Performance Study of Triple Concentric Pipe Heat Exchanger

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Abstract— In present study, triple concentric pipe heat exchanger is designed and developed for thermodynamic and hydrodynamic analysis. Researchers have shown that three pipe heat exchanger transfers heat at a higher rate as compared to double pipe heat exchanger. Experimental setup is fabricated to study the two different flow arrangements, called N-H-C and C-H-N. In this paper, three fluids have been considered are hot water, cold water and normal tap water. Flow arrangements are tested for various flow rates of hot and normal water keeping cold water flow rate constant. Overall heat transfer coefficients for cold and normal side are obtained by LMTD method. Objective of this paper is to study heat transfer and pressure drop characteristics for triple concentric pipe heat exchanger with counter flow configuration.

Keywords: Triple Concentric Pipe Heat Exchanger, overall heat transfer coefficient

I. INTRODUCTION

Heat exchangers have several industrial and engineering applications. Heat exchangers are classified in many different types because the equipment type, field of application and design techniques generally differ. The type of heat exchanger to be used is determined by the process and product specifications. Concentric tube heat exchanger plays a major role in fulfilling the needs of heat exchanger in food industry. The most commonly used heat exchanger is double pipe heat exchanger which consists of one pipe inside another pipe placed concentrically. It is used in different products such as dairy, food, beverage and pharmaceutical industries. There are some disadvantages of this exchanger and to overcome this, there is need to enhance the performance of double pipe heat exchanger. Adding an intermediate tube to a double pipe heat exchanger converts it to a triple pipe heat exchanger. Triple concentric pipe heat exchanger has better heat transfer efficiencies and performs better as compared to double pipe heat exchanger. It has larger area per unit length for heat transfer and better overall heat transfer coefficient due to higher fluid velocities in the annular regions. Some researchers have been studied the thermal performance of triple pipe heat exchanger. G. A. Quadir [1] studied the performance of triple concentric pipe heat exchanger numerically using finite volume method. They carried out parametric analysis which shows the effect of one parameter on the heat exchanger keeping other parameters constant. Experimentation of triple pipe heat exchanger is carried out under steady state condition and results are expressed in terms of temperature distribution along the length of heat exchanger by G. A. Quadir [2]. They concluded that N-H-C arrangement is better for heat transfer than C-H-N. Ahmet Unal [3,4,7] carried out theoretical study and case studies on triple pipe heat exchanger and derived the effectiveness-NTU relations. It has been shown that the performance of heat exchanger depends on the relative sizes of three tubes. A basic procedure for calculating overall heat transfer coefficient and length is given by T. M. Ghiwala et al [5]. This study is useful for calculating the dimensions for required temperature drop. O. Garcia-Valladares [6] developed a numerical model considering realistic situations which may be used to optimize the efficiency of triple concentric tube heat exchanger. A set of analytical equations for fluid temperatures along the length of heat exchanger for both parallel and counter flow arrangement was developed by C. A. Zuritz [8]. Simulation shows that by creating annular region in the pipe increases the overall heat transfer efficiency and reduces the length requirement by 25%. Ediz Batmaz [9] concluded that overall heat transfer coefficients and temperature profiles are useful for designing the heat exchanger. V. M. Behera [10] carried out simulation and presented temperature distribution using ANSYS 14 which shows that the better results are obtained with counter flow N-H-C arrangement. An algorithm for the calculation of partial coefficient of heat transfer and correlation for the design purpose of heat exchanger was developed by Sinziana Radulescu [11]. Abdalla Gomma [12] carried out experimental and numerical investigation of triple concentric tube heat exchanger with reference to double pipe heat exchanger and developed CFD model using finite volume discretization method. He concluded that triple tube heat exchanger contributes higher effectiveness and more energy saving per unit length compared with double tube heat exchanger.

II. EXPERIMENTAL SETUP

A triple concentric pipe heat exchanger is fabricated to carry out experiments. Three pipes of different diameters and lengths are used in the fabrication of the heat exchanger. Outer pipe is made up of stainless steel, middle and inner pipes are of copper. Outside diameters of the three pipes are 0.0254 m, 0.0381 m and 0.0508 m respectively with thickness of each pipe as 1.5 mm only. Length of innermost pipe is 170 cm, middle pipe is 138 cm and that of outer pipe is 101 cm. Baffles are inserted in the middle tube in which hot water flows. In this experiment, three fluids are used namely hot water, normal water and cold water.

