A Review of 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.

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 twoor 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.

1.1 Classifications of Heat Exchangers: There are different types of heat exchangers depending on the type of flow configuration, the type of heat transfer and the design features. The process designer must select the most appropriate type that meets the operational and performance requirements. Below is the list of heat transfer devices.

- **Parallel flow**
- **Counter flow**
- **Cross Flow**

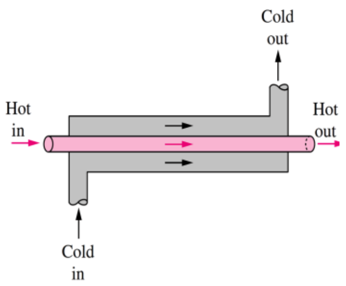

Figure 1.1: Parallel flowheat exchanger

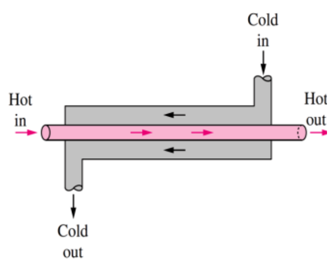

Figure 1.2: Counter flowheat exchanger

1.2 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.

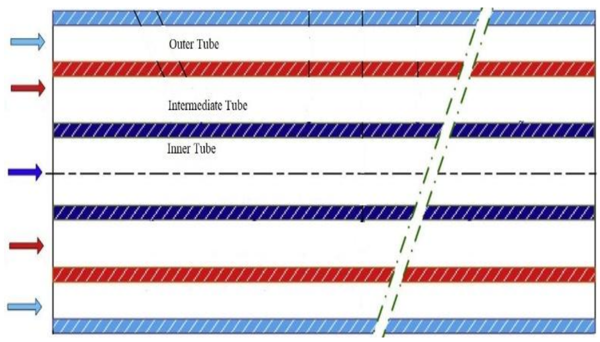

Figure 1.7: Schematic representation of a triple tube heat exchanger

II. LITERAURE REVIEW

2.1 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.

2.2 **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.

2.3 **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.

2.4 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 nano-liquids 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%.

2.5 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.

III. OBJECTIVE OF THESIS

3.1 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.

IV. RESEARCH METHODOLOGY

4.1 EXPERIMENTAL SETUP

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 flowing through the closely spaced thin plates outside attached to the tubes.

Heat transfer in a heat exchanger usually involves convection in each fluidand conduction through the wall separating the two fluids. In the analysis ofheat exchangers, it is convenient to work with an overall heat transfer coefficient (U) that accounts for the contribution of all these effects on heat transfer. The rate of heat transfer between the two fluids at a location in a heat exchanger depends on the magnitude of the temperature difference at that location, which varies along the heat exchanger. In the analysis of heat exchangers, it is usually convenient to work with the logarithmic mean temperature difference (LMTD), which is an equivalent mean temperature difference between the two fluids for the entire heat exchanger.

4.2 Assumptions:

- 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.
- Heat conduction in the tubes along axial direction is negligible.
- Changes in kinetic energy and potential energy of fluid streams are negligible.
- Fluid propertied remain constant and there is no fouling.
- The operating conditions are under steady state and the overall heat transfer coefficient remain constant.

The readings of various parameters were taken to calculate values of several quantities like Reynolds number, Nusselt number heat transfer rate. So by keeping this in account the experiments were conducted by maintaining a constant head of the water tank in order to get a constant value of discharge with an error margin of about 5%. The inlet temperature of hot water has been maintained at 45 ˚C, inlet temperature of cold water is maintained at 18 ˚C and that of normal water is maintained at 27 ˚C to 28 ˚C. There were number of experiments performed in order to study the heat transfer phenomenon by triple tube heat exchanger. The readings were taken by varying the discharge of the inlet water flow of hot water while the discharge at inlet of cold water and that of normal water were kept constant.

4.3 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

The water at room the temperature i.e. the normal water was allowed to flow through the outer pipe, the cold water was allowed to flow through inner pipe and hot water was allowed to flow through the inner annulus. To study 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 and try to make it more turbulent, which will cause more intermixing and hence 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 and using them in analytical calculations.

