Numerical Investigation on Triple Concentric Tube Heat Exchanger with Helical Insert Baffles

Kaif Ahmad[1], Dr.Arvind Gwatiya [2]

Kaif Ahmad, M.Tech Research Scholar, Dept. of Mechanical Engineering, Bhopal, MP, India
Dr. Arvind Gwatiya, Assistant Professor, Dept. of Mechanical Engineering, RKDF University, MP, India

Kaif1998786@gmail.com[1], arvindrkdf786@gmail.com[2]

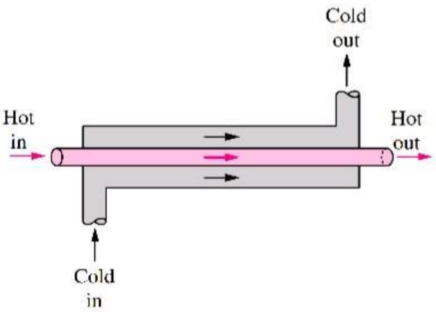
* Corresponding Author: Kaif Ahmad

Abstract:
The present study focuses on the experimental analysis of a Triple Concentric Tube Heat Exchanger (TCTHE) enhanced with helical insert baffles to investigate its performance in improving heat transfer efficiency. A triple concentric tube configuration allows simultaneous heat exchange between three fluid streams, making it ideal for applications requiring compactness and high thermal effectiveness. To further enhance the heat transfer rate, helical insert baffles are introduced into the annular regions of the heat exchanger.The experiment was conducted under varying flow rates and inlet temperatures to evaluate parameters such as the overall heat transfer coefficient, Nusselt number, effectiveness, and pressure drop. The results indicate that the inclusion of helical baffles significantly disrupts the boundary layer, induces secondary flow, and increases turbulence, leading to a notable enhancement in the convective heat transfer coefficient without a proportionate rise in pressure drop.This study confirms that a triple concentric tube heat exchanger with helical insert baffles not only improves thermal performance but also maintains a reasonable hydraulic efficiency, making it a promising solution for advanced thermal systems in process industries and energy recovery systems.

1. Introduction

A heat exchanger is a system utilized at dissimilar temperatures and in thermal contact to transfer thermal energy amongst two or more liquids, amongst a solid surface and a liquid, or amongst solid particles and a liquid.In most heat exchangers, heat is transferred amongstliquids through a wall. Liquids are separated by a heat transfer surface in a large number of heat exchangers and do not mix or leak ideally. These exchangers are called direct or recovered transfer modes. Conversely, the intermittent exchange of heat amongst hot and cold liquids - by accumulation and release of thermal energy through the surface or matrix of the heat exchanger - is called indirect or simply regenerative transfer. Typically, exchangers leak fluid from one fluid to another due to pressure differences and matrix / valve switching.Heating or cooling a fluid stream and vaporization or condensation of the fluid stream into one or more components are common applications. Other applications may be aimed at recovering or repelling heat, pasteurizing, fractionating, distilling, concentrating, gluing or controlling a therapeutic fluid. The heat exchange fluids are in direct contact with some heat exchangers.

Shell and tube heat exchangers, automotive coolers, condensers, evaporators, air preheaters, and cooling towers are typical examples of heat exchangers. It is often referred to as a rational heat exchanger whenever there is no phase shift in any of the heat exchange fluids. Internal sources of thermal energy may be present in the heat exchangers of electric heaters and nuclear fuel assemblies. In the heat exchanger, combustion and chemical reactions can occur, e.g. B. Boilers, combustion heaters and heat exchangers for fluidized beds.