There are two different flow arrangements namely N-H-C and C-H-N. In N-H-C arrangement, normal water flows through the innermost pipe, hot water flows through the inner annulus formed between 0.0254 m pipe and 0.0381 m pipe and the cold water flows through the outer annulus formed between 0.0381 m pipe and 0.0508 m pipe. This arrangement is called N-H-C configuration of heat exchanger as shown in fig. 1.

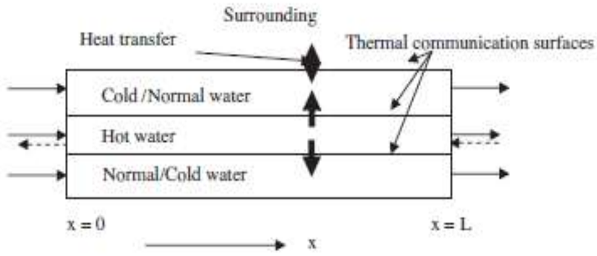

Fig. 1 Flow directions of three fluids for N–H–C and C–H–N arrangements [2]

In C-H-N arrangement, cold water flows in the innermost pipe, hot water flows through the inner annulus and the normal water flows through the outer annulus. Outer surface of the heat exchanger in both arrangements is insulated to avoid heat exchange with the surroundings. Two thermostatic heaters of each 3KW are used to heat the water. Hot water is taken at 60 to 65℃. Normal water is taken from tap water which is available at 29 to 32 ℃ and cold water from cooler at 19 to 23℃. Hot water starts flowing from the tank through the pump then it passes through rotameter measuring the volume flow rate and enters the heat exchanger inlet. Outlet of hot water is collected in another tank and is heated with the help of heater having capacity of 1.5 KW. Similarly, normal and cold water are passed through rotameter measuring the volume flow rate to respective heat exchanger inlet. Two thermocouples are placed at entry and exit of each fluid stream to measure the inlet and outlet temperature. These six thermocouples are connected to digital multipoint temperature indicator.

