis

Thermal analysis of U-tube heat exchanger involves rating and sizing of heat exchanger. Rating problem deals with determination of rate of heat transfer, heat transfer coefficient, outlet temperature. Sizing problem involves selection of tube material, flow arrangement, determining physical size of heat exchanger to meet specified heat transfer. It is used to calculating different parameter of U-tube heat exchanger using plain tube and corrugated tube for obtaining comparative result between corrugated tube and plain tube. U - tube heat exchanger is designed by TEMA Standard(Tubular Exchanger Manufacture Association) .There are many equation to finding thermal analysis for u-tube heat exchanger with plain tube and corrugated tube as follows:-

LMTD = Logarithmic Mean Temperature Difference

$$LMTD = \frac{(T_{h1}-T_{c2}) - (T_{h2}-T_{c1})}{\ln\frac{(T_{h1}-T_{c2})}{(T_{h2}-T_{c1})}} \text{ (for counter flow arrangement)} \ldots(1)$$

$$LMTD = \frac{(T_{h1}-T_{c1}) - (T_{h2}-T_{c2})}{\ln\frac{(T_{h1}-T_{c1})}{(T_{h2}-T_{c2})}} \text{ (for parallel flow arrangement)} \ldots(2)$$

Heat transfer rate is given by,

$Q = U \times A \times \Delta T_m$ ....(3)

Where Q = Total heat transfer rate

    A = Required outside effective heat transfer surface area = $\pi \times d_o \times L \times N_t$

    d_o = Tube outside diameter

    L = Length of tube

    U = Overall heat transfer coefficient

    N_t = No of tubes

    F = correction factor

    $\Delta T_m = \theta_m \times f$

Bundle diameter of heat exchanger,

$N_t = k_1 [(D_b/d_o)^{n1}]$ ....(4)

Baffle spacing,

$B_s = (0.4 \text{ to } 0.5) \times D_s$ ....(5)

Number of Baffles,

$N_b = (L/B_s) - 1$ ....(6)

Baffle cut,

$B_c = (0.20 \text{ to } 0.25) \times D_s$ ....(7)

Tube pitch,

$P_t = 1.25 \times (\text{Tube OD})$ ....(8)

For finding Access area,

Provided area $= \frac{\pi}{4} \times D_i{}^2$

Required area $= (11 \times \frac{\pi}{4} \times d_o{}^2) + (11 \times \frac{\pi}{4} \times d^2)$

Access area = (Provided area – Required area)............(9)

For finding equivalent diameter,

$$De = 4 \times \frac{(Pt^2 \times \frac{\sqrt{3}}{4}) - \frac{\pi do^2}{8}}{\frac{\pi do}{2}}$$

(for triangular pitch layout)(10)

$$De = 4 \times \frac{Pt^2 - \frac{\pi do^2}{4}}{\pi do}$$

(for square pitch layout)…………......…(11)

Overall Heat Transfer Coefficient is given by:

$$U = \frac{1}{[\{\frac{1}{ho} + ro\} \times \frac{1}{Ef} + rw + ri(\frac{Ao}{Ai}) + \{\frac{1}{hi}(\frac{Ao}{Ai})\}]}$$ (12)

Where,

ho= Film Coefficient of shell side fluid

hi= Film Coefficient of tube side fluid

r_o = Fouling Resistance on outside surface of tubes = 0.003

r_i = Fouling Resistance on inside surface of tubes = 0.001

r_w = Resistance of tube wall referred to outside surface of tube wall including extended surface if present

Tube wall resistance can be find by,

$$rw = \frac{d}{24k}\{\ln\frac{d}{(d-2t)}\}$$ …………………………………....(13)

Shell side heat transfer coefficient can be find by,

$$\frac{hoDe}{k} = 0.36(\frac{De\,Gs}{\mu})^{0.55} \times (\frac{Cp\,\mu}{k})^{0.55} \times (\frac{\mu b}{\mu w})^{0.14}$$ (14)

Mass flow density,

$G_s = \frac{m}{As}$……………………………………………………(15)

$A_s = \frac{DsCB}{Pt}$…………………………………………………(16)

Where , As is bundle cross flow area at center of shell.