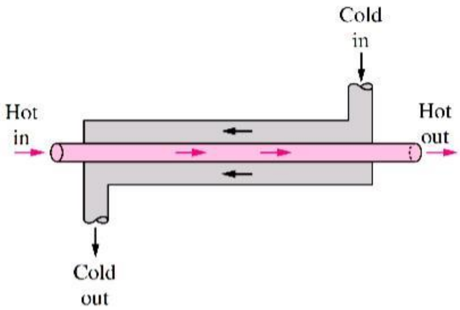


Figure 1 : Parallel flow heat exchanger   Figure 2: Counter flow heat exchanger

Two dissimilar diameter concentrate tubes (as displayed in Figure 1, called dual tube heat exchangers) form the simplest type of heat exchanger. It becomes a three-pipe heat exchanger whenever this structure is inserted into another pipe. One liquid is usually hot and two other liquids can be cold or normal and cold. The smaller tube carries a fluid in a three-tube heat exchanger while the other two fluids move through the ring amongst the other two tubes. Numerous types of configurations are possible in a three-pipe heat exchanger: All liquids are present in parallel, i. H. All hot, natural and cold liquids connect to the heat exchanger at the same end and move in the same direction. However, heat enters the opposite direction from one point of view, while normal and colder fluids enter the heat exchanger. Other arrangements may include parallel flow of hot and cold liquids and normal liquids flowing in the opposite direction, or hot and normal liquids flowing in the same direction and cold liquids flowing in the opposite direction.

The two fluids normally move perpendicular to each and every other in compact heat exchangers, and this flow arrangement is called cross flow. As displayed in Figure 3, cross flow is also referred to as unmixed and mixed flow according to the flow chart. It is said that because the plate baffles force the fluid to flow some distance amongst the ribs and prevent it from moving in the transverse direction, the cross flow is not mixed. Subsequently the liquid can now move freely through it, the cross-flow is called a mixture. Not all fluids are mixed in a vehicle's radiator. The presence of the mixture in the liquid can have a great influence on the heat transfer properties of the heat exchanger.

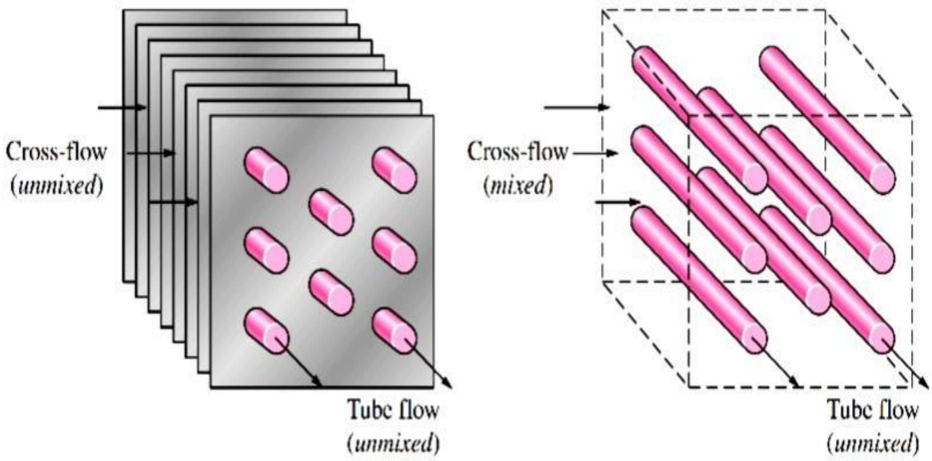


Figure 3: Dissimilar flow configurations in cross flow heat exchangers (both fluids unmixed, one fluid mixed)

2. Literature Review

The investigation was conducted by Gomaa et al. (2017) with lamellar inserts to evaluate the performance of the three-pipe heat exchanger. The main investigation design parameters include mass movement, flow pattern, temperature variation, height&spacing of the ribs. Using the FLUENT trading code, digital CFD modeling is developed&validation criteria are applied to extend the investigation parameters for additional ranges. The results displayed a significant improvement in convective heat transfer by introducing fine particles into the inner ring of the 3-tube fluid flow from the heat exchangers.Aquirea higher index with a finer tone&a lower tone. On the basis of the obtained data, a series of empirical expressions with dimensionless design parameters were considered.

Second law properties of advanced nano-liquid with nano-plate hybrid graphite nanoparticles through a three-fin tube heat exchanger (RTTHX) were investigated by Mazaheri&Bahiraei (2019). The hot nano-liquid enters the rain ring from the side, the inner tube enters the cold water,&plain water flows through the outer ring. The effects of the nanoparticle weight fraction&geometric parameters, including pitch&height, are evaluated. Depending on the power of the heat exchanger, the overall entropy rate decreases, which displays the great advantage of using nano-liquid. By increasing the fine height&decreasing the spacing amongst the ribs, the overall entropy of the nano-liquid is reduced by improving the overall RTTHX entropy production. Furthermore, at a distance of 150 mm&a sound level of 3 mm, the total heat exchange decreases by about 23%, which reduces the weight fraction from 0 to 0.1%. Also, as the weight fraction increases, the effectiveness of the second law increases because it decreases as the spacing of the ribs decreases&the height of the ribs increases. In all the conditions examined, the effectiveness of the second law scores highly.

