Experimental and CFD Analysis of Concentric Dimple Tube Heat Exchanger

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Abstract – An experimental and cfd analysis of concentric tube heat exchanger by using plain and spherical dimpled tube under different mass flow rate by using water as a working fluid is presented in this work. Heat transfer techniques refer to different method used to increase rate of heat transfer without affecting much the overall performance of the system. In the past decade, several studies on the passive techniques of heat transfer have reported. Present study to modify the inner tube of concentric tube heat exchanger with dimpled tube. The effects of the dimple tube on the heat transfer rate, heat transfer coefficient and effectiveness are compared with the plain tube for different flow rate. The experimental and CFD results reveal that the use of water in a spherical dimpled tube increases the heat transfer rate, overall heat transfer coefficient and also effectiveness as compared to plain tube.

Index Terms – CFD, Dimple, Tube, Concentric, Heat.

1. INTRODUCTION

A large portion of energy being consumed in industry processes and the energy resources are depleting at an alarming rate. Energy conservation is therefore, become an important issue. In many areas of the industries, using of high-performance heat exchanger is one of the promising energy-saving manners. The high-performance heat exchangers can be obtained by utilization of heat transfer enhancement techniques. In general, heat transfer enhancement creates one or more combinations of the following conditions that are favorable for the increase in heat transfer rate with an undesirable increase in friction, interruption of boundary layer development and rising degree of turbulence, increase in heat transfer area, and generating of swirling and/or secondary Flows. Several enhancement techniques have been introduced, for example, treated surfaces, rough surfaces, swirling flow devices, coiled tubes, and surface tension devices.

1.1 Heat Exchangers

In engineering practice, heating and cooling of materials and fluids is an essential part of processing, production, and fabrication and shop floor jobs. Heat exchangers are used for the above purpose by utilizing the basic principles and correlations of heat transfer along with other relevant physical and engineering principles. The heat transfer can be increased by the following different Augmentation Techniques. They are broadly classified into three different categories:

- Passive Techniques
- Active Techniques
- Compound Techniques.

1.2 Types of Heat Exchangers (Design & Construction)

The types of heat exchanger according to the design and construction are classified as follows

- Concentric tube heat exchanger
- Shell and tube heat exchanger
- Plate heat exchanger
- Plate and shell heat exchanger
- Adiabatic wheel heat exchanger
- Plate fin heat exchanger
- Pillow plate heat exchanger
- Fluid heat exchangers
- Direct contact heat exchangers

1.2.1 Concentric Tube Heat Exchanger

Concentric tube heat exchangers are used in a variety of industries for purposes such as material processing food preparation and air-conditioning. They create a temperature driving force by passing fluid streams of different temperatures parallel to each other separated by a physical boundary in the form of a pipe. This induces forced convection, transferring heat to and from the product.

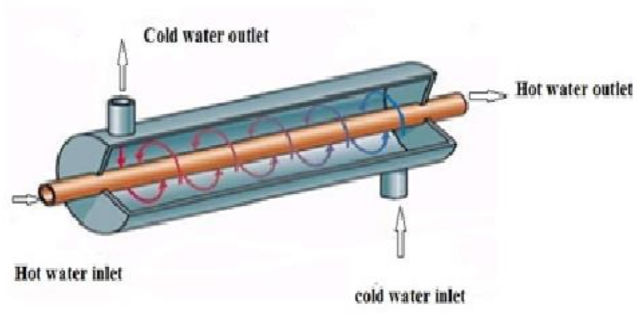

Fig. 1.1 Concentric Tubes Heat Exchanger

The thermodynamic behaviour of concentric tube heat exchangers can be described by both empirical and numerical analysis. The simplest of these involve the use of correlations to model heat transfer however the accuracy of these predictions varies depending on the design. For conditions where thermal properties vary significantly such as for large temperature differences the seidertate correlation is used. This model takes into consideration the differences between bulk and wall viscosities.

1.3 Types of Heat Exchanger (Fluid Motion)

The types of heat exchanger according to the fluid motion are classified as follows

- Parallel flow heat exchanger
- counter flow heat exchanger
- Cross flow heat exchanger

1.3.1 Parallel flow

For parallel flow, also known as co-current flow, both the hot and cold fluids flow in the same direction. Both the fluids enter and exit the heat exchanger on the same ends.

