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COMPUTATIONAL ANALYSIS OF DOUBLE PIPE COUNTER FLOW HEAT EXCHANGER USING FINS ATTACHED TO THE INNER PIPE

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ABSTRACT

Heat transfer enhancement in a heat exchanger can be improved by active and passive techniques. In the present study, heat transfer rate from the hot fluid to cold fluid in a double pipe counter flow heat exchanger having fins attached to the inner pipe along its length is analyzed. The whole analysis is carried out by using commercial CFD code. The two fin configurations of rectangular and triangular fins are used in the study. Computational analysis was carried on counterflow double pipe heat exchanger with constant mass flow rate for hot and cold fluids for exit temperature. It is found that exit temperature of the hot fluid is low and that of cold fluid is high for the rectangular fin. Using this exit temperature, the heat transfer rate and fin effectiveness are calculated. The results show that heat transfer in a finned configuration is comparatively greater than unfinned one. Among these fin configurations, the rectangular fin shows improvement over triangular fin in terms of heat transfer rate, this is due to the rectangular fin has the large surface area for a given volume and also the effectiveness of the fin show the higher value than the triangular fin.

Keywords: double pipe heat exchanger, triangular fins, rectangular fins, mass flow rate

I. INTRODUCTION

The heat exchanger is a device in which the efficient heat transfer from one fluid to another takes place. In the heat exchanger, two modes of heat transfer occur such as convection and conduction. Usually, convection takes place in between fluids and conduction takes place through the walls of the heat exchanger which separated by the fluids. Overall heat transfer coefficient, surface area, and logarithmic mean temperature difference play an important role in the analysis of heat transfer. Reducing the heat transfer area of a heat exchanger is an opportunity to enhance the heat transfer rate and also it is getting Industrial importance. energy, material and cost saving related to a heat exchange process is supported by an increase in the performance of the heat exchanger. Double pipe heat exchangers are the simplest of heat exchangers in which heat is transferred from the hot fluid to the cold fluid through a separating cylindrical wall. Double pipe heat exchangers have smaller diameters so they are primarily adapted to high pressure and high-temperature applications. They are fairly cheap but compared to the other types the amount of space they occupy is relatively high. Enhancement of heat transfer in a heat exchanger is done by several methods. These techniques are divided into active and passive techniques. In active method, external input for the enhancement of heat transfer like jet impingement, induced vibrations etc. are used. In passive method is something without the stimulation by external power such as surface coating, surface roughness, and extended surfaces. Double pipe heat exchanger uses one heat exchanger pipe inside another. The pipe sizes and a number of bends for the double pipe heat exchanger can be selected only after determining the required heat exchanger surface area, for either parallel flow or counter flow. Type of flow pattern in the heat exchanger is an important factor in a double pipe heat exchanger design. The calculation of the log mean temperature difference is taken by the flow pattern of a heat exchanger. An estimated overall heat transfer coefficient allows calculation of the required heat transfer surface area. Hence pipe sizes, pipe lengths and a number of bends can be determined. In the present study, the heat transfer enhancement is carried out through a DPHE by using computational fluid dynamics using two types of fins such as Triangular, and Rectangular fins arranged on inner pipe surface which contains cold process fluid i.e. water. The overall analysis is carried out by considering the system in a steady state condition.

CFD is essentially a branch of Continuum mechanics which deals with numerical simulation of fluid flow and heat transfer problems. Analyzing a fluid problem using CFD requires the following steps. First, Conversion of the governing equations for a continuum medium in to a set of discrete algebraic expressions using a process called discretization because the computer can only work with discrete numbers. Then finding the solutions of