3.Objective

Experimental&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&baffle pitch. They also developed numerical computational fluid dynamics model&did validation to extend investigation parameters with extra ranges.

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

1. To observe the rate of heat transfer of parallel flow arrangement of the triple tube heat exchanger.
2. To analyze the heat transfer rate at dissimilar values of Reynolds number in a parallel flow heat exchanger.
3. 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&details of experimental setup related to offered work.

4.Research Methodology and Experimental Setup

4.1 Research Methodology

Heat exchangers are devices that facilitate the exchange of heat amongst two liquids at dissimilar temperatures&at the same time prevent their mixing. In practice, heat exchangers are often utilized in a variety of applications, from heating&air conditioning systems in a home to chemical treatment&power generation in large systems. The heat exchangers differ from the mixing chambers in that they do not permit mixing of the two liquids involved. For example, in a car radiator, heat is transferred from the hot water flowing through the radiator tubes to the air circulating through the thin spaced plates attached to the outside of the tubes.

Heat transfer in a heat exchanger generally involves convection in each&every fluid&conduction through the wall separating the two fluids. Whenever analyzing heat exchangers, it is advisable to work with a total heat transfer coefficient (U) that takes into account the contribution of all these effects to heat transfer. The speed of heat transfer amongst the two fluids in a position in a heat exchanger depends on the amount of temperature change in that position, which changes along the heat exchanger. Whenever analyzing heat exchangers, it is generally advisable to work with the logarithmic mean temperature change (LMTD), which is an average equivalent temperature change amongst the two liquids for the entire heat exchanger.

4.2 Assumptions:

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

4.3 Experimental Setup

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

i. ID of inner pipe = 19.05 mm
ii. OD of inner pipe = 25.05 mm
iii. ID of intermediate pipe = 50.8 mm
iv. OD of intermediate pipe = 56.8 mm
v. ID of outer pipe = 76.2 mm
vi. OD of outer pipe = 82.2 mm
vii. Length of the heat exchanger or Heat Transfer length = 2.896 m

The water at room the temperature i.e. the normal water was permitted to flow through the outer pipe, the cold water was permitted to flow through inner pipe&hot water was permitted to flow through the inner annulus. To investigation the rate of heat transfer by creating obstruction in the path of fluid, the baffles having cross section of rectangular shape strips inserted on the intermediate tube. The purpose of baffles is to create an obstruction in the flow of water which will break the laminar characteristic of the flow&try to make it more turbulent, which will cause more intermixing&henceforth resulting in more heat transfer from one fluid to another which was found to be true from the observation of the pattern of the reading obtained by changing the parameters of discharge&using them in analytical calculations.

.

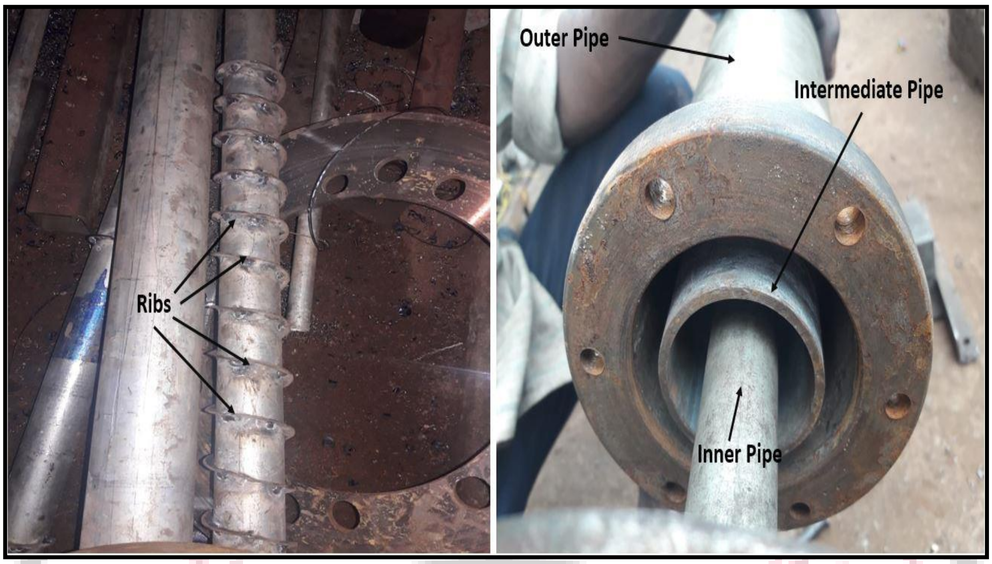


Figure 4 : Arrangement of baffles over the pipe.