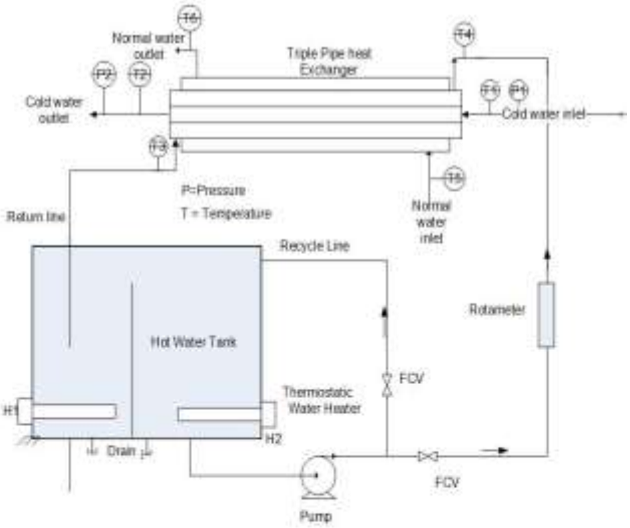

Fig. 2 Schematic diagram of the experimental setup

2.1 Experimental Procedure

First of all water is filled in the tank up to certain level and electric heaters having capacity 3 KW are switched on. As thermostatic heaters are used and set to 65 ℃, it maintains the constant temperature in the tank. This hot water is pumped by pump and it passes through the rotameter of range 100 to 1000 LPH measuring the flow rate. The mass flow rate of hot water is controlled by flow control valve (FCV) and is supplied at inlet of middle tube. Hot water outlet is collected in another tank having heater of capacity of 1.5 KW. Normal water which is tap water pumped and passed through another rotameter having range 1 to 10 LPM. Similarly cold water is taken form water cooler and supplied to respective exchanger inlet through rotameter of range 0 to 10 LPM. The test is conducted for both N-H-C and C-H-N arrangement with counter flow configuration. The readings are taken in two sets. Cold water is kept constant at 20 LPH for both the sets. In first set, for different constant mass flow rate of normal water from 60 to 195 LPH, hot water is varied from 100 LPH to 400 LPH. In second set, normal water flow rate is varied from 60 to 195 LPH for different flow rates of hot water keeping constant from 100 to 400 LPH. For each fluid, two T type thermocouples are placed at entry and exit. For steady state condition 7-8 min are required. The pressure drop along the heat exchanger is measured by U tube manometer which shows the differences in pressure at inlet and exit of heat exchanger. Pressure drop readings are also taken at various flow rates similar to that of temperature readings.

Fig. 3 Actual experimental setup

2.2 Mathematical Formulation

The basic equations used to describe the thermal characteristics of the triple tube heat exchanger are summarized as follows: The heat transfer rate of the hot water through the inner annulus is calculated as follows:

$$\dot{Q}_h = \dot{m}_h\, c_h\, (T_{h_i} - T_{h_o}) \qquad (1)$$

The heat transfer rate of the cold water in the inner tube is calculated as:

$$\dot{Q}_c = \dot{m}_c\, c_c\, (T_{c_o} - T_{c_i}) \qquad (2)$$

The heat transfer rate of the normal water in the outer annulus is calculated as:

$$\dot{Q}_n = \dot{m}_n\, c_n\, (T_{n_o} - T_{n_i}) \qquad (3)$$

The heat transfer rate between the cold, normal and hot water for the triple concentric-tube heat exchanger is as follows:

$$\dot{Q}_h = (\dot{Q}_c + \dot{Q}_n) \qquad (4)$$

The average heat transfer rate ,$\dot{Q}_{av}$ is determined between the three fluid sides as:

$$\dot{Q}_{av} = \left(\frac{\dot{Q}_h + \dot{Q}_{cn}}{2}\right) \qquad (5)$$

Where $\dot{Q}_{cn}$is the aggregate of the cold and normal tap water heat transfer rate as:

$$\dot{Q}_{cn} = (\dot{Q}_c + \dot{Q}_n) \qquad (6)$$

The heat transfer coefficient of the inner annulush_{im} is calculated from:

$$\dot{Q}_h = h_{im}\, A\, (LMTD)_{av} \qquad (7)$$

The average log-mean temperature difference between the three fluids is calculated from:

$$LMTD_{av} = \frac{LMTD_{hc} + LMTD_{hn}}{2} \qquad (8)$$

Where $LMTD_{hc}$ is the log-mean temperature difference between hot and cold water while $LMTD_{hn}$ is the log-mean temperature difference between hot and normal tap water.

Nusselt number is determined from:

$$Nu = \frac{h\, D_h}{k} \qquad (9)$$

The effectiveness of the triple tube heat exchanger is calculated as:

$$\varepsilon = \frac{\dot{Q}_{av}}{\dot{Q}_{max}} = \frac{\dot{Q}_{av}}{(\dot{m}\, c)_{min}\, (T_{h_i} - T_{c_i})} \qquad (10)$$

The friction factor of the inner annulus of the triple concentric-tube is calculated as:

$$f_{im} = \frac{2\, \Delta P_{im}\, D_h}{\rho\, L\, v^2} \qquad (11)$$

III. RESULTS AND DISCUSSION

In this section, triple pipe heat exchanger is analyzed for temperature variation, heat transfer rate and pressure drop. Various test were performed to determine heat transfer in triple pipe having counter flow arrangement with normal water flowing through inner pipe, hot water through inner annulus and cold water through outer annulus.

3.1 Overall Heat Transfer Coefficients

Fig. 4 represents the comparison between cold side overall heat transfer coefficient with hot water Reynolds number when normal water mass flow rate is kept constant at 60, 120 & 180 LPH and cold water flow rate at 20 LPH. As seen from the graph, overall heat transfer coefficient increases with increase in Reynold number when normal and cold water flow rate kept constant. If mass flow rate of normal water is increased from 60 to 120 LPH keeping constant, overall heat transfer coefficient is decreased to some extent. Similarly, it is decreased for constant flow rate 180 LPH because heat transfer rate is more for normal side and less for cold side.

