Experimental Investigation On- Triple Concentric Tube Heat Exchanger with Helical Baffles

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Abstract :- A heat exchanger is a device used to transfer thermal energy between two or more liquids, between a solid surface and a liquid, or between solid particles and a liquid at different temperatures and in thermal contact where shell and tube heat exchangers contain a large number of tubes packed in a jacket whose axes are parallel to those of the shell. Heat transfer occurs when one fluid flows into the pipes while the other flows out of the pipes through the jacket. In industry, the tube in triple tube heat exchangers are used as condensers, vaporizers, sub-coolers, heat recovery exchangers etc. The triple concentric tube heat exchanger is a modified constructive version of double concentric tube heat exchanger by adding an intermediate tube some advantages compared to double tube heat exchangers, as larger surface area for heat transfer per unit length. In the present study, the triple tube heat exchanger is further modified by inserting helical baffle over the surface of one of the tubes and observed turbulence flow which may lead to high heat transfer rates between the fluids of heat exchanger. Further, the Reynolds number, Nusselt number, friction factor of the flow at different mass flow rates of the hot fluid while keeping a constant mass flow rate of cold and normal temperature fluids were calculated. It was found that as the mass flow rate of the fluid increases the Reynolds number increases, the turbulence in the flow will increase which will cause the intermixing of the fluid, higher the rate of intermixing, more will be the heat transfer of the system.

Keywords: Triple tube, heat exchanger, helical baffle, Reynolds number, Nusselt number, friction factor, heat transfer.

I. INTRODUCTION

A heat exchanger is a device used to transfer thermal energy between two or more liquids, between a solid surface and a liquid, or between solid particles and a liquid at different temperatures and in thermal contact.

In most heat exchangers, heat transfer between fluids occurs through a wall. In many heat exchangers, liquids are separated by a heat transfer surface and ideally do not mix or lick. These exchangers are called direct transfer types or simply recuperates. Conversely, heat exchangers that undergo intermittent heat exchange between hot and cold liquids - through the accumulation of thermal energy and their release through the surface or matrix of the heat exchanger - are referred to as indirect transfer or simply regenerative. These exchangers normally lose fluid from one fluid flow to another due to pressure differences and matrix / valve switching.

Typical applications include heating or cooling a fluid flow and vaporizing or condensing the flow of fluid to one or more components. In other applications, the goal may be to recover or repel heat or to sterilize, pasteurize, fractionate, distill, concentrate, crystallize or control a treatment fluid. In some heat exchangers, the heat exchange liquids are in direct contact.

Common examples of heat exchangers are shell and tube heat exchangers, automotive cooling devices, condensers, evaporators, air preheaters and cooling towers. If no phase change occurs in any of the heat exchanger fluids, it is sometimes referred to as a sensible heat exchanger. Internal heat energy sources may be present in heat exchangers in electric heaters and nuclear fuel elements. Combustion and chemical reaction can take place in the heat exchanger, for example boilers, fired heater and fluidized-bed heat exchangers.

Mechanical devices can be used in some exchangers, such as scrapped surface exchangers, agitated tanks and agitated tank reactors. The heat transfer in the separator wall of a recuperator is generally carried out by thermal conduction. However, in a heat pipe heat exchanger, the heat pipe not only serves as a partition, but also facilitates heat transfer by condensation, evaporation and conduction of the working fluid in the heat pipe. In general, when fluids are immiscible, the septum can be omitted and the interface between fluids replaces a heat transfer surface as in a direct contact heat exchanger.