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 amongst them, a flange has been welded at both the ends of the above arrangement&proper cut outs on these flanges have been made in order to send dissimilar temperature water in dissimilar pipes. Another flange was manufactured having three major holes on it&on these holes the90˚ elbows&straight pipe has been welded to make arrangement for inlet&outlet of water as displayed in Figure 4. Two such flanges were manufactured to be fixed at both ends of triple tube heat exchanger. These flanges have been joined with the flanges of the pipe with the help of nut&bolt as displayed in Figure 5.

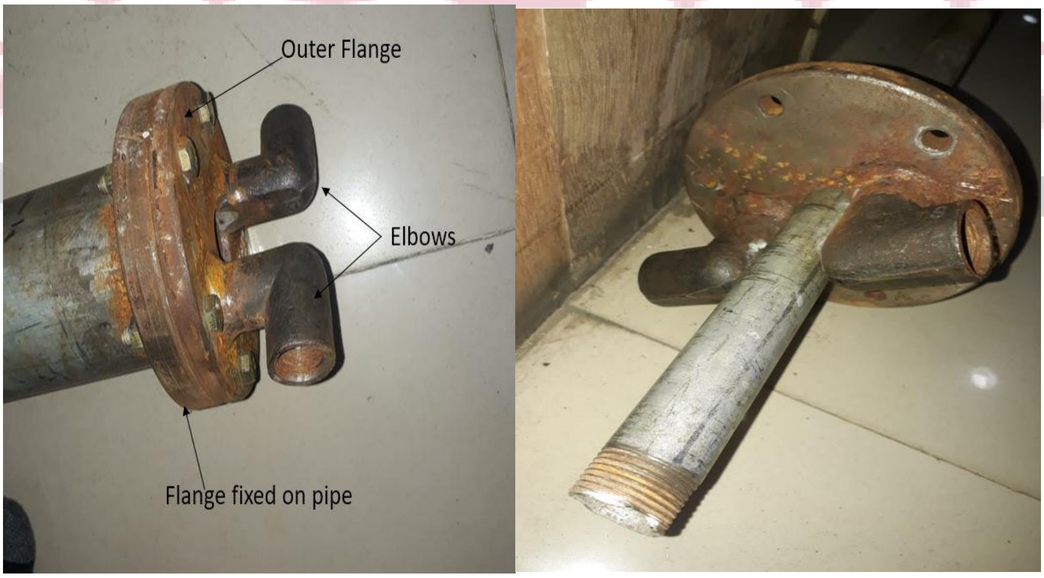


Figure 5: Arrangement of the flange with elbows&pipe of heat exchanger

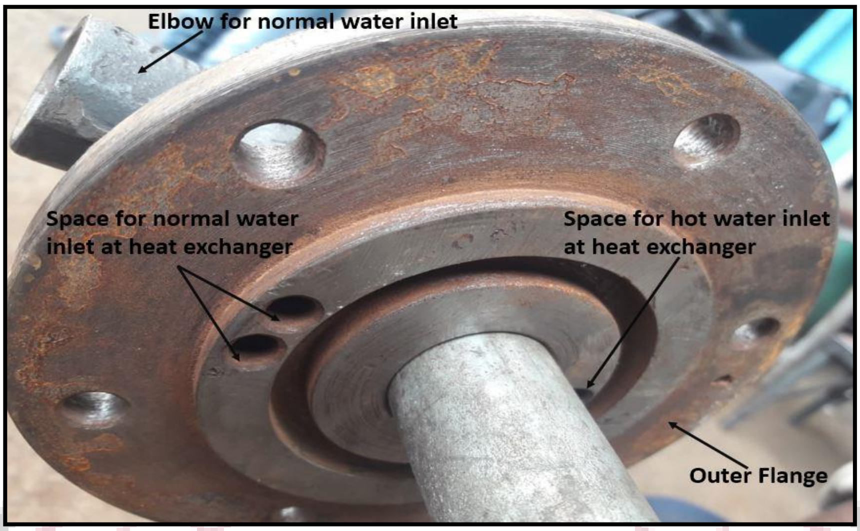


Figure 6: Arrangement of elbows&straight pipe on outer flange

To gaquireet the temperature values of fluids at inlet&outlet, the thermocouples were installed on the PVC pipes, which were fitted at all the exits&inlets of the heat exchanger. Also the temperature sensor were mounted over the PVC pipes by making a hole big enough to insert temperature sensor in it to measure the temperature of hot water, normal water&cold water both at inlet&outlet. These pipes also facilitated the fluids from dissimilar storage tanks to reach the triple tube heat exchanger. The schematic arrangement of the triple tube heat exchanger along with the other components is displayed in Figure 6.

5.Result and Discussion

5.1 Sample Calculations