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these discrete equations using a high speed digital computer to obtain the numerical solution to desired level of accuracy. The three main elements of CFD codes are: (1) A pre-processor is used to input the problem geometry, grid generation, define the flow parameters and the boundary conditions to the code. (2) A solver, for the conditions provided it solve the governing equations of the flow subject. four different methods are used by a flow solver: (i) finite difference method; (ii) finite element method, (iii) finite volume method, and (iv) spectral method. (3) A post-processor, is used to show the results in graphical and easy to read format. Some of the attempts made by different persons making observations to increase thermal characteristics of heat exchanger are Shiva Kumar et al. [1] have analysed concentric tube heat exchanger with passive heat transfer technique. This performance is determined for different longitudinal fin profiles, rectangular, triangular, parabolic. Numerical analysis was carried out in parallel flow double pipe heat exchanger for different profiles and for varied mass flow rates. Here analysis was done by both experimental and CFD method. In experimental method, the setup of concentric tube double pipe heat exchanger the inner tube was made of copper and hot water flows from the geyser attached to it. The inlet temperature of cold and hot fluid was maintained at 303K and 323K. The mass flow rate of hot water was varied from 0.02kg/s to 0.1kg/s with increase of 0.02kg/s each time by keeping mass flow rate of cold water as constant (0.02kg/s). Similarly, experiment was conducted by varying mass flow rate of cold water by keeping the mass flow rate of hot water constant. These two iterations were conducted by using CFD technique for heat exchangers having different profiles of fin attached for their inner tube. The results obtained were plotted against one another for comparison. The graph of Temp vs length of heat exchanger, Temp vs height of fin, Cold water outlet temp vs mass flow rate of hot water, Cold water outlet temp vs cold water mass flow rate, Heat transfer coefficient vs mass flow rate of cold water, Fin effectiveness vs mass flow rate, Pressure drop vs mass flow rate were plotted for selection of best alternative. J. Manohar et al. [2] considered that designing of heat exchangers is the one of the important aspects to be considered while, to increase the effectiveness of heat exchangers. In their work heat transfer enhancement was done using fins, which are attached to the inner pipe of heat exchanger. Rectangular fins are attached over inner tube along its length, for various increase in surface area rate of heat transfer was calculated theoretically by logarithmic mean temperature difference method. In the experiment, the temperature T1(hot water inlet),

T2(hot water outlet), T3(cold water inlet), T4(cold water outlet) are noted, after achieving constant flow rate. The flow of water is varied by adjusting the value, for various flow rate, the inlet and outlet of the hot and cold water temperatures were noted for doing calculation In designing part, it consists of a stack of alternate flat plates called 4 parting sheets and corrugated rectangular fins brazed together as a block to inner pipe, these fins are characterized by high effectiveness, compactness, low weight and moderate cost. Streams exchange heat by flowing along the passages made by the fins between the parting sheets. Separating plate acts as the primary heat transfer surface and the projected part known as fins act as the secondary heat transfer surfaces intimately connected to the primary surface. Fins not only form the extended heat transfer surfaces, but also work as strength supporting member against the internal pressure. These fins are generally made up of alloy of aluminium or stainless steel and it is depending upon working temperature and pressure. The setup consists of an inner tube and an outer tube. The inner tube is provided with an external fin, to improve the active surface area. Then hot fluid is passed through inner pipe, for various temperature of fluid, length of pipe; Nusselt number, Heat transfer coefficient, LMTD, Overall heat transfer rates are calculated. Then results are compared by conducting experiment without using fins and with using fins. Kanade Rahul H et al. [3] have carried out the heat transfer enhancement through a DPHE by using computational fluid dynamics using different types of baffles such as Semi-circular and Quarter-circular baffles arranged on inner pipe surface which contains cold process fluid i.e. water. These baffles are arranged in such a manner that increases that retention time of fluid, pressure drop and turbulence inside the annulus which contains hot process fluid i.e. water. Overall analysis is carried out by considering the DPHE in a steady state condition. Heat transfer rate, overall heat transfer coefficient and pressure drop are determined for fully developed condition for several Reynolds numbers based on the pipe diameter and flow mean velocity with water as working fluid. Kern method is used as a correlation for the design of heat exchanger. In Grid generation, fine mesh size is selected, in order to capture both thermal and velocity boundary layer with nodes of 64332 and 23100 elements. The analysis was carried out for a DPHE without baffles at 0.0583 m/s hot and 0.116 m/s cold velocities and was validated with analytical design and it was found that the temperature variation was ≤ 1%. Heat exchanger with quarter circular baffles arranged on outer surface of inner pipe resulted in an increase of heat transfer rate by 9.5% in comparison with no baffles. The performance of heat exchanger was increased by minimizing hot fluid temperature and maximizing the cold fluid temperatures. The optimal heat transfer rate was achieved for quarter-circular baffles with lower pressure