The baffles were made of carbon steel and having a constant height of 10 mm and thickness of 2 mm. The baffles are inclined at an angle of 90˚ over the pipe as shown in figure 4.1. A constant baffle pitch of 50.8 mm has been maintained along the length of pipe.

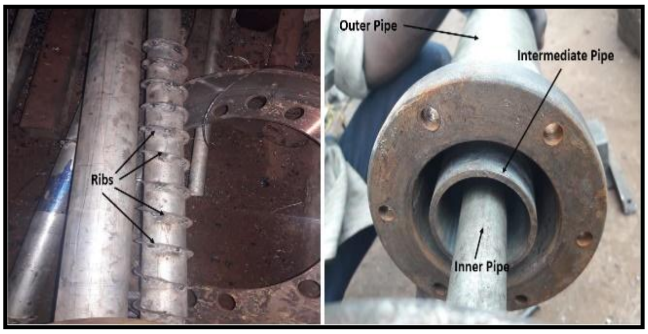

Figure 4.1: Arrangement of baffles over the pipe.

4.4 Observation Table

Table 4.1: Observations made during the experiments conducted

S No.	Discharge (m^3/s) x10^{-4}	T1 (K)	T2 (K)	T3 (K)	T4 (K)	T5 (K)	T6 (K)
1	0.694	318	291.0	301.1	314.3	292.74	302.39
2	0.966	318.7	291.1	301.4	314.5	293.85	303.45
3	1.14	318.1	290.4	301.5	312.7	295.56	304.60
4	1.40	317.7	290.6	301.7	311.6	296.38	305.00
5	1.59	316.9	292.9	301.9	310	298.33	306.44
6	1.75	318.4	291.2	301	310.7	300.32	30779
7	2.02	318.2	291.3	301.2	309.9	302.65	309.66

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. Another flange was manufactured having three major holes on it and on these holes the90˚ elbows and straight pipe has been welded to make arrangement for inlet and outlet of water as shown in Figure 4.2. 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 and bolt as shown in Figure 4.3.

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

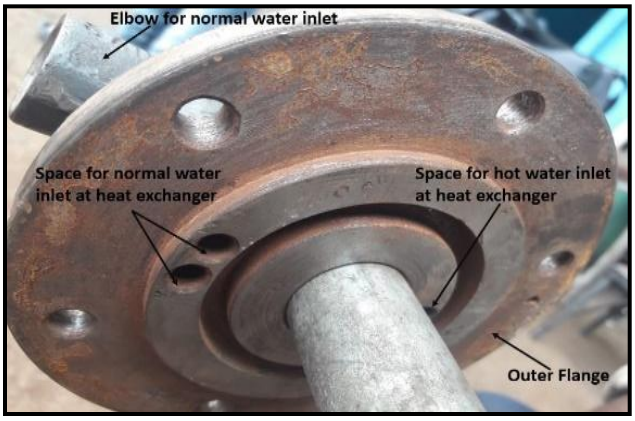

Figure 4.3: Arrangement of elbows and straight pipe on outer flange

V. RESULT AND DISCUSSION

The main focus in this thesis is the study of cooling characteristics of the intermediate tube in which the hot water is flowing. The basic equations used to calculate the thermo-fluid characteristics of triple tube heat exchanger are summarized as follows:

$\mathring{Q}_h$ = Heat transfer of hot water in kJ/s

$\mathring{Q}_c$ = Heat transfer of cold water in kJ/s

$\mathring{Q}_n$ = Heat transfer of normal water in kJ/s

$\mathring{m}_h$ = Mass flow rate of hot water in kg/s

$\mathring{m}_c$ = Mass flow rate of cold water in kg/s

$\mathring{m}_n$ = Mass flow rate of normal water in kg/s

T_{hi} = Temperature of hot water at inlet in K

T_{ci} = Temperature of cold water at inlet in K

T_{ni} = Temperature of normal water at inlet in K

T_{ho} = Temperature of hot water at outlet in K

T_{co} = Temperature of cold water at outlet inK

T_{no} = Temperature of normal water at outlet in

c_h = Specific heat capacity of hot water in kJ/kg K

c_c = Specific heat capacity of cold water in kJ/kg K

c_n = Specific heat capacity of normal water in kJ/kg K

Table 5.1: Properties of water at atmospheric pressure

Temperature [°C]	**Density (ρ) [kg/m3]**	**Dynamic Viscosity (μ) (Ns/m2)x10-3**	**Kinematic Viscosity (v) (m2/s2)x10-6**	**Specific Heat (c_p) kJ/kg.K**	**Thermal conductivity (k) [W/m K] x10-3**	**Prandtl Number (Pr)**
0	999.84	1.792	1.792	4.219	0.561	13.47
5	999.97	1.518	1.518	4.205	0.571	11.19
10	999.7	1.306	1.306	4.195	0.58	9.45
15	999.1	1.138	1.139	4.189	0.589	8.09
20	998.21	1.002	1.003	4.185	0.598	7
25	997.05	0.89	0.893	4.182	0.607	6.13
30	995.65	0.797	0.801	4.18	0.616	5.41
35	994.04	0.719	0.724	4.179	0.623	4.82
40	992.22	0.653	0.658	4.179	0.631	4.33
45	990.22	0.596	0.602	4.179	0.637	3.91
50	988.05	0.547	0.553	4.18	0.644	3.55
55	985.71	0.504	0.511	4.181	0.649	3.25
60	983.21	0.466	0.474	4.183	0.654	2.98
65	980.57	0.433	0.442	4.185	0.659	2.75
70	977.78	0.404	0.413	4.188	0.663	2.55
75	974.86	0.378	0.387	4.192	0.667	2.37

80	971.8	0.354	0.365	4.196	0.67	2.22
85	968.62	0.333	0.344	4.2	0.673	2.08
90	965.32	0.314	0.326	4.205	0.675	1.96
95	961.9	0.297	0.309	4.211	0.677	1.85
100	958.43	0.282	0.294	4.217	0.679	1.75

5.1 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.

S. No	Reynolds Number	Nusselt Number
1	1943.35	15.416
2	2703.3	20.078
3	3182.53	22.875
4	3908.73	26.963
5	4451.29	29.918
6	4894.37	32.277
7	5653.11	36.222

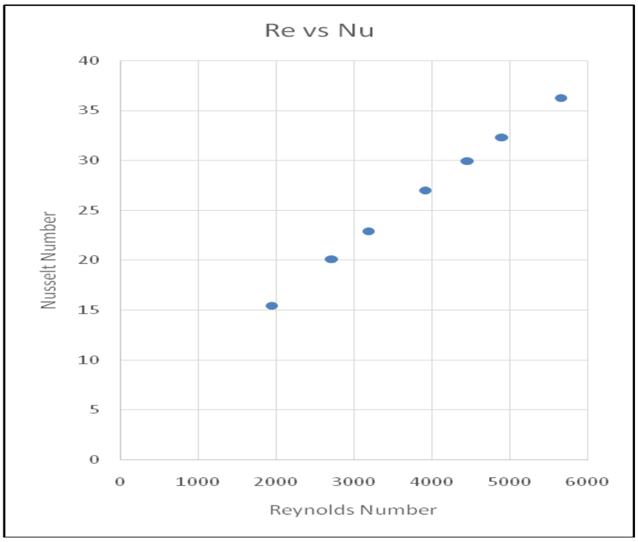

Figure 5.1: Variation of Reynolds number and Nusselt number

S. No	Reynolds Number	Friction Factor x10^{-2}
1	1943.35	1.25
2	2703.3	1.14
3	3182.53	1.09
4	3908.73	1.03
5	4451.29	0.99
6	4894.37	0.96
7	5653.11	0.92

It can be seen in the Figure 5.1 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 study has been done by increasing the mass flow rate of hot water gradually and friction factor was calculated against different values of Reynolds number obtained by varying the mass flow rate. The same has been shown by help of table and graph.

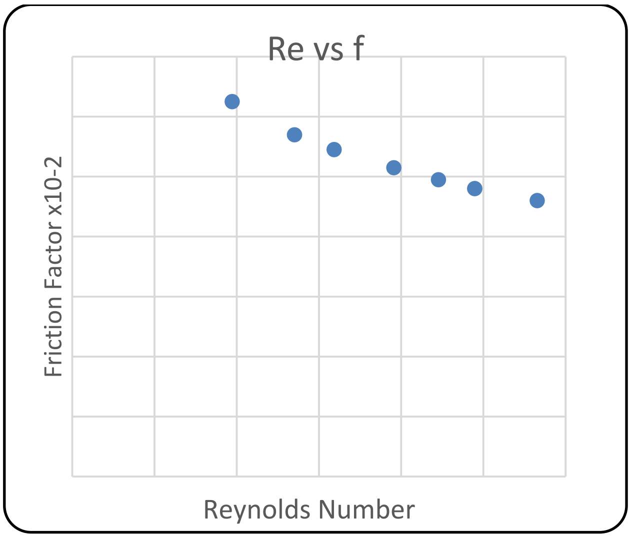

Figure 5.2: Variation of Reynolds number with friction factor.

It can be seen in Figure 5.2 that the friction factor is decreasing as the Reynolds number is increasing the friction factor is getting decreased. This type of variation implies that as the turbulence in the flow increases, the variation in the pressure drop also increase when the diameter, length of tube are constant and the density and dynamic viscosity of the fluid may get enhanced which will result the increase in friction factor.

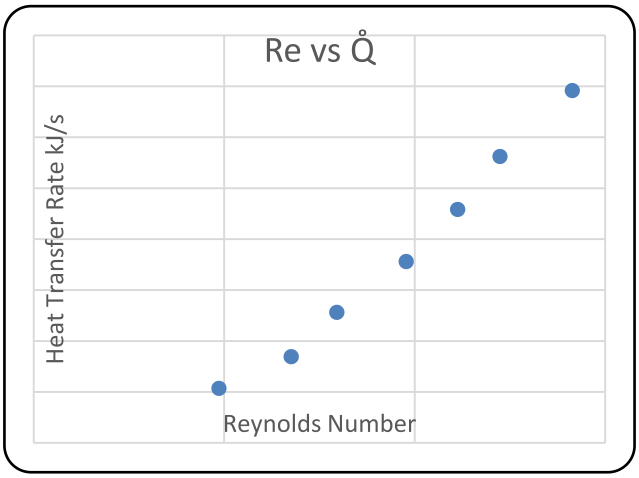

Figure 5.3: Reynolds number variation with rate of heat transfer

5.2 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.

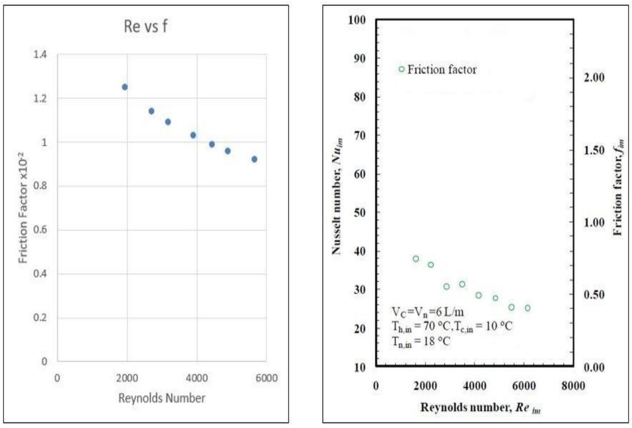

Figure 5.4: Comparison between current study and base paper of Re vs f

VI. CONCLUSIONS

In current work, the experiments have been performed on triple tube heat exchanger with 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 (Q̊) 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.

The conclusionwhich can be drawn from the study is,as the discharge of the fluid increases, the mass flow rate will increase due to which the velocity of the fluid increase, which will result in increase of Reynolds number. As the Reynolds number increases, the turbulence in the flow will increase which will cause the intermixing of the fluid. Higher the rate of intermixing, higher will be the value of heat transfer due to convection.

Future Scope

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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