The cross section area of inner tube, intermediate tube and the outer tube are 2.9x10-4 m^2, 1.51x10^{-3} $m^2$and 2.01x10^{-3} m^2respectively. The discharge taken in m^3/s whenever divided by cross section area of respective pipe will give velocity of water in m/s. With the help of velocity, the Reynolds number of flow was determined. The sample calculation of Reynolds number of hot water at outlet, flowing through intermediate pipe, whenever discharge was kept at 6.94x10-5 m^3/s, is displayed below:

$$v=\frac{6.94\ X{\ 10}^{-5}}{1.51\ X\ {10}^{-3}}=0.046\ m/s$$

$$Re=\frac{1000\ X\ 0.046\ X\ 0.02545}{0.686\ X\ {10}^{-3}}=1943.35$$

The value of dynamic viscosity varies with the variation of water temperature. The value of dynamic viscosity at dissimilar outlet temperature of hot water are taken from table 5.1After doing numerous experiments and calculating the values of Reynolds number for numerous values of gradually increasing discharge, the Nusslet number was calculated. The sample calculation of Nusselt number is displayed below:

$$Nu=\ 0.023\ X\ {(1943.35)}^{0.8}X\ {(3.91)}^{1/3}=15.416$$

5.2 Results

In the present work the experiments have been performed to understand the working of triple tube heat exchanger and also the variation temperature at inlet and outlet of heat exchanger. It has been tried to keep the errors at minimal and within acceptable limits.

The analysis has been done by studying the behavior of variation in Nusselt number by gradually increasing the Reynolds number of hot water. The same has been presented in table and plotting the same in graphs below.

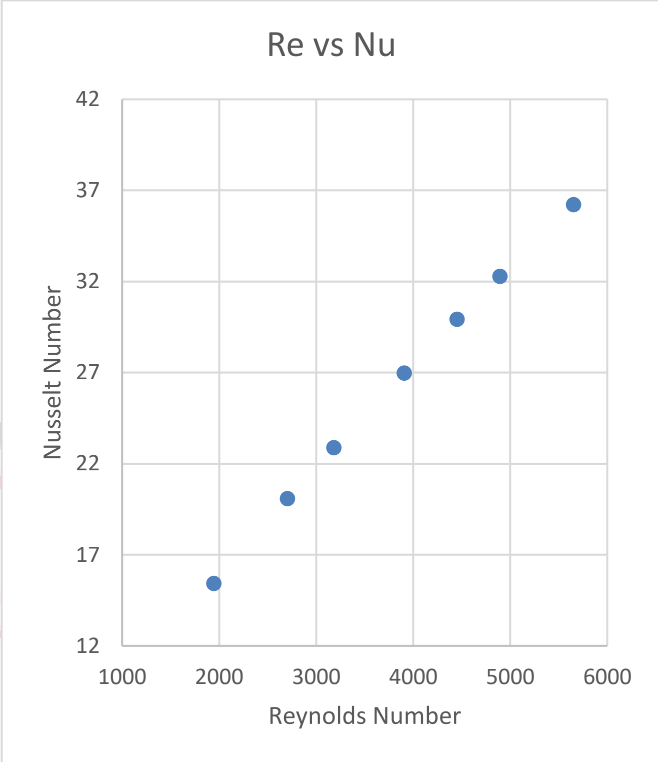


Figure 7: Variation of Reynolds number and Nusselt number

It can be realized in the Figure 7 that the value of Nusselt number is increasing as the value of Reynolds number is increased. As the flow becomes turbulent in nature and as the turbulence in the flow increases the heat transfer through convection becomes dominant over heat transfer through conduction.