1.3.2 Counter flow

For counter flow, both the hot and cold fluids flow in the opposite direction. Both the fluids enter and exit the heat exchanger on the opposite ends.

1.3.3 Cross flow heat exchanger

In cross flow heat exchanger, the hot and the cold fluids move at right angles

1.4 Dimpled Tube

The dimpled tubes provide heat transfer rates that are higher than the rates found in smooth tubes under similar conditions. This is an important development for the energy conversion and process industries. It was demonstrated that more heat transfer and an earlier transition to high heat transfer can be accomplished through the use of dimpled tubes. Tubes have been evaluated and can be designed to produce more heat transfer than smooth tubes under fouling conditions.

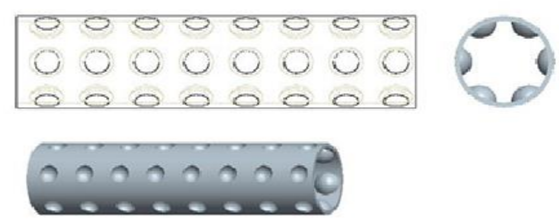

Fig.1.2 Dimpled Tube

Dimpled surfaces can create one or more combinations of the following conditions that are favorable for increasing the heat transfer coefficient with a consequent increase in the friction factor:

Interruption of the development of the boundary layer and increase of the degree of turbulence.

Effective heat transfer area increase, and

Generation of rotating and/or secondary flows.

Two different dimpled shapes are used

- Spherical dimpled tube
- Ellipsoidal dimpled tube

The enhanced structure for both the ellipsoidal and spherical dimple could disturb, swirl, break the boundary layer developing, and enhance the mixing of the hot and cold fluid and then improve the heat transfer of the tubes

1.5 Dimpled Tube Manufacturing Methods

1.5.1 Selecting a Tube End Forming Method

Abdicators that need to do end forming have many choices. Even after narrowing the process down to using a ram or segmented tooling, choices abound-the tooling can form the ID, the OD, or both; and operation can be manual or CNC. Understanding the processes and their capabilities are the keys to choosing the best one for the application. Focusing on the function of the tubes to be reshaped, and not on the forming method, can lead you to select an end forming method that optimizes the part cost, particularly if the opportunity involves a new part. The ways to form the tube end boil down to a few basic methods, so understanding their capabilities and limitations is critical to selecting the best process for a particular part. Thinking about creative ways to employ the process can help to improve product performance and reduce process cost.

1.5.2 Defining the Forming Requirements

Fabricators who need to do end forming frequently ask many of the same questions, whether the project is a part or an assembly of parts. The tube alloy and production process are important factors regarding the part design and the forming method. Understanding the assumptions behind the assembly's design is necessary for optimizing the end forming process. For instance, the part design for an automotive exhaust component might be based on a particular assembly method, resulting in a two-piece welded assembly. Focusing solely on the application and cosmetic requirements might alter the part design, leading to a change in the forming method and a significant cost reduction.

1.5.3 Ram Forming

Also called bulldozing, ram forming uses an impact process to drive a tapered plug inside or a tapered cup over the outside of a securely held tube end. The tapered angles convert this vertical (axial) force to radial changes in the tube end shape. The process works the full circumference of the tube end uniformly. The tooling is designed to smoothly transition the tube end to the finished contour, and has allowances that compensate for spring back. Hydraulic systems typically are most effective in delivering the power and speed required.

1.5.4 Segmented Tool Sizing

Segmented tool sizing works the tube circumference radically. For reducing the tube, the process uses a set of segmented dies that look like a ring of pizza slices with the center cut out. The end former pulls a tapered ring over the taper on the outside of the die set, squeezing the dies together to reduce the tube's diameter. Each tooling segment initially contacts the tube at two points. At the end of the process, the segments contact the entire tube circumference. Expanding the tube relies on a similar approach. Segmented tools, or fingers, start out packed together so they fit inside a tube. A tapered arbor, driven by a hydraulic cylinder, advances through the center of the tooling to spread the fingers uniformly until the tube reaches the finished diameter. Like the external tooling, segmented fingers initially contact the tube at two points.