1.1 Triple tube heat exchanger

The tube in tube heat exchanger is the same as double concentric tube heat exchanger and it is composed by two concentric tubes with identical length and different diameters as shown in figure 1.7. This heat exchanger has the advantage to work in both parallel flow as well as counter-current flow, with a better heat exchange, it can be operating to high temperatures and has a good resistance to high pressure. In industry, the tube in triple tube heat exchangers are used as condensers, vaporizers, sub-coolers, heat recovery exchangers, crystallizers etc. The triple concentric tube heat exchanger is a modified constructive version of double concentric tube heat exchanger by adding an intermediate tube. Thus, triple concentric heat exchanger is constructed by three concentric tubes and it is possible to have the different lengths. The triple concentric heat exchangers have some advantages compared to double tube heat exchangers, as larger surface area for heat transfer per unit length and higher overall heat transfer coefficients. Adding the third tube, the thermal contact between the fluids was improved. Also, by using these types of heat exchangers, one can obtain technical and economic advantages due to the possibility of heat exchange between three fluids in one equipment.

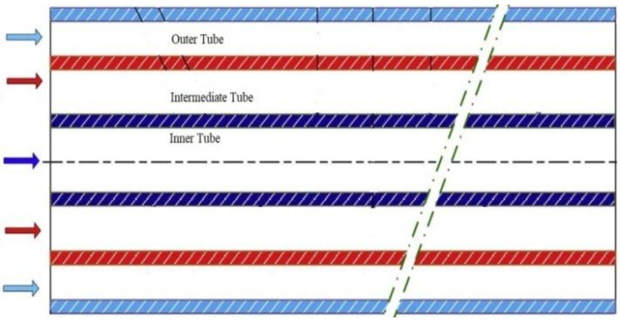

Figure 1.7: Schematic representation of a triple tube heat exchanger

This project work is based on the thermal analysis of three-tube heat exchangers. The three-tube heat exchangers are characterized by a design that gives the heat exchanger a different appearance. In its classic sense, the term triple or triple tube means a heat exchanger consisting of three concentric tubes, generally with straight legs and without curves. Due to the need to build a detachable spoke and the ability to handle differential thermal expansion by avoiding the use of expansion joints (often the weak point of the heat exchanger), the current configuration has become the industry standard. Another difference from the conventionaldefinition arises when more tubes are used to create a bundle of tubes containing tubular plates and tube supports similar to those mentioned in TEMA (Tubular Exchanger Manufactures Association)guidelines.

II. LITERAURE REVIEW

Gomaa et. al. (2017)conducted the study to evaluate the performance of the three-tube heat exchanger with finned inserts. The main design parameters of the study include the mass flow, the flow configuration, the temperature variation, the height and the spacing of the fins. The CFD numerical modeling is developed using the FLUENT commercial code and validation criteria are applied to extend the study parameters of additional intervals. The results showed that the introduction of fins in the inner ring of the three-pipe heat exchanger fluid flow results in a significant improvement in convective heat transfer. A higher performance index is obtained with a finer tone and a lower height. On the basis of the data obtained, a series of empirical expressions with design parameters without dimensions have been envisaged.

Mazaheri andBahiraei (2019) studied the characteristics of the second law of an innovative nano-fluid with nano-plate hybrid graphite nanoparticles through a ribbed three-tube heat exchanger (RTTHX). The hot nano-fluid flows into the side of the grooved ring, cold water enters the inner tube and normal water flows into the side of the outer ring. The effects of the weight fraction of the nanoparticles and the geometric parameters are evaluated, including the pitch and height of the baffles. The total entropy production rate of the heat exchanger decreases according to the weight fraction, which demonstrates the great advantage of using the nanofluid. Increasing the height of the fins and reducing the distance between the fins reduces the total production of nanofluid entropy, while increasing the total production of RTTHX entropy. Furthermore, the total of the heat exchanger increasing the weight fraction decreases, therefore decreases by increasing the weight fraction from 0 to 0.1% for a baffle distance of 150 mm and a baffle height of 3 mm of about 23 %. Moreover, the efficiency of the second law increases with the increase in the weight fraction, since it decreases with the decrease in the spacing of the baffles and with the increase in the height of the fins. The effectiveness of the second law has high values in all the conditions studied.