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drop and higher turbulence at 0.0583 m/s velocity of hot fluid. Deepali Gaikwad et al. [4] have done the experimental study to investigate the heat transfer performance and friction factor characteristics for laminar flow through a tube by means of twisted wire brush inserts. The mass flow rates in inner tube and in annulus were varied during experimentation. Air to water heat transfer study is performed and tested for counter flow configuration. Effect of inlet fluid temperature and relevant parameters on heat transfer characteristics and friction factor is considered. Their study revealed that the twisted wire brush inserts provided significant enhancement of heat transfer with the corresponding increase in friction factor, and the pressure drop also slightly increases. Due to the turbulence created and swirl flow generated, the convective heat transfer obtained from the tube with twisted wire brush inserts are higher than that with the plain tube without twisted wire brush inserts. The twisted wires brush inserts was made from straight copper tube with inner tube and outer tube diameters of 15 mm and 25 mm, respectively. The plain tubes with full-length twisted wires and with regularly spaced twisted wires brush inserts are tested. The twisted wires brush inserts are fabricated by winding 0.2 mm diameter of the copper wires over 2 mm diameter two twisted iron core-rods. They found the increased performance of concentric pipe heat exchanger with plain tube and tube with twisted wire brush inserts having a plot between tube side Nusselt number and Reynolds number. Based on their experimental results, The Nusselt number obtained for the tube with twisted wire brush inserts varied from 1.55 to 2.35 times in comparison to those of the plain tube. The inner convective heat transfer coefficient for twisted wire brush inserts is approximately 9-11 % higher than that for plain tube. The pressure drop for twisted wire brush inserts is 4- 5 % higher than that obtained for plain tube. The variation between theoretical Nusselt number and experimental Nusselt number is approximately 10-15 % because of influence of viscosity effects and the experimental values are in reasonable agreement with predicted values. The friction factor values for twisted wire brush inserts decrease than that for plain tube. It is 7-8% less than that obtained for plain tube.

II. NUMERICAL SCHEME

Double pipe heat exchanger without fins

The geometric model of the double pipe heat exchanger was constructed using work bench in Ansys 16 environment. The complete domain consists of 54650 Elements. Grid independent test was performed to check the validity of the quality of the mesh on the solution as shown in the Fig. 1. Inlet temperature and mass flow rate of the cold and hot fluid was specified. At the outlet, a pressure outlet boundary is enforced. Pressure velocity coupling was resolved using SIMPLE algorithm with a skewness correction factor of 1. For pressure, linear discretization was used. For momentum, turbulent kinetic energy and turbulent dissipation rate with power law scheme was used. For the energy equation second order upwind was used. Conservation equations were solved for the control volume to yield the velocity and temperature fields for the water flow in the heat exchanger. Convergence was affected when residuals fell below 10^{-3} in the computational domain. A sample convergence plot is shown in the Fig. 2. Simulations were done by changing the mass flow rates of hot fluid as well as cold fluid.

