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Parametric Analysis of Shell and Tube Heat Exchanger

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Abstract: The present work investigated the effect of mass flow rate, hot and cold fluid temperature on total heat transfer and effectiveness for shell and tube heat exchanger. In addition, the effect of Reynolds number and type of fluid on heat transfer coefficient and effectiveness was studied. Increasing Reynolds number by 500 from 7000, 8% increasing in heat transfer coefficient has been observed. While 7% increase in Reynolds number, effectiveness has been increases by 5%. Nusselt number change shows higher effect on effectiveness for shell side as compared to tube side.

A MATLAB program has been formulated to calculate the result by changing different parameters. During experimental observation, the rate of heat transfer is 143.74 kW and effectiveness of shell and tube heat exchanger is 0.50. The optimum heat transfer through shell and tube heat exchanger had been achieved at 0.0084 m^2 surface area of tube and 27 number of tube.

1. Introduction

Shell and tube heat exchanger is a common types of exchangers widely used in the industrial processes. It consists of a vessel inside which a number of tubes are situated. Heat transfers takes place between these tubes and through tube walls. Shell and tube exchangers are manufacture in different dimension to obtained different flow rate. The rate of heat transferred is mainly depends upon fluid temperature and mass flow rate. In such type of heat exchangers, heat transfer takes place in a transient manner through separating wall.

Dubey and Verma investigated experimentally the performance and heat transfer through wall of shell & tube type heat exchangers [1]. Patel and Rao explored the optimization of design parameter of shell and tube heat exchanger under the consideration of economic view point. The main purpose of given paper to minimize the total annual cost type of heat exchanger. During the optimization baffle spacing, shell internal and external diameter is considered. For optimization, triangular and square types