Bahiraei and Mazaheri (2018)tried to study numerically the hydrothermal properties and energy efficiency of a hybrid nanofluid containing a composite graphene-nanoplate-platinum powder in a heat exchanger with three tubes with integrated fins. The nanofluid flows on the side of the inner ring, while cold water and normal water respectively flow on the side of the tube and on the side of the outer ring. The baffles are attached to the outer surface of the inner tube. The overall heat transfer coefficient, efficiency and heat transfer rate of the heat exchanger are improved by increasing the concentration of nanoparticles and the height of the fins and reducing the spacing of the fins. The pressure drop is more intense with a smaller pitch of the fins and a greater height of the fins when the particles travel longer distances in these conditions. On the basis of a better heat transfer, the case of a higher fin height and a smaller pitch of the fin at the higher concentration is suggested as it indicates the greater heat output of the heat exchanger. However, in terms of energy efficiency, it is recommended to use the heat exchanger with the height and height of the smallest fins with the highest concentration of nanoparticles, since the performance index is in this case higher than the others cases.

Amanuel and Mishra (2018)conducted the numerical study of CuO / water nano-fluids in a triple concentration tube heat exchanger was conducted with commercial CFD software. The main objective of this study is to study the heat transfer and pressure loss of water-based CuO nanoliquids under turbulent flow conditions. The Reynolds number for the nano-fluid was also considered in the range from 2500 to 10,000 with a volume concentration of nanoparticles from 0% to 3%. The effects of flow, nanoparticle volume and flow arrangement on nano-fluids heat transfer performance have been studied for four flow configurations. Performance comparison was performed with and without nano-fluid. It has been discovered that the thermal performances and the overall efficiency increase with the increase of the Reynolds number and of the volumetric concentration of nanoparticles in the four flow devices for the range of operating parameters considered.

Touatit and Bougriou (2018) developed a Fortran calculation code is used to determine the temperature profiles of three fluids, as well as the various heat transfer coefficients and the total friction force in a three-tube heat exchanger and steady-state concentric tubes. The system consists of three concentric tubes, hydrogen flowing in the central tube, nitrogen in the inner ring and oxygen in the co-current and counter-current of the outer ring. It is assumed that the thermo-physical properties used in this study are variable with temperature. In this study, we use a techno-economic method of optimizing the heat exchanger looking for the optimal diameter that corresponds to the minimum total cost of the heat exchanger (operation and investment). Now we have only one optimal diameter of the tube for each heat exchanger, which corresponds to the minimum total cost of the heat exchanger (total friction and production of heat exchanger), unlike previous studies in literature in which it had two optimal pipe diameters: the first corresponds to the maximum efficiency of the heat exchanger The heat exchanger is the last the minimum energy consumption, necessary to overcome the pressure drop in the heat exchanger.

Shariff and Quadir (2017) performed analysis of a tubular heat exchanger (SDCTHEX) using commercially available CFD software ANSYS FLUENT 14.0. First, SDCTHEX with fixed internal diameter of the tube is compared with the conventional tubular heat exchanger (STHEX) as regards its thermo-hydraulic properties for the different mass flows of the hot fluid. Subsequently, the effects of different inner tube diameters on SDCTHEX performance are examined. The results show that the average increase in heat transfer rate percentage of the SDCTHEX total pressure drop for an inner tube diameter of 8/12 mm / mm is almost 343% greater than that of STHEX, while the friction force total SDCTHEX is about 85 compared to STHEX. , Reduced by 5%. Furthermore, the total heat transfer rate for SDCTHEX total pressure drop depends on the internal diameter of the pipe. It turns out that with a mass flow rate up to 22.5 kg / s with an internal tube diameter of 12/16 mm / mm, the value is about 400% higher than that of STHEX. The simulation results show that SDCTHEX shows superior heat transfer performance while maintaining a lower pressure drop.