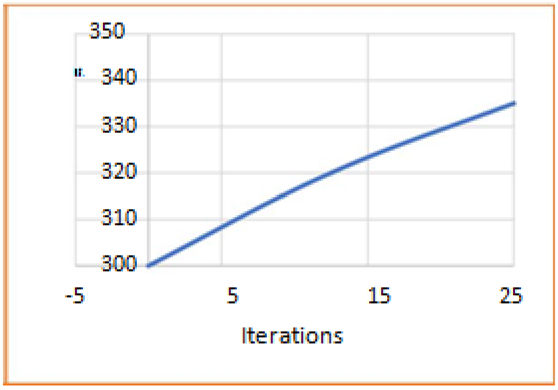

Fig-1: Variation of cold water outlet temperature with number of iterations

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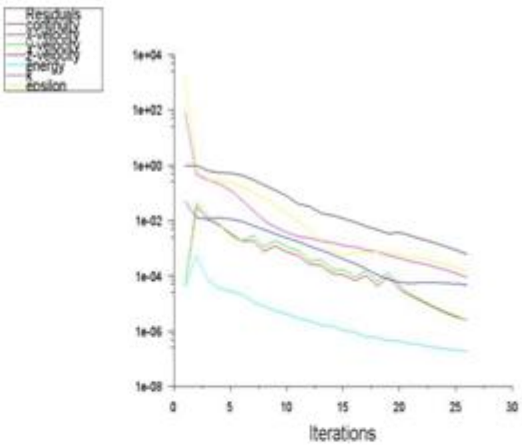

Fig-2: Sample of Residual convergence plot for the double pipe heat exchanger

Validation of the numerical results.

The Nusselt number obtained from the numerical results of plain double pipe heat exchanger is verified with the experimental Nusselt number of Deepali Gaikwad et al. [4]. The error is found to be 12.2%.

Rectangular finned double pipe heat exchanger

A double pipe heat exchanger with rectangular longitudinal fins was modeled in the Ansys work bench environment. Base width of the fin was 2mm (18 degrees) kept constant throughout the study. The simulation was done using different fin heights 3mm, 6mm and 7mm. 12 fins were placed circumferentially around the thickness of the inner tube which remained constant throughout the study. Simulation was carried out for various mass flow rates of cold and hot water. For mch = 0.01kg/s and mcc = 0.02kg/s temperature distribution at the outlet for both unfinned and finned (height = 6mm) heat exchanger is shown in Fig .3 which clearly indicates the increase in the average temperature in the annulus for a finned tube. Annulus fluid temperature along the length of heat exchanger was plotted for different fin heights and is as shown in Fig .4. It can be observed that the temperature rise for the finned heat exchanger is more than that of the unfinned type. As the fin height increases the average water temperature increased. But on comparing the temperature rise for different fin heights, as the height increases, rise in average temperature was found to be lower. Also, the curve shows that the temperature rise along the length of exchanger is gradual and not steep. Fig .5 represent the temperature plot along the vertical length at the centre of the fin for 3mm, 6mm and 7mm height fins at a midsection of the heat exchanger. Fin tip temperature for 3mm, 6mm and 7mm height fins are 326.84, 325 and 323.95K respectively. It indicates that there was a decrease of temperature by 1.84K when the height was increased from 3mm to 6mm and a decrease of 1.05K when the height was increased from 6mm to 7mm which indicates the reduced fin performance on increasing the fin height. Simultaneously increasing the fin height increases the weight of the finned assembly. Hence an optimum fin height of 6mm was chosen for further comparison between different profiles for fins.

III. RESULTS AND DISCUSSIONS

Geometrical modelling of the heat exchanger was constructed by changing the fin configuration to tri-angular profile keeping the fin base width, height and number of fins constant as discussed in Section 3. Fig.6 shows the different fin configurations undertaken in the present study. Simulation was done for different mass flow rates of hot water through the inner tube for a constant cold water flow rate of 0.02kg/s in the annulus. Fig .7 indicates the temperature plot of all fin profiles with mch= 0.01kg/s and mcc = 0.02kg/s. It depicts that the cold-water outlet temperature for the finned tube is higher than the bare tube. Fins promote boundary layer