The friction factor is another important parameter by which helps in analysis of triple tube heat exchanger. The investigation has been done by increasing the mass flow rate of hot water gradually and friction factor was calculated against dissimilar values of Reynolds number obtained by varying the mass flow rate. The same has been displayed by help of table and graph.

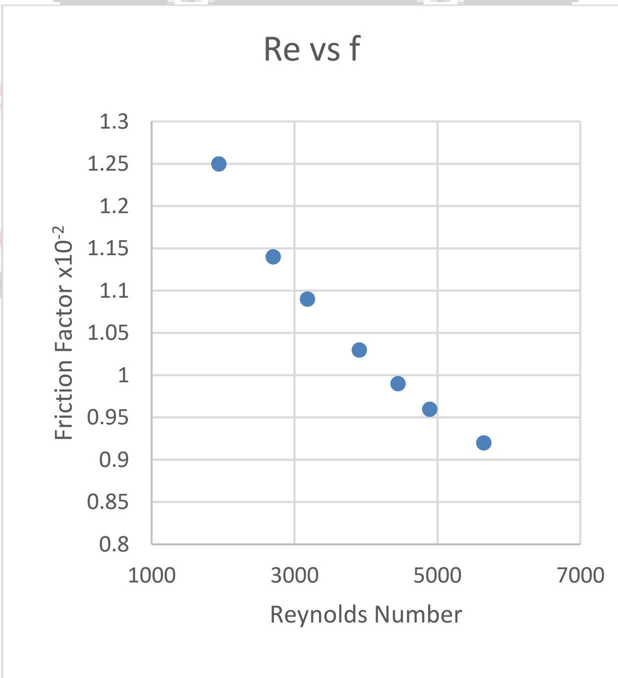


Figure 8: Variation of Reynolds number with friction factor.

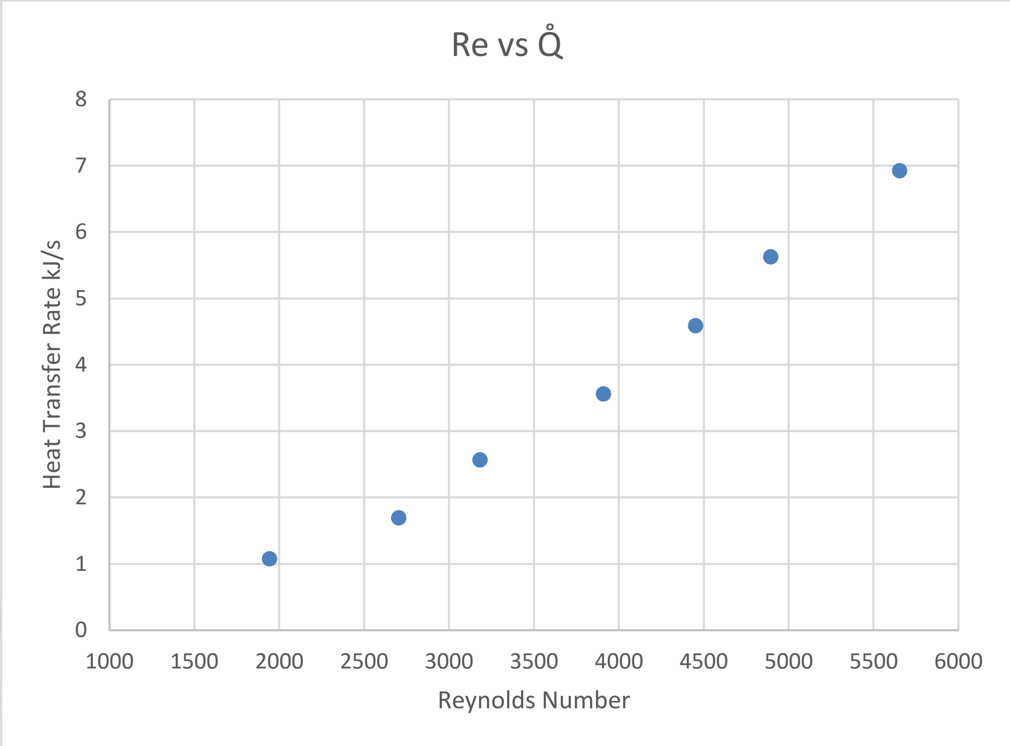


Figure 9: Reynolds number variation with rate of heat transfer

The rate of heat transfer is also getting increased by increasing the Reynolds number of hot fluid. The same can be realized from the Figure 9.