Tube side heat transfer coefficient can be given by,

$h_i = N_{ub} \times k/d_i$ …………………………………………(17)

Tube side flow area is determined by,

$A_{tp} = [\pi/4 \times di^2] \times [Nt/2]$…………………………………(18)

Mass flow velocity is given by,

$V_m = \dot{m}/(\rho \times A_{tp})$……………………………………………(19)

Reynolds number at tube side fluid given by,

$Re_t = (\rho \times Vm \times di)/\mu$………………………………………(20)

Nusselt number is given by using **GnieLinskl's Correlation,**

$N_{ub} = [(f_t/2) \times (Re_t - 1000) \times P_r]/[(1 - 12.7(f_t/2)0.5 \times (pr^{2/3} - 1)]$..(21)

Where, **Friction factor** at tube side,

$F_t = (1.58\ln Re_t - 3.28)^{-2}$………………………………(22)

Pressure drop at shell side,

$\Delta Ps = [f \times Gs^2 \times (Nb+1) \times Ds]/2 \times \rho \times \Phi s \times De$………………(23)

Where,

$f = \exp(0.576 - 0.19\ln Res)$

Tube Side Pressure Drop,

$\Delta Pt = (4 \times f \times L \times Np \times Gs^2)/(di \times 2 \times \rho)$……………………………(24)

Effectiveness,

$$\varepsilon = \frac{Q}{Qmax} = \frac{Ch(th_1 - th_2)}{Cmin(th_1 - tc_1)} = \frac{Cc(tc_2 - tc_1)}{Cmin(th_1 - tc_1)}$$ ……………(25)

Efficiency of the heat exchanger is given by,

$\eta = \frac{Qc}{Qh} \times 100$……………………………………………(26)

3. EXPERIMENTAL SETUP AND DESIGN DATA

3.1 Test Setup

The experimental setup consists of U-tube heat exchanger, thermocouple with temperature indicator, reservoirs (pails), stop watch, pipes, and flask. The heat exchanger has total 11 tubes of copper and it shell is made of MS. As the name implies, the tubes of a U-tube heat exchanger [UTHX] are bent in U shape and has thickness of tube is 1.244 mm. The total heat transfer area for plain tube is 0.260 m^2 and for corrugated u-tube heat exchanger is 1.041 m^2. Tube length is 700 mm and shell length is 300 mm. External pipes are used to carry hot and cold water streams. Cold fluid is supplied at room temperature. Thermocouples with temperature indicator are placed to measure inlet and outlet temperatures of hot and cold water.

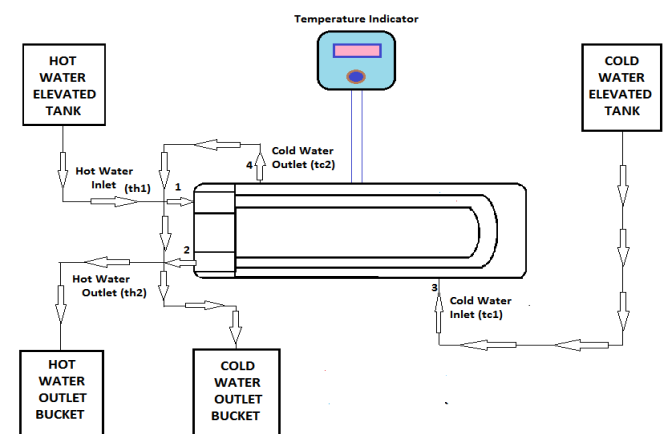**Fig -2**: Model of U-Tube Heat Exchanger [UTHX]

Fig -3: Line Diagram of Experimental Layout

3.2 Test Procedure

Here in the schematic diagram of experiment layout is in which U-tube heat exchanger is use. Here tube side flow is hot fluid flow which use hot water and shell side flow is cold fluid flow which uses cold water. The flow arrangement in UTHX is counter flow type for high heat transfer area. Here in this experiment hot side and cold side tank is put at gravity level so fluid flow at respective inlet of heat exchanger in pipe line. Here for outlet fluid of hot side (at point 2) and cold side (at point 4) two 15 liter capacity pail is taken which is filled with outlet hot and cold water in respective bucket. At every 5 minute interval reading is taken and temperature reading is taken and flow measure from 15 liter capacity pail after every 5 minute. There is a sensor with thermocouple is provide at respective inlet--outlet at shell and tube side and measure a common temperature indicator is provided   so we can   take measurement with accuracy. In this temperature indicator four reading is take first reading is for hot side inlet temp, second is for hot side outlet temp , third is for cold side inlet temp and fourth is for cold side outlet temp.