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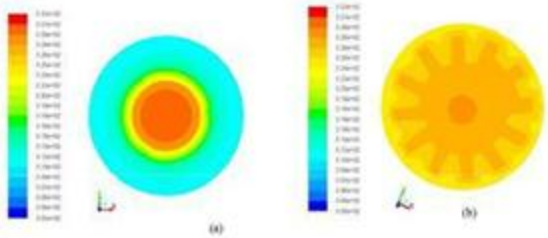

Fig. 3. Temperature distribution at the outlet surface for
(a) unfinned (b) rectangular finned double pipe heat exchanger (6mm) for mh = 0.01 and mc = 0.02kg/s

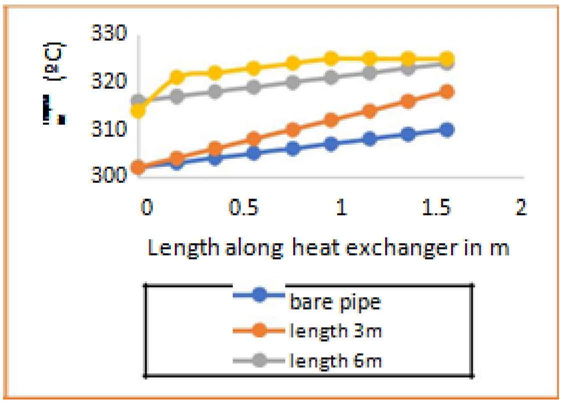

Fig. 4 Variation of cold water temperature along the length of exchanger for different heights of rectangular fins for mh = 0.01 and mc = 0.02kg/s

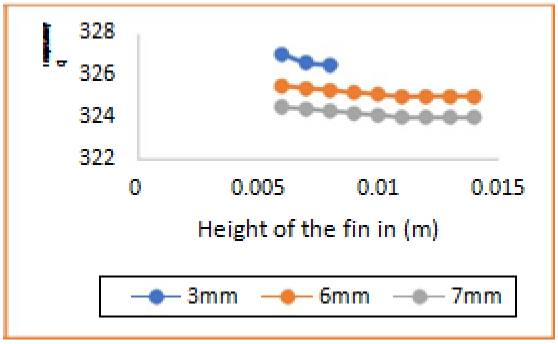

Fig. 5 Variation of temperature along the height of fin at the mid-section of the heat exchanger mh = 0.01 and mc = 0.02

separation of the fluids and disturb the whole bulk flow field inside circular tubes. Separation and restarting of the boundary layers increases the heat transfer rate. It can be further noted that the bulk of the fluid layer is being disturbed the rise of temperature is also uneven along the length of the tube as shown in Fig. 8. Temperature for triangular profile is slightly higher than the rectangular at the entry of the heat exchanger, and as fluid progresses along the length of the heat exchanger temperature for the rectangular profile increases sharply than the triangular profile and at the outlet it is marginally higher than triangular type. The fin form adjustment effects not only the mass of the heat exchanger, but also has an effect on the move liquid-like direction that causes the temperature changes on the fin contact surfaces.

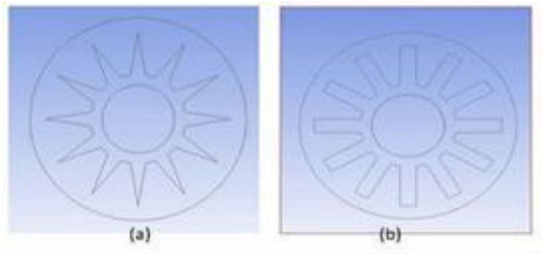

Fig. 6 Different types of finned configurations (a) triangular, (b) rectangular

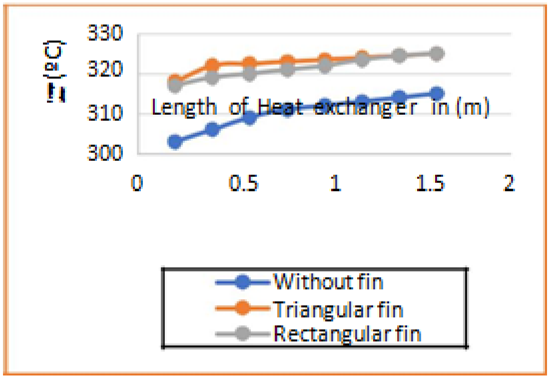

Fig. 7 Variation of temperature along the length of heat exchanger for different fin profiles at mh = 0.01 and mc = 0.02kg/s