Wen and Gu (2017) proposed an optimization strategy that combines the Entransy theory and the genetic algorithm. The applicability of the Entransy theory for tubular spiral tube heat exchangers (STHXsHB) has been demonstrated by the agreement of the performance evaluation criteria (PEC) and by the Entransy dissipation theory based on experimental data. . The effects of the helical angle, the degree of overlap and the lateral speed of the shell on the thermal resistance (optimization objective) were examined on the basis of the principle of minimum thermal resistance. The results showed that the thermal resistance of the dissipation decreased during the transmittance with the speed of the hull side, but increased with the angle of the helix. The degree of overlap has practically no influence on the variation of the thermal resistance of the power dissipation. According to the sensitivity study, it was assumed that the thermal resistance was mainly influenced by the speed of the side of the hull and therefore by the angle of the spiral. With the genetic algorithm three optimal configurations were obtained in which the thermal resistance decreased by 7%. The combination of the Entransy theory and the genetic algorithm can provide theoretical insights to effectively optimize the configuration of the coiled tube heat exchangers of the spiral heat exchanger.

Wang and Xiao (2017)proposed a type of tubular heat exchanger with bent baffles to eliminate triangular dispersion zones between adjacent baffles. An efficient algorithm that combines the second-order polynomial reaction surface method and the multi-target genetic algorithm was used to study the effect of convolution configuration parameters on heat transfer and flow performance. The spiral angle, the degree of overlap and the speed of entry of the hull side have been chosen as design parameters. The Nusselt number and the pressure drop on the hull side were considered objective functions. The results show that the Nusselt number and the pressure drop on the hull side increase with the decrease of the spiral angle and the speed of entry on the side of the hull and increase with increasing degree of overlap. A number of Pareto optimal points were obtained and the optimization results show a good agreement with the CFD simulation data with a relative difference of less than ± 3%. Empirical correlations of the Nusselt number and the coefficient of friction were obtained based on the response surface method; the helix angle and the degree of overlap were initially adjusted as correction factors in the empirical correlations. It can be seen that the coefficient of determination of the Nusselt number and the coefficient of friction set are respectively 0.943 and 0.999, which illustrates the precision and reliability of the regulation.

III. OBJECTIVE

Experimental and numerical investigation as performed by Gomaa et. al. (2017) was carried out to evaluate performance characteristics of triple tube heat exchanger with baffles inserts. The investigation's key involved important parameters like water mass flow rate, flow pattern, temperature variation, baffle height and baffle pitch. They also developed numerical computational fluid dynamics model and did validation to extend study parameters with extra ranges.

In present study the parameters such as baffle height, baffle pitch and mass flow rate have been varied to conduct the study and evaluate parameter like heat transfer rate, friction factor of the flow.In most practical applications of heat transfer enhancement techniques, the following performanceobjectives, along with a set of operating constraints and conditions, are usually considered foroptimizing the use of a heat exchanger.

To observe the rate of heat transfer of parallel flow arrangement of the triple tube heat exchanger.

To analyze the heat transfer rate at different values of Reynolds number in a parallel flow heat exchanger.

Compare the experimental results of Reynolds number, Nusselt number, friction factor of triple tube heat exchanger in parallel flow arrangement with previous studies.

Next chapter deals with research methodology and details of experimental setup related to proposed work.

IV. RESEARCH METHODOLOGY AND EXPERIMENTAL SETUP

4.1 Research Methodology

Heat exchangers are devices that facilitate the exchange of heat betweentwo fluids that are at different temperatures while keeping them frommixing with each other. Heat exchangers are commonly used in practicein a wide range of applications, from heating and air-conditioning systemsin a household, to chemical processing and power production in large plants.Heat exchangers differ from mixing chambers in that they do not allow thetwo fluids involved to mix. In a car radiator, for example, heat is transferredfrom the hot water flowing through the radiator tubes to the air flowingthrough the closely spaced thin plates outside attached to the tubes.

4.2 Assumptions:

1. The heat exchanger is well insulated from surrounding and hence the total heat lost by the hot water is equal to the summation of heat gained by the cold water and normal water and the heat lost to surrounding is negligible.
2. Heat conduction in the tubes along axial direction is negligible.
3. Changes in kinetic energy and potential energy of fluid streams are negligible.
4. Fluid propertied remain constant and there is no fouling.
5. The operating conditions are under steady state and the overall heat transfer coefficient remain constant.