2. OBJECTIVES OF THE PROJECT

1. To simulate the concentric heat exchangers with plain tube and dimple tube and to determine the tube wall temperature variation along the flow length and the pressure difference across the tube wall by CFD analysis.

2. To investigate the effect on heat transfer rate in concentric heat exchangers with plain tube and dimple tube.

3. To determine the overall Heat transfer coefficient and Effectiveness of hot and cold streams of water for a plain tube and dimple tube in concentric heat exchanger at different flow regimes.

3. LITERATURE REVIEW

Chinaruk Thianpong.et.al, Compound heat transfer enhancement of a dimpled tube with a twisted tape swirl generator, Dimpled tube with twisted tape and plain tubes are compared. The Reynolds numbers are ranged from 12,000 to 44,000 with hot/cold water as working fluid. Twisted tapes were made of straight aluminum tape with thickness (δ) of 0.5 mm, width (w) of 22 mm, and twist ratios y/w=3, 5 and 7. The experimental results reveal that both heat transfer coefficient and friction factor in the dimpled tube fitted with the twisted tape, are higher than those in the dimple tube acting alone and plain tube. It is also found that the heat transfer coefficient and friction factor in the combined devices increase as the pitch Heat transfer rate and friction factor dimpled tube with twisted tape, are respectively 1.66 to 3.03 and 5 to 6.31 times of those in the plain tube.

JuinChen.et.al. Heat transfer enhancement in dimpled tubes, Coaxial-pipe heat exchanger using Six dimpled copper tubes of varying geometries were used for comparison with a standard smooth tube. This experiment under performed by turbulent flow. Water as test fluid and experimental method. Best dimpled tube was tube 6, which had the largest dimple depth-to-tube inside diameter ratio, dimple depth to- pitch ratio, dimple depth-to-dimple diameter ratio, and number of dimple columns. Tube 6 have high heat transfer coefficient are significantly larger (between 1.25 and 2.37 times) than those for the smooth tube. Friction factor for all the dimpled tubes are 1.08 to 2.3 times higher than the value for the smooth tube.

J.E.Kim.et.al, Numerical study on characteristics of flow and heat transfer in a cooling passage with protrusion-in-dimple surface, Four different protrusion heights were considered and protrusion height to channel height (h/H) of 0.05, 0.10, 0.15, and 0.20. This experiment under performed by turbulent flow. Water as test fluid. CFD analysis and Experimental method and 40% negligible pressure drop, 24% increase heat transfer, increase friction factor up to 5–6% and volume goodness factor slightly increases by 4%.

J.Kukulka.et.al, Development and evaluation of enhanced heat transfer tubes, Enhancement tube and smooth tubes are compared and material is enhanced 304 L stainless steel tube and steel. This experiment under performed by Turbulent flow in the range of Reynolds Numbers near 2900. Water as working fluid. Increases in heat transfer for most Enhancement tubes are in excess of 120% over smooth tubes and minimize the fouling rate. Inlet water flow was a constant rate of 6 L/min. After the prescribed time, the tubes were drained, samples dried and measurements made. Rate of fouling for the smooth stainless steel tubes were compared to the average values of the four dimpled tubes. Dimpled tubes minimize the fouling rate and also provide heat transfer performance gains in excess of 100%.

A. García.et.al, The influence of artificial roughness shape on heat transfer enhancement: Corrugated tubes, dimpled tubes and wire coils, corrugated tubes, dimpled tubes and wire coils are compared. Water as working fluid in the range of Reynolds numbers between 200 and 2000.Laminar, transition and turbulent flows are used. The heat transfer co-efficient on maximum Nusselt number augmentations of 250% can be expected at low Prandtl numbers. While for Reynolds numbers higher than 2000, the use of corrugated and dimpled tubes is favored over the wire coils.