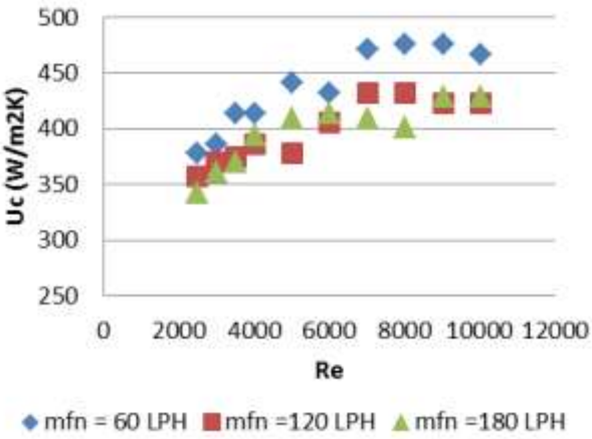

Fig. 4 Variation of cold side overall heat transfer coefficient with hot water Reynold number

Fig. 5 shows the variation of overall heat transfer coefficient for normal side with hot water Reynold number when normal and cold water mass flow rate kept constant. From Fig. 5, it is observed that overall heat transfer coefficient is increased when Reynold number is increased while keeping normal water mass flow rate at 60 LPH and cold water at 20 LPH. When mass flow rate of normal water is increased from 60 to 120 LPH, overall heat transfer coefficient is increased as compared to that at 60 LPH. When normal water mass flow rate is at 180 LPH, it is again increased because more heat is transferred to normal side as compared to cold side. Experimental values of cold side and Normal side heat transfer coefficient are found in well agreement with literature, with a percentage deviation of 10-15%.

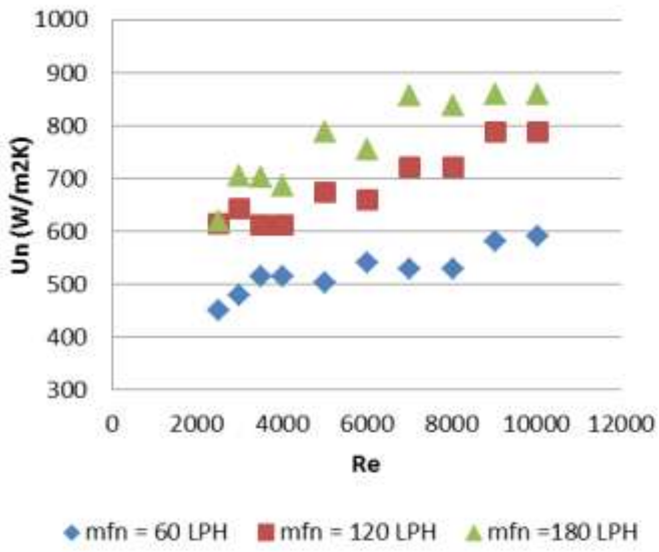

Fig. 5 Variation of normal side overall heat transfer coefficient with hot water Reynold number

3.2 Average Heat Transfer Rate

Fig. 6 shows the variation of average heat transfer rate with hot water Reynold number for constant cold and normal water mass flow rate.

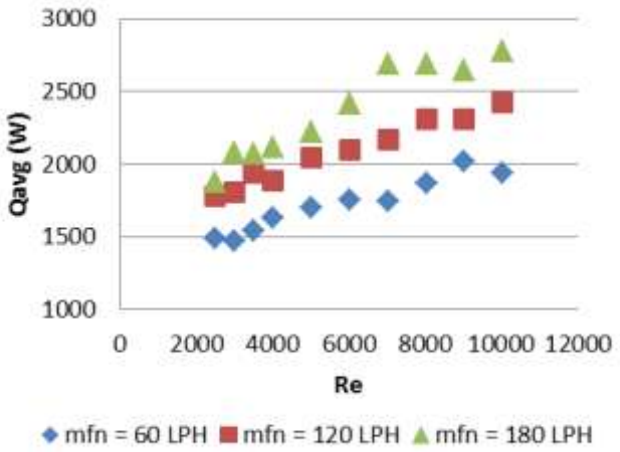

Fig. 6 Variation of average heat transfer rate with hot water Reynold number

It is clear that, average heat transfer rate increases with increase in hot water Reynold number when normal and cold water flow rate remains constant. As mass flow rate of normal water increases average heat transfer rate also increases. Average heat transfer rate is more for 180 LPH as that of 60 and 120 LPH.