T_{h1} = Hot fluid inlet temp, T_{h2} = Hot fluid outlet temp,
T_{c1} = Cold fluid inlet temp, T_{c2} = Cold fluid outlet temp.

3.3 Parameters of U-tube heat exchanger

Component	Parameter	Value
Shell	Shell Material	MS
	Shell Length	300 mm
	Shell OD	115 mm
	Shell ID	100
Tube	Tube Material	Copper
	Tube ID	9.525 mm
	Tube OD	10.77 mm
	Tube Length	700 mm
	Tube Thickness	1.245 mm
Baffle	Baffle Material	MS
	Baffle Cut	25 mm
	Baffle Space	50 mm
	No. of Baffle	3
Tube-Sheet	Tube-sheet material	MS
	Tube-sheet size	170 mm
	No. of tube-sheet	1

Table -1: Parameter of component of UTHX

3.3 Fluid properties

	Hot water	Cold water
Thermal Conductivity K (W/m K)	0.6424	0.6305
Density ρ (kg/m³)	987.71	992.22
Specific Heat Cp (J/kg-K)	4181.4	4178.5
Viscosity (N-s/m²)	0.00055985	0.0006532

Table -2: Property of hot and cold fluid

3.3 Experimental result

Experimental result for plain tube heat exchanger	
Hot Fluid	Hot water
Hot water inlet temperature	327.6 K
Hot water outlet temperature	324.1 K
Hot water mass flow rate	0.120 kg/s
Cold fluid	Cold water
Cold water inlet temperature	306.8 K
Cold water outlet temperature	309.3 K
Cold water mass flow rate	0.112 kg/s

Table -3: Experimental result for plain tube heat exchanger

Experimental result for corrugated tube heat exchanger	
Hot Fluid	Hot water
Hot water inlet temperature	327.6 K
Hot water outlet temperature	322.9 K
Hot water mass flow rate	0.127 kg/s
Cold fluid	Cold water
Cold water inlet temperature	306.8 K
Cold water outlet temperature	310.1 K
Cold water mass flow rate	0.119 kg/s

Table -4: Experimental result for corrugated tube heat exchanger

4. RESULT AND ANALYSIS

The reading are taken on U-tube heat exchanger with plain tube and corrugated tube arranged with counter flow arrangement in order to determine effectiveness, efficiency, overall heat transfer coefficient. For water to water heat transfer different results are plotted based on different parameters such as overall heat transfer coefficient, exchanger effectiveness, NTU, heat capacity ratio, Reynolds number.
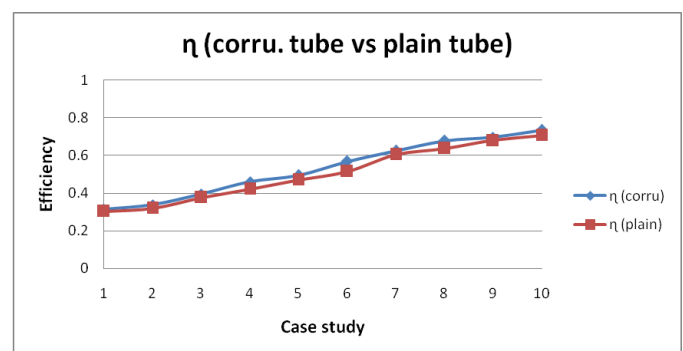

Figure 4-Graph of Efficiency (Corrugated tube vs. Plain tube)