Fig. 8 indicates the plot of cold water outlet temperature Vs mass flow rates of the hot water. The outlet temperature for the rectangular fin is 0.1% and 0.2% more that of triangular shape for the highest mass flow rate of hot water. Fig. 9 shows temperature rise along the length for a particular value of mch = 0.02kg/s and mcc = 0.01kg/s. It can be revealed that rise in the temperature is higher for a finned tube than the unfinned one. In case of finned tube, the rise is not uniform and smooth as the entire flow field is being disturbed along the length. Rectangular finned tubes show a marginal improvement over the other types

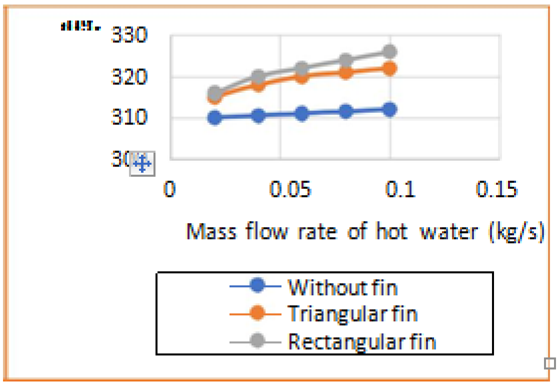

Fig. 8 Variation of cold water outlet temperature with mass flow rates of hot water

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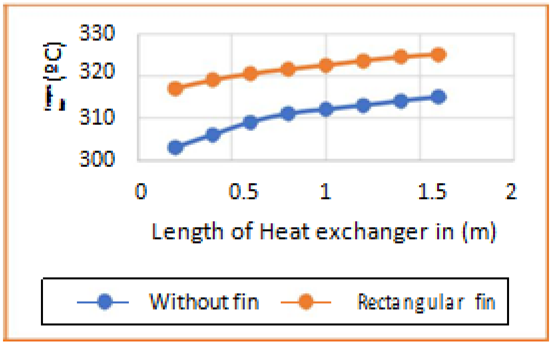

Fig. 9 Variation of temperature along the length of heat exchanger for rectangular fin profile at mh = 0.01 and mc = 0.02kg/s

Fig. 10 shows the variation of outlet temperature of cold water for varying mass flow rates of cold water with mass flow rate of hot water being fixed. It indicates as the mass flow rate increases the outlet temperature decreases for all profiles. This is because for a fixed value of mch heat energy dissipated from the inner tube remains constant and hence as mcc is increased heat transfer rate is being increased due to the increased turbulence, but the retention time of the fluid in the exchanger will be reduced which decreases the cold-water outlet temperature. Drop in outlet temperature or the rectangular profile is marginally lesser than the other two types showing its better performance.

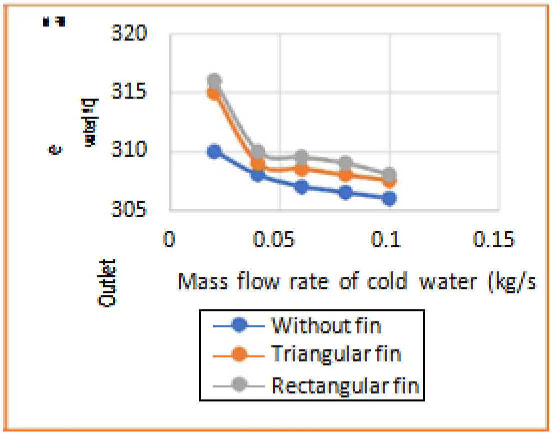

Fig. 10 Variation of cold water outlet temperature with varying mass flow rates of cold water