4. METHODOLOGY

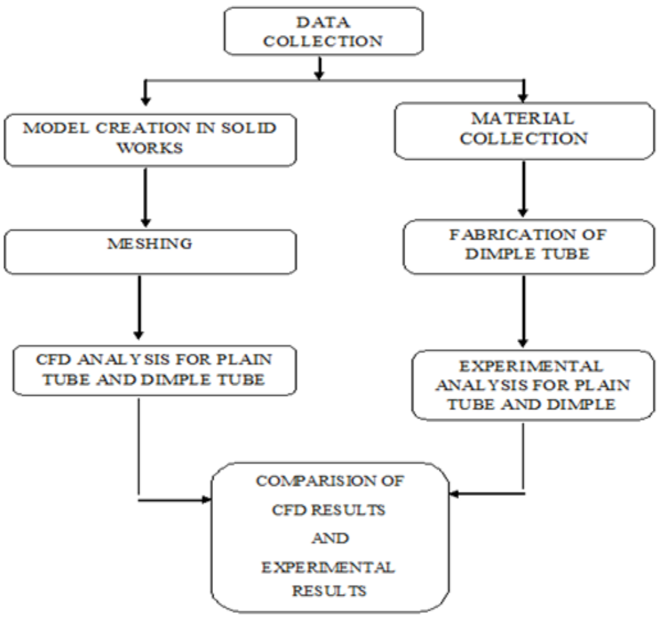

Fig.4.1 Methodology

5. DESIGN AND EXPERIMENTAL WORK

5.1 concentric tube heat exchanger (dimple tube)

5.1.1 Plain Tube

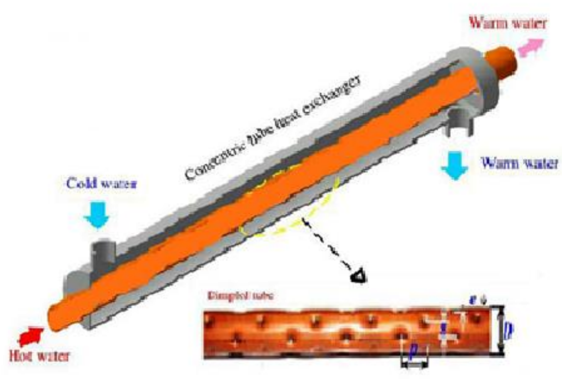

Fig.5.1 Concentric Tube Heat Exchanger

5.1.2 Diagram for Concentric Tube Heat Exchanger

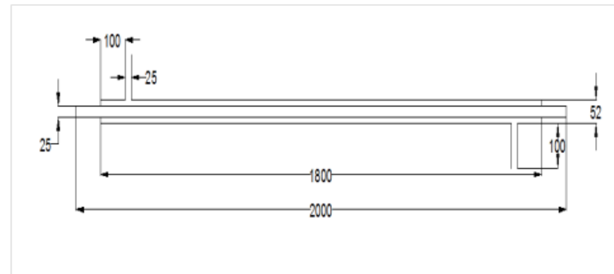

Fig.5.2 Plain Diagram for Concentric Tube Heat Exchanger

5.1.3 Dimple Tube Diagram For Concentric Tube Heat Exchanger

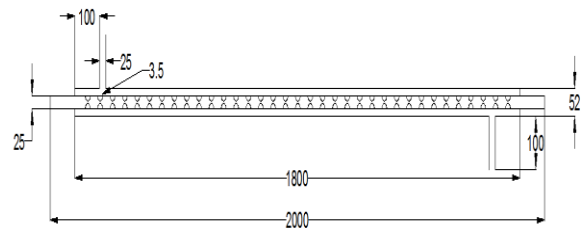

Fig.5.3 Dimple Diagram for Concentric Tube Heat Exchanger

5.1.4 Specifications of Double Pipe Heat Exchanger

Table 5.1Specifications of Double Pipe Heat Exchanger

Specifications	Inner Tube	Outer Tube
	mm	Mm
Inner diameter(D1)	25	50
Outer diameter(D2)	28	52
Length(L)	2000	1800
Thickness(T)	1.5	1
Layout	Circle	Circle
No. of tube(n)	1	1
Material	Copper	GI