Following graph shows comparative result of efficiency of U-tube heat exchanger with plain tube and corrugated tube. Graph clearly shows that efficiency of corrugated tube heat exchanger is higher than plain tube.
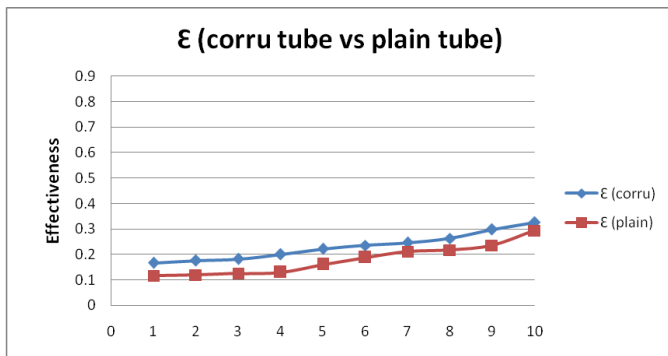
Figure 5-Graph of Effectiveness (Corrugated tube vs. Plain tube)

Following graph shows comparative result of effectiveness of U-tube heat exchanger (UTHX) with plain tube and corrugated tube. Graph clearly shows that effectiveness of corrugated tube heat exchanger is higher than plain tube.
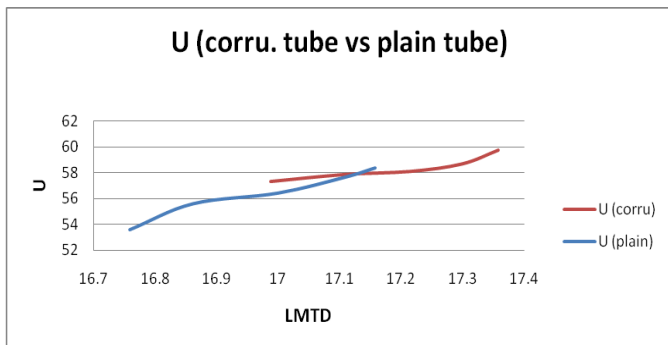

Figure 6-U vs. LMTD (Corrugated tube vs. Plain tube)

This graph shows comparative difference result of Overall Heat transfer coefficient vs. LMTD of U-tube heat exchanger (UTHX) with corrugated tube and plain tube. Graph shows that Overall heat transfer coefficient for corrugated tube is more compared to plain tube.
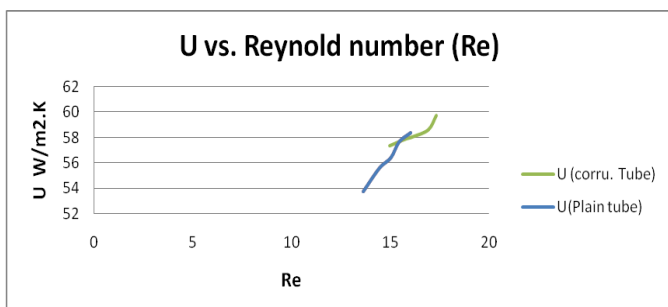

Figure 7-U vs. Re (Corrugated tube vs. Plain tube)

This graph shows comparative difference result of Overall Heat transfer coefficient vs. Reynolds number of U-tube heat exchanger (UTHX) with corrugated tube and plain tube. Overall heat transfer coefficient is also dependant on convective heat transfer coefficient so increase in Reynolds number results into higher heat transfer rates.
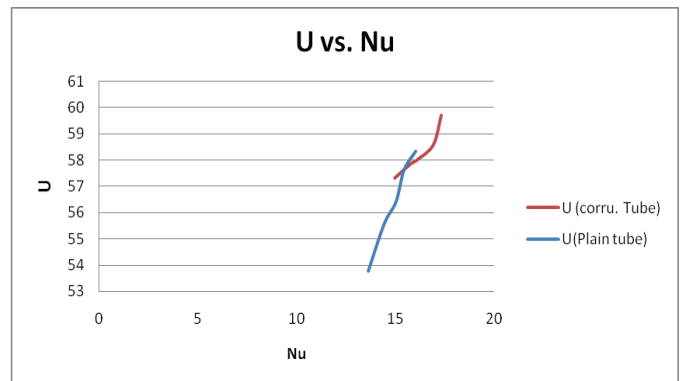

Figure 8-U vs. Nu (Corrugated tube vs. Plain tube)