5.3 Validation

The current investigation was compared with that in the investigation conducted byGomaa 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]. Henceforth it can be said that the current investigation is validated.

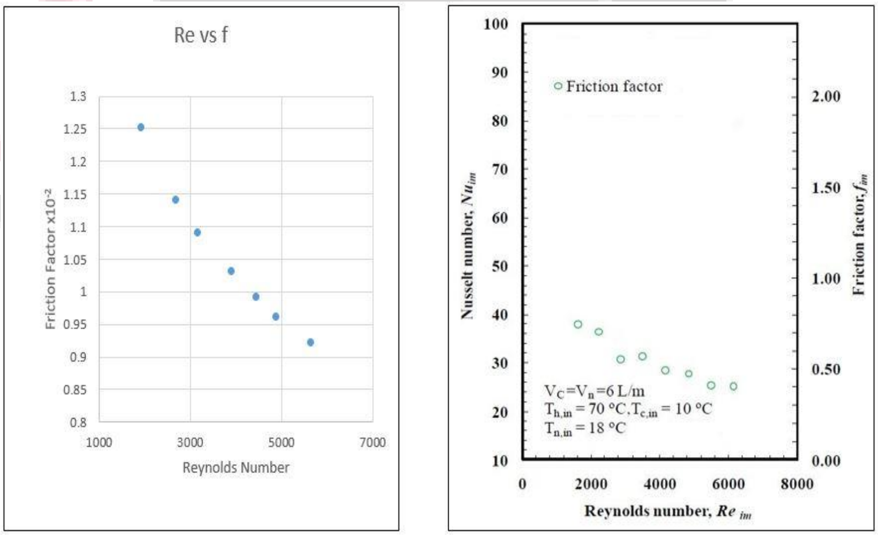


Figure 10: Comparison amongst current investigation and base paper of Re vs f

The reason for such variation of friction factor with Reynolds number is that the friction factor the relation amongst them varies inversely and henceforth as one value increases the other gets decreased which can be realized in Figure 10 for both current investigation andGomaaet. al. [1] study.

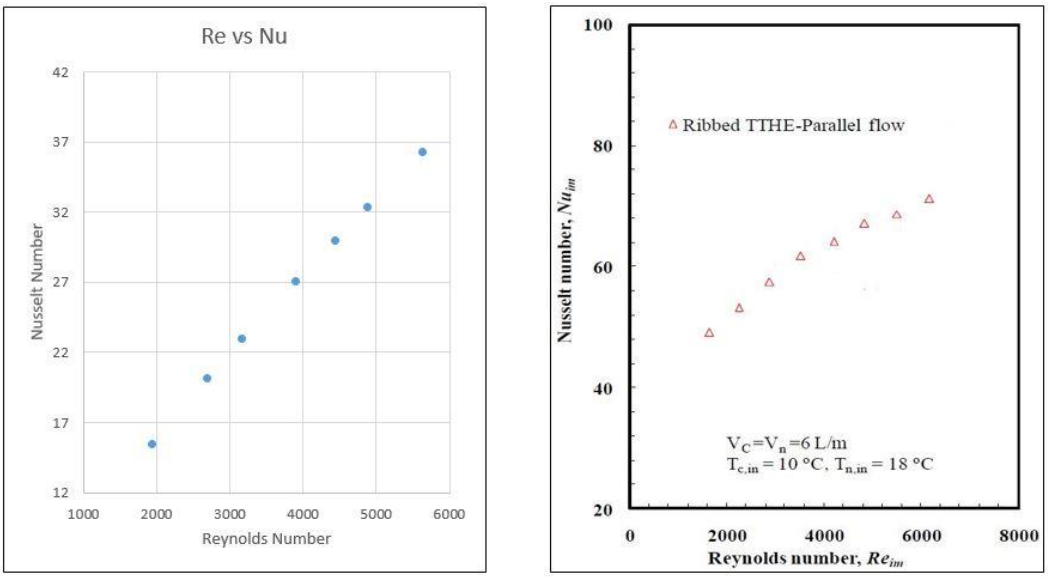


Figure 11: Comparison amongst current investigation with base paper of Re vs Nu

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 realized in both in current investigation and Gomaa's [1] investigation as displayed in Figure 11.