5.3 Experimental Setup

The experimental study has been conducted on a Triple Tube Heat Exchanger (TTHE) consisting of three concentric pipes, the inner pipe, the intermediate pipe and the outer pipe made of carbon steel having following dimensions:

ID of inner pipe = 19.05 mm

OD of inner pipe = 25.05 mm

ID of intermediate pipe = 50.8 mm

OD of intermediate pipe = 56.8 mm

ID of outer pipe = 76.2 mm

OD of outer pipe = 82.2 mm

Length of the heat exchanger or Heat Transfer length = 2.896 m

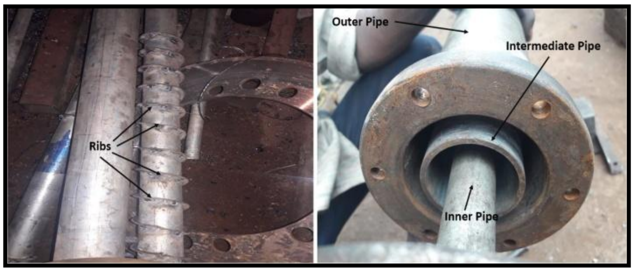

Figure 4.1: Arrangement of baffles over the pipe.

The inner pipe was inserted inside the intermediate pipe which is having baffles over it, this assembly was then inserted inside the outer pipe to complete the arrangement of triple tube heat exchanger. To hold the three pipes in place i.e. to maintain a constant space between them, a flange has been welded at both the ends of the above arrangement and proper cut outs on these flanges have been made in order to send different temperature water in different pipes.

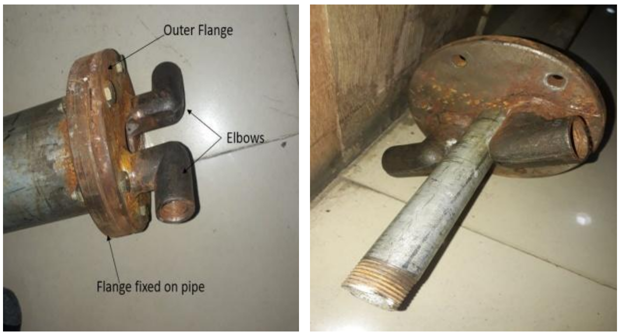

Figure 4.2: Arrangement of the flange with elbows and pipe of heat exchanger

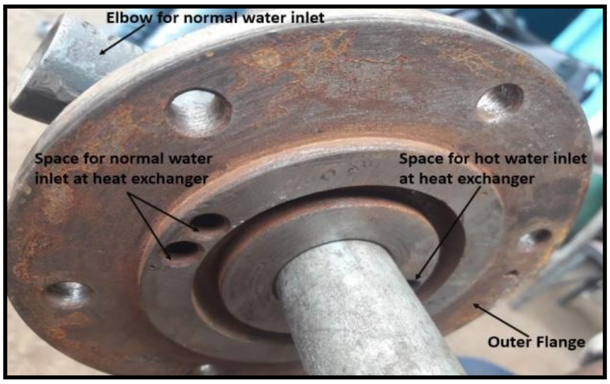

Figure 4.3: Arrangement of elbows and straight pipe on outer flange

Though all the precautions and measures were taken while making the triple tube heat exchanger well insulated thermally, but practically it was seen that some amount of heat was still getting lost to the atmosphere. But that amount of heat which was getting lost could be safely neglected in lieu of the results which were plotted on graph and compared with the result of previous findings is studies conducted by other researchers.

V. RESULT AND DISCUSSION

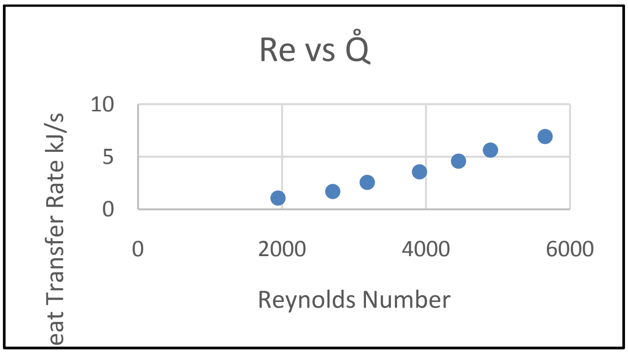

Figure 5.3: Reynolds number variation with rate of heat transfer

Validation The current study was compared with that in the study conducted by *Gomaa et al.* [1], and the trend of graph for Reynolds number versus friction factor and Reynolds number versus Nusselt numberwere found to be similar [1]. Hence it can be said that the current study is validated.