This graph shows comparative difference result of Overall Heat transfer coefficient vs. Nusselt number is function of Reynolds number so, as Nusselt number increases overall heat transfer coefficient increases.
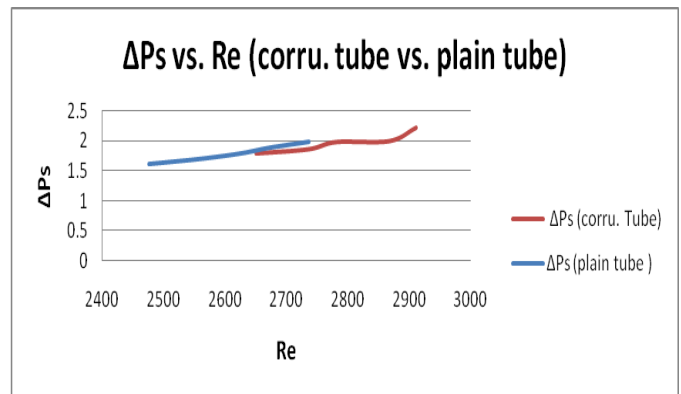

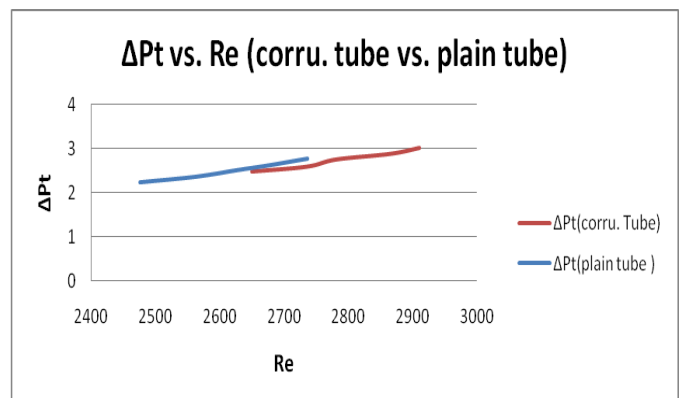**Figure 9-ΔPs vs. Re (Corrugated tube vs. Plain tube)**

Figure 10-ΔPt vs. Re (Corrugated tube vs. Plain tube)

Graphs shows variation pressure drop at shell side and tube side with Reynolds number of U-tube heat exchanger with plain tube and corrugated tube. Pressure drop increase with increase in Reynolds number. The friction factor obtain with corrugated tube heat exchanger is higher than compare to plain tube heat exchanger thus pressure drop at shell as well as tube side increase.

4. CONCLUSION

The main focus of this research work is to investigate experimentally the performance of U-tube heat exchanger with counter flow arrangement with regard to heat exchanger effectiveness, overall heat transfer coefficient, efficiency, pressure drop at shell side and tube side, Nusselt number, and Reynolds number. The following are the results of experimental investigation:

1. Corrugated U-tube heat exchanger has higher efficiency and effectiveness compared to plain u-tube heat exchanger.
2. The special channel of corrugated tube can enhance heat transfer largely, it makes this kind of heat exchanger suitable for the situation of low Reynolds number especially.
3. The pressure drop of corrugated tube is bigger than straight tube, the existence of corrugation has more influence to tube side than shell side.
4. Overall heat transfer coefficient increase with increase with Reynold number and Nusselt number. Vice versa heat transfer rate increase with overall heat transfer coefficient.

This experimental investigation of u-tube heat exchanger can be extended with Design & analysis by a CFD of model of U-tube Heat Exchanger with plain tube and corrugated tube which obtained from the present study. This work can also be extended for use of nano-fluids as working fluid for heat exchanger.

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BIOGRAPHIES

Dhavalkumar A. Maheshwari, studying final year in thermal engineering at L.J.I.E.T, Ahmedabad and working on thesis project "Experimental Investigation of U-tube heat exchanger using plain tube and corrugated tube" under the guidance of Prof. Kartik Trivedi in PG dept of L.J.I.E.T, Ahmedabad)

Prof. Kartik Trivedi. M.E.(Mechanical Engg.) working as a assistant professor in department of mechanical engineering at L. J. I. E. T, at Ahmedabad.