5.15 Specification of Dimpled Tube

Table 5.2 Specifications of Dimpled Tube

Specifications	Symbol	Dimpled Tube
		mm
Inner diameter	D_1	25
Outer diameter	D_2	28
Depth of dimple	E	1.3
Length	L	2000
Thickness	T	1.5
Dia of dimple	D	3.5
Material	Copper	Copper

5.1.6 Material Properties of Double Pipe Heat Exchanger

Table 5.3 Material Properties of Double Pipe Heat Exchanger

Properties	Inner tube (copper)	Outer tube (GI)
Density (in Kg/m^3)	8954	7850
Specific heat capacity(in J/kgK)	0.3831	452
Thermal conductivity (in *W/ mk*)	394	70.7
Thermal diffusivity(in m^2/s)	11.24	20.34 e^{-6}

5.2 Design of Concentric Tube Heat Exchanger

Modelling is carried using the SOLIDWORKS 2014 CAD package. Based on the design data tube, shell and tube sheet are modelled and assembled to required concentric tube heat exchangers. The dimpled tube supports the inner tube inside the dimple which is arranged in hemisphere

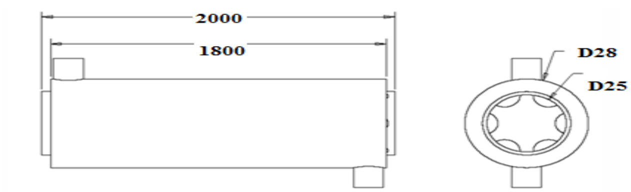

Fig.5.4 Design of Concentric Tube Heat Exchanger

5.3 Fabricated Inner Dimple Tube

Fig. 5.5 Inner Dimple Tube

5.4 Experimental Setup

Fig.5.6 Experimental Setup

Fig 5.6 shows the experimental setup used to conduct the experiments. It consists of double pipe heat exchanger consisting of a test section, electric geyser to supply constant hot water and the control system. The test section is a copper as an inner tube and an outer galvanised iron pipe. The outer pipe is well insulated using glass wool held with jute rope to reduce heat losses to the atmosphere. Tap water is sent to geyser and then the heated water is directed to the inner tube through a control valve. Temperature measuring devices to measure the inlet and outlet temperature of hot water and outlet of cold water. The inlet temperature of cold water is measured using mercury thermometer.

5.5 Experimental Procedure

1. Start the water supply. Adjust the water supply on hot and cold sides. Firstly, keep the valves V2 and V3 closed and V1 and V4 opened so that arrangement is parallel flow

2. Put few drops of oil in thermometer pockets. Put the thermometer in the thermometer pockets.

3. Switch 'ON' the geyser. Temperature of water will start rising. After temperatures become steady, note down the readings and fill up the observation table.

4. Repeat the experiment by changing the flow.

5.6 Observations

5.6.1 Plain Tube Readings

Table 5.4 Plain tube readings

S.No	Hot Water			Cold Water		
	Temperature		Time for 1 liter water	Temperature		Time for 1 liter water
	Inlet (thi) ^{0}C	Outlet (tho) ^{0}C	x_h sec	Inlet (tci) ^{0}C	Outlet (tco) ^{0}C	x_c sec
1	327	317.6	15.6	303	307.1	15.2
2	327	319.5	15.9	303	309.4	15.4
3	327	320.7	16.2	303	309.4	15.8
4	327	321.7	16.8	303	311.1	16.4
5	327	322.3	17.3	303	311.5	16.9

5.6.2 DIMPLE TUBE READINGS

Table 5.5 Dimple tube readings

S.No	Hot Water			Cold Water		
	Temperature		Time for 1 liter water	Temperature		Time for 1 liter water
	Inlet (thi) ^{0}C	Outlet (tho) ^{0}C	xh sec	Inlet (tci) ^{0}C	Outlet (tco) ^{0}C	xc sec

1	327	317.6	15.6	303	307.1	15.2
2	327	319.5	15.9	303	309.4	15.4
3	327	320.7	16.2	303	309.4	15.8
4	327	321.7	16.8	303	311.1	16.4
5	327	322.3	17.3	303	311.5	16.9