Conclusion

The further research which can be carried out on this same experimental setup is that the heat transfer rate at dissimilar 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 utilized for evaluating data for counter flow arrangement and can be compared with the present study. A similar setup can be designed with dissimilar values of baffle height, baffle thickness and baffle pitch and a comparative investigation can be conducted for optimum dimensions of baffle.

Reference

1. Gomaa A, Halim M, Alsaid A. Enhancement of cooling characteristics and optimization of a triple concentric-tube heat exchanger with inserted baffles. International Journal To Thermal Science 2017;120:106-120
2. Mazaheri N,Bahiraei M "Analyzing performance of a baffled triple-tube heat exchanger operated with graphenenanoplateletsnanofluidbased upon entropy generation and exergy destruction" International Communications in Heat and Mass Transfer 2019; 107:55-67.
3. Bahiraei M, Mazaheri N. Application of a hybrid nanofluid containing graphenenanoplatelet–platinum composite powder in a triple-tube heat exchanger equipped with inserted baffles. Applied Thermal Science 2019; 149:588-601.
4. AmanuelT, Mishra M. Investigation ofthermohydraulic performance of triple concentric-tube heat exchanger with CuO/water nanofluid: Numerical approach. Heat transfer Asian research 2018; 47: 974-995.
5. Touatit A, Bougriou C. Optimal diameters of triple concentric-tube heat exchangers. InternationalJournalofHeatandTechnology 2018; 36: 367-375.
6. Shahril S, quadir G. Thermo hydraulic performance analysis of a shell-and-double concentric tube heat exchanger using CFD. International Journal of Heat And Mass Transfer 2017; 105: 781-798.

7. Wen J,Gu X. Multi-parameter Optimization of Shell-and-Tube Heat Exchanger with Helical Baffles Based upon Entransy Theory. Applied Thermal Science 2018;130: 804-813
8. Wang S, Xiao J. Application of Response Surface Method and Multi-objective Genetic Algorithm to Configuration Optimization of Shell-and-tube Heat Exchanger with Fold Helical Baffles. Journal Of Applied Thermal Engineering 2018; 129: 512-520.
9. AbadiG, Kim K. Experimental Heat Transfer and Pressure Drop in a Metal-Foam-Filled Tube Heat Exchanger. Journal Of Experimental Thermal And Fluid Science 2017; 82: 42-49.
10. Kumar K, Pillai P. Numerical Analysis of Triple Concentric Tube Heat Exchanger using Dimpled Tube Geometry. Asian Journal Of Research In Social Sciences And Humanities 2016;6: 2078-2088.
11. Radulescu S, NegoiţăL. Analysis of the heat transfer in double and triple concentric tube heat exchangers. International Conference on Advanced Concepts in Mechanical Engineering 2016;147: 012148
12. Mohan D, Chaitanya P. Comparison of the overall heat transfer coefficient value of double pipe heat exchanger without and with numerous twisted inserts of dissimilar twist ratios.IOSR Journal of Mechanical and Civil Engineering 2015;12: 115-124
13. Negoita I,Onutu I. Heat Transfer Coefficient for Hydrocracked Oil Flow in Laminar Regime through an Annular Space. Revista de Chimie -Bucharest- Original Edition 2015;66:83-87.
14. quadir G, Badruddin I. Numerical investigation of the performance of a triple concentric pipe heat exchanger.International Journal of Heat and Mass Transfer 2014;75: 165–172.
15. Zuritz C. On the design of triple concentric-tube heat exchangers. Journal of Food Process Engineering 2007; 12: 113-130.
16. Saeid N, Seetharamu K. Finite element analysis for co-current and counter-current parallel flow three-fluid heat exchanger. International Journal of Numerical Methods for Heat and Fluid Flow 2006;16:324-337
17. Malinowski L,Bielski S. An analytical method for determining transient temperature field in a parallel-flow three-fluid heat exchanger. International Communications in Heat and Mass Transfer 2005; 31:683-691.
18. Ünal A. Effectiveness-Ntu Relations for Triple Concentric-Tube Heat Exchanges. International Communications in Heat and Mass Transfer 2003;30: 261-272