Tab. 1 indicates the heat transfer rate for different simulated conditions for the finned and unfinned tubes. It can be revealed that heat transfer rate increases with the increase in mass flow rate and finned tubes show higher value than the unfinned condition. For a constant value of mc = 0.02kg/s and varying mc, rectangular finned tubes showed an average improvement of 6.1% over the triangular finned tube. Similarly, for a constant value of mh = 0.02kg/s and varying mcc, it showed an improvement by 2% over the triangular

Table 1. Comparison of experimental and CFD simulated results for unfinned the double pipe heat exchanger

S. No	Condition	Mass flow rate (kg/s)	Unfinned tube (W)	Rectangular finned tube (W)	Triangular finned tube (W)
1	**mc constant at 0.02**	**0.02**	**621**	**1069**	**1023**
2		**0.04**	**718**	**1430**	**1348**
3		**0.06**	**759**	**1620**	**1515**

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4		0.08	784	1741	1623
5	kg/s and mh varying	0.1	800	1828	1700
6	mh constant at 0.02 kg/s and mc varying	0.02	621	1069	1023
7		0.04	841	1372	1284
8		0.06	992	1541	1487
9		0.08	1102	1589	1507
10		0.1	1187	1680	1604

Fig. 11 shows the variation of annulus heat transfer coefficient for different varied mcc keeping mch constant at 0.02kg/s. It is observed that annular heat transfer coefficient is found to be reduced for finned structure since effective heat transfer coefficient is related to the efficiency of the fin as Hannular = Fin efficiency × hnormal. Further on comparing the values for different fin profiles it is observed that rectangular profiles the heat transfer coefficient is slightly higher than the others at all mass flow rate conditions.

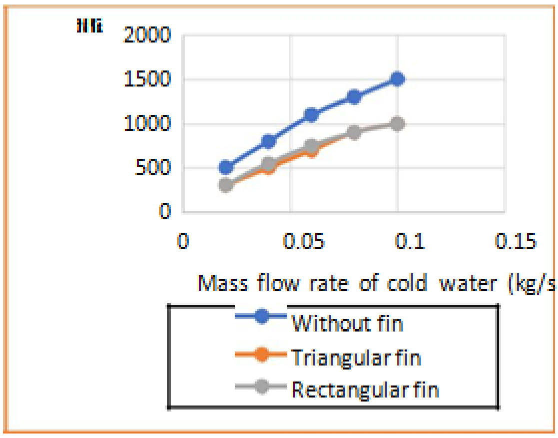

Fig. 11 Variation of annulus heat transfer coefficient with varying mass flow rates of cold water

Fig. 12 represents fin effectiveness for various types of fins under different conditions. Fin Effectiveness was calculated by the simple relation fin.

with fin effectiveness, ε= without fin For a constant value of mcc of 0.02kg/s, as mch was increased the effectiveness of the fins increased and rectangular fins showed highest effectiveness among the different types. Similarly, for a constant mh and as m_c are varied fin effectiveness decreases as seen in the graph. The rise in temperature for varying mcc decreases for a finned tube compared with the unfinned one. At higher mass flow rates the flow field is being disturbed severely when compared to the bare tube. Hence heat transfer capability of the fins decreases causing reduction in fin effectiveness. Hence in order to have a better performance by the fins for heating a liquid flowing in the annulus region, mass flow rate of liquid in the annulus should be minimum and mass flow rate of hot liquid flowing inside the inner tube should be maximum