6. CALCULATIONS AND MODELLING

6.1 MODEL CALCULATIONS:

1. Hot water inlet temperature, t_{hi} = 327 ^{0}C

Hot water outlet temperature, t_{ho} = 317.6 ^{0}C

2. Hot water flow rate, m_h

Let time required for 1lit of water be x_h sec

Mass of 1lit water = 1kg

Therefore, $m_h = 1/ x_h$ kg/s = 1/15.6 = 0.064 kg/s

3. Cold water inlet temperature, t_{ci} = 303 ^{0}C

Cold water outlet temperature, t_{co} = 307.1 ^{0}C

4. Cold water flow rate, m_c

$m_c = 1/ x_C$ kg/s = 1/15.2 = 0.066 kg/s

5. Heat given by hot water (inside heat transfer rate)

$Q_h = m_h c_p (t_{hi} – t_{ho})$ Watts (where c_p =specific heat of water = 4200 J/kgK) = 0.064*4200*(327-317)

= 2530.77 J/s

6. Similarly, for cold water

Heat collected by cold water (out side heat transfer rate)

$Q_c = m_c c_p (t_{co} – t_{ci})$ Watts = 0.066*4200*(307.1-303)

= 1137.6 J/s

7. Logarithmic mean temperature difference (LMTD)

for parallel flow

$T_i = t_{hi} - t_{ci}$

= 327 – 303 = 24 ^{0}C

$T_o = t_{ho} - t_{co}$

= 317.6 – 307.1 = 10.5 ^{0}C

Therefore, LMTD = $\Delta T_m = (T_i – T_o) / \ln (T_i / T_o)$

= (24-10.5)/ln(24/10.5) = 16.32 ^{0}C

8. Overall heat transfer coefficient, U

a) Inside overall heat transfer coefficient, U_i

Inside diameter of tube = 2 m

Inside surface area of the tube,

$A_i = \pi$ x d x L= π x 0.025 x 2

Now $Q_h = U_i \Delta T_m A_i$

Therefore $U_i = Q_h / (\Delta T_m A_i)$ W/m^2 ^{0}C

= 2530.77/(16.32* π x 0.025 x 2)

=987.42 W/m^2 ^{0}C

b) Outside overall heat transfer coefficient, U_o

Outside diameter of tube = 0.012 m

Outside surface area of the tube, $A_o = \pi$ x 0.028 x 2

Similarly $Q_c = U_o \Delta T_m A_o$

Therefore $U_o = Q_c / (\Delta T_m A_o)$ W/m^2 ^{0}C

= 1137.6/(16.32* π x 0.028 x 2)

= 395.93 W/m^2 ^{0}C

1.Effectiveness of heat exchanger

Є = Rate of heat transfer in heat exchanger / Max. possible heattransfer rate

= $(m_h c_p (t_{hi} – t_{ho})) / ((mc_p)_{min} (t_{hi} – t_{ci}))$

= (0.064*4200*(327-317.6)) / (0.064*4200(327-303)

= 0.39

6.2 Isometric View of Concentric Tube Heat Exchanger:

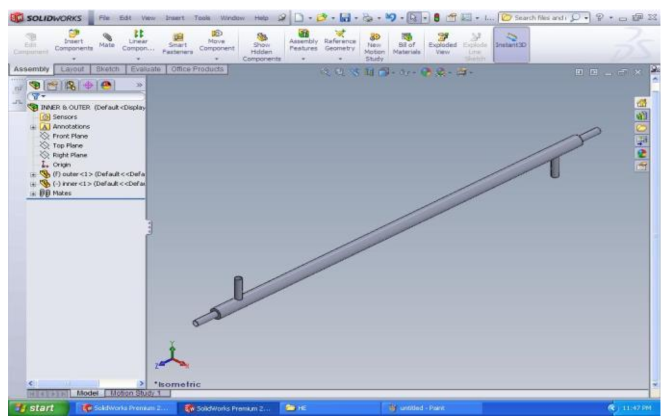

Fig.6.1 Isometric view of concentric tube heat exchanger

7. RESULTS AND DISCUSSION

7.1 Comparision Of Cfd Results

CFD Analysis was done in ANSYS FLUENT SOLVER. CFD analysis were done in both plain tube and dimpled tube with inner diameter as 0.025m , outside diameter as 0.028m and length as 2m. The obtained results were given below. The CFD results shows that the temperature and velocity increases in the dimple tube as compared with plain tube. The pressure is reduced in dimple tube as compared with plain tube.