3.3 Pressure Drop

Fig. 7 shows the variation of hot water pressure drop with hot water Reynolds number. It is observed from the figure that pressure drop is continuously increasing with hot water Reynolds number. Large pressure drop is observed because baffles are placed in the inner annulus through which hot water flows. A baffle increases the pressure drop. The pressure drop is 666.65 Pa at Reynolds number 2508 and it is 5199.87 Pa at Reynolds number 10034.

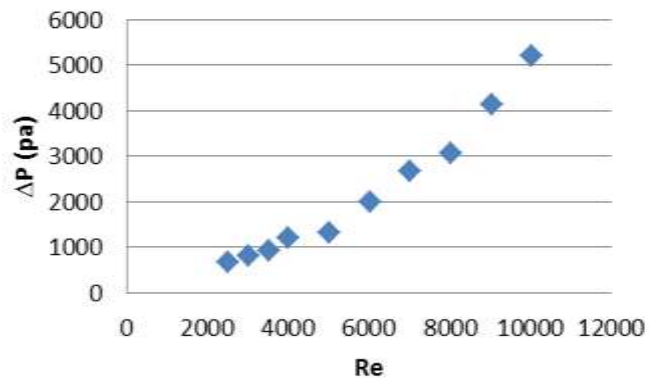

Fig. 7 Variation of hot water pressure drop with hot water Reynolds number

Fig. 8 shows the variation of normal water pressure drop with normal water Reynolds number. From the figure, it is clear that pressure drop of normal water increases with normal water Reynolds number. Less pressure drop is observed as compared to hot water because in the inner pipe (normal water) no baffles are used. Pressure drop is increased from 333 Pa to 519 Pa when Reynolds number is increased from 1193 to 3513.

Also it is clear from the graph that, testing of the heat exchanger is done, for the maximum value of pressure drop. Results of pressure drop agree considerably with that of the literature values, with a percentage deviation of 10-15%.

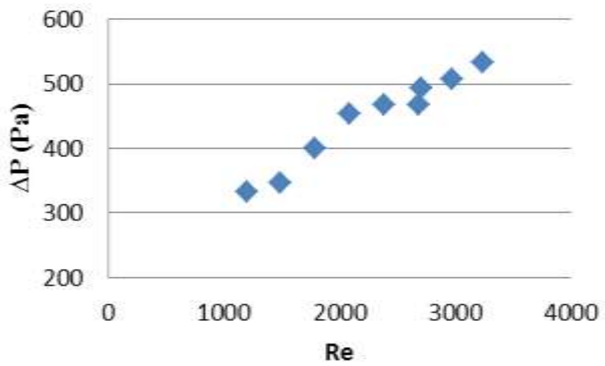

Fig. 8 Variation of normal water pressure drop with normal water Reynolds number

IV. CONCLUSIONS

An experimental study has been carried out to investigate the heat transfer performance and pressure drop of triple concentric pipe heat exchanger. The mass flow rate of hot water in the inner annulus and normal water in the inner pipe are varied during experiment. Effect of mass flow rate on heat transfer characteristics and pressure drop are considered. With increase in hot water Reynolds number, both normal and cold side overall heat transfer coefficient increases. But with increase in normal water mass flow rate, normal side overall heat transfer coefficient increases and cold side heat transfer coefficient decreases. Average heat transfer rate increases with hot water Reynolds number and normal water mass flow rate. Hot water pressure drop is more than normal water pressure drop because of baffles in the inner annulus and higher values of mass flow rate. Also the heat transfer coefficients pressure drop agrees considerably, with that of the literature values with percentage deviation of about 10-15%.

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