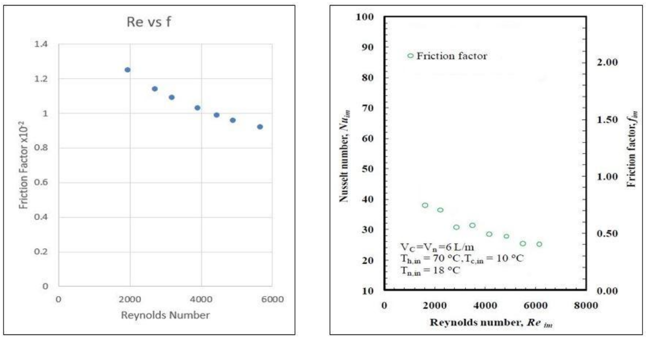

Figure 5.4: Comparison between current study and base paper of Re vs f

The reason for such variation of friction factor with Reynolds number is that the friction factor the relation between them varies inversely and hence as one value increases the other gets decreased which can be seen in Figure 5.4 for both current study and *Gomaa et. al.* [1] study.

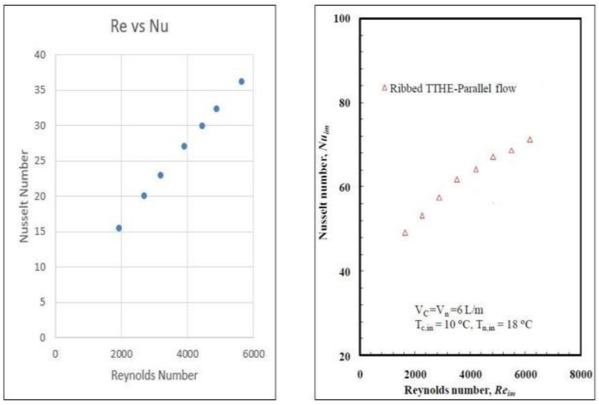

Figure 5.5: Comparison between current study with base paper of Re vs Nu

The increase in value of Reynolds number leads to increase in value of Nusselt number because as Reynolds number increases the heat transfer due to convection also gets increased, which can be seen in both in current study and *Gomaa's* [1] study as shown in Figure 5.5.

VI. CONCLUSIONS

helical baffles used to create the obstruction in path of the fluid in order to create turbulence in the flow through the heat exchanger. After performing number of experiments, the calculations were done to determine the velocity (v), Reynolds number (Re)of flow, friction factor (f) and Nusselt number (Nu) associated with it based on the discharge rate of fluid. The following conclusions can be drawn:

1. As the discharge was increased, the mass flow rate of fluid was increased, the value of Nusselt number (Nu) associated with the flow also got increased from 15.4 to 36.2.

2. The value of friction factor (f) of the flow was observed to be decreasing from 0.0125 to 0.0092 as the velocity of the flow was increasing.
3. The rate of heat transfer ($\mathring{Q}$) was found to be increasing from 1.073 to 7.005 kJ/s as the value of Reynolds number (Re) associated with the flow increased.

6.1 FUTURE SCOPE OF WORK :-

The further research which can be carried out on this same experimental setup is that the heat transfer rate at different values of inlet temperature of hot water can be can be computed and effectiveness of the system can be compared. The same experimental setup can be used for evaluating data for counter flow arrangement and can be compared with the present study. A similar setup can be designed with different values of baffle height, baffle thickness and baffle pitch and a comparative study can be conducted for optimum dimensions of baffle.

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