7.2 Calculated Experimental Results

7.2.1 Plain Tube Experimental Results

S.no	Mass Flow Rate		Heat Transfer		LMTD	Inside Overall heat Transfer	Outside Overall heat Transfer	Effectiveness
	Hot Water (mh) Kg/s	Cold Water (mc) Kg/s	Inside (Qh) watts	Outside (Qh) Watt	^{0}C	Ui W/m2K	Uo W/m2 K	
1	0.064	0.066	2530.8	1137.6	16.33	987.4	395.9	0.392
2	0.063	0.065	1991.7	1742.7	16.05	790.4	617.1	0.314
3	0.062	0.063	1625.6	1702.9	16.88	613.4	573.2	0.261
4	0.060	0.061	1335.1	2082.7	16.35	520.1	723.7	0.223
5	0.058	0.059	1133.8	2115.2	16.54	436.6	726.6	0.195

7.2.2 Dimple Tube Experimental Results

Table 7.2 Dimple Tube Experimental Results

S.no	Mass Flow Rate		Heat Transfer		LMTD	Inside Overall heat Transfer	Outside Overall heat Transfer	Effective ness
	Hot Water (mh) Kg/s	Cold Water (mc) Kg/s	Inside (Qh) watts	Outside (Qh) Watt	^{0}C	Ui W/m2K	Uo W/m2 K	
1	0.062	0.062	4407.4	4018.5	22.95	1878.2	1527.6	0.708
2	0.060	0.060	3850.1	4073.5	22.19	1728.5	1631.4	0.642
3	0.059	0.060	3829.5	4625.1	24.01	1524.5	1642.4	0.646
4	0.057	0.058	3234.5	5071.7	24.41	1279.6	1789.8	0.558
5	0.056	0.057	3054.6	5061.7	24.80	1227.8	1814.9	0.533