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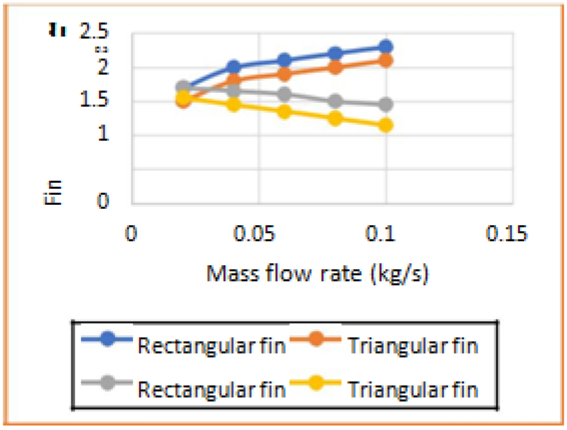

Fig. 12 Variation of fin effectiveness with varying mass flow rates of cold water and hot water

Fig. 13 represents the pressure drop variation for unfinned and the finned tube for various mass flow rates of cold fluid. It can be seen that pressure drop for unfinned tube is lesser than the finned tube. In case of a finned tube pressure drop was highest for the fin with rectangular shape. Higher pressure losses increase the pumping power. Since the pressure losses are more in case of rectangular finned tube the pumping power required will be more when compared to the triangular finned tube.

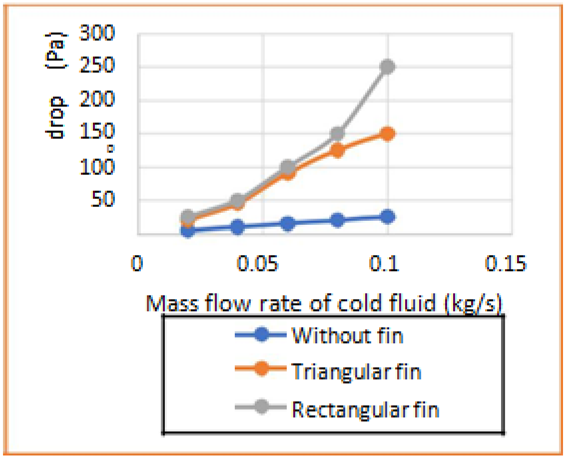

Fig. 13 Variation of pressure drop with varying mass flow rates of cold water

IV. CONCLUSION

In the present study, numerical simulation of finned double pipe heat exchanger is carried out with hot fluid flowing in the inner tube and cold fluid in the annulus. The simulation was carried out using rectangular, triangular finned configurations on the outer body of the inner tube. Results indicated finned configuration gives overall better thermal qualities compared with unfinned one. Rectangular finned con-figuration shows a marginal improvement over the triangular fin in terms of temperature rise, heat transfer rate, and heat transfer coefficient. The effectiveness value of the rectangular fin showed greater value than triangular fins.

REFERENCES

[1] *Shiva Kumar, K. Vasudev Karanth, Krishna Murthy. (2015) "Numerical study of heat transfer in a finned double pipe heat exchanger", World Journal of Modelling and Simulation, Vol. 11, No. 1, pp. 43-54*

[2] *J. Manohar, J. Sundhar Singh Paul Joseph, J. Lakshmipathy & M. Sathishkumar. (2016), "Experimental study on Fabrication of finned double counter flow heat exchanger". International Journal of Multidisciplinary Research and Modern Education Vol. 2, No. 1, pp. 2454 - 6119*

IJERMS
International Journal of Engineering Researches and Management Studies

[3] *Kanade Rahul H.1, Kailash B A, Gowreesh. (2015) "Heat transfer enhancement in a double pipe heat exchanger using CFD", International Research Journal of Engineering and Technology Vol. 2, No. 9, pp. 2395-0072*

[4] *Deepali Gaikwad, Kundlik Mali. (2014) "Heat Transfer Enhancement for Double Pipe Heat Exchanger Using Twisted Wire Brush Inserts", International Journal of Innovative Research in Science, Engineering and Technology Vol. 3, No. 7, pp. 2319-8753*

[5] *FP Incropera, TL Bergman, DP DeWitt, AS Lavine, Fundamentals of Heat and Mass Transfer, John Wiley and Sons Inc., New York, 7th edition, 2011*