7.3 Comparison of Calculated Experimental Results

7.3.1 Comparison of Inlet and Outlet Temperatures

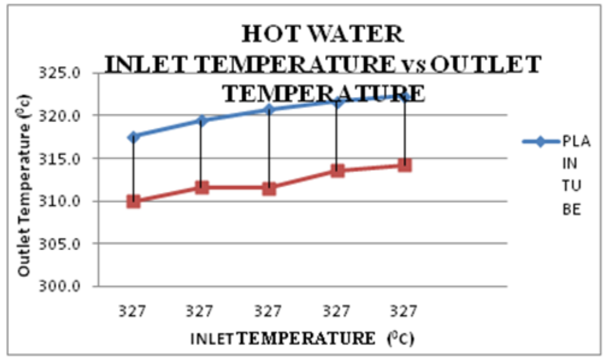

Fig.7.1 Comparison of inlet and outlet hot water temperature

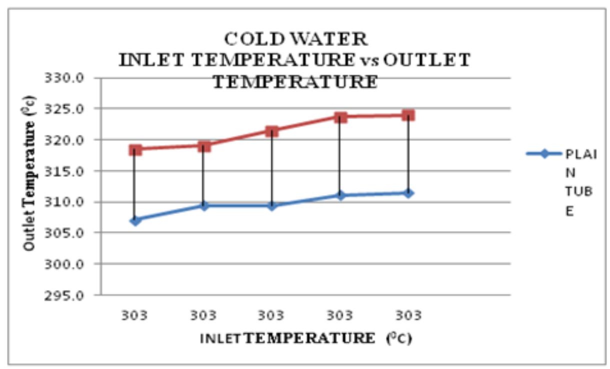

Fig.7.2 Comparison of inlet and outlet cold water temperature

7.3.2 Comparison Of Mass Flow Rates And Overall Heat Transfer Coefficient

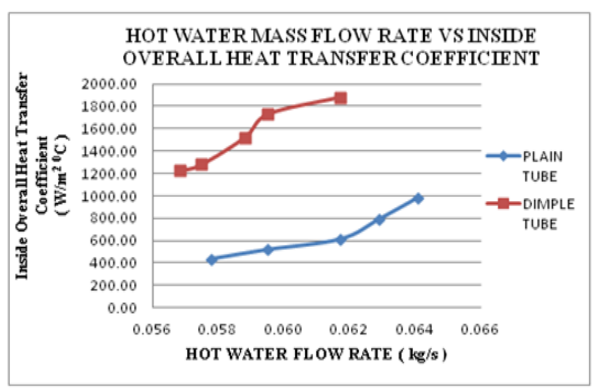

Fig.7.3 Comparison of hot water mass flow rate and inside overall heat transfer coefficient

The experimental results shows that the effect of inside overall heat transfer coefficient was high in dimple tube when compared to plain tube. The inside overall heat transfer coefficient in dimple tube was increased to 56% as compared to plain tube.

7.3.3 Comparison of Mass Flow Rates and Heat Transfer Rate

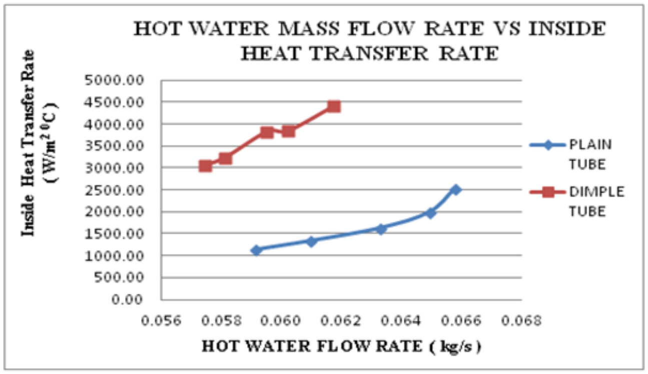

Fig.7.4 Comparison of hot water mass flow rate and inside heat transfer rate

The experimental results shows that the effect of inside heat transfer rate was high in dimple tube when compared to plain tube. The inside heat transfer rate in dimple tube was increased to 53% as compared to plain tube.

7.3.4 Comparison of Mass Flow Rates and Effectiveness.

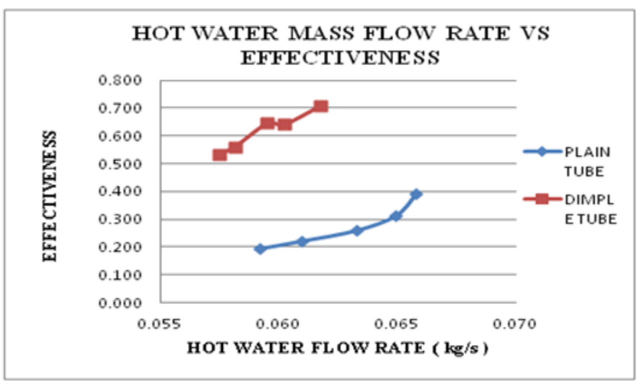

Fig.7.5 Comparison of hot water mass flow rate and effectiveness

The CFD results shows that the effect of effectiveness was high in dimple tube when compared to plain tube. The effectiveness in dimple tube was increased to 55% as compared to plain tube.

8. CONCLUSION

This project focused on investigating whether the use of Spherical dimples can enhance heat transfer characteristics for a circular tube. The simulation of the concentric heat exchangers with plain tube and dimple tube was done in CFD analysis and it shows that temperature and velocity increases in the dimple tube as compared with plain tube. The pressure is reduced in dimple tube as compared with plain tube. The dimpled geometries on the wall of a tube and plain tube were tested experimentally for different flow rates by keeping inlet temperature as constant. The Inside and Outside overall heat transfer coefficient of concentric dimple tube heat exchanger was increases to 56% to 64% as compared with concentric plain tube heat exchanger. The Effectiveness obtained by concentric dimple tube heat exchanger was increases to 55% as compared with concentric plain tube heat exchanger. Thus the CFD results and experimental results shows that the dimpled tube is used in concentric tube heat exchanger will give high heat transfer and it can be used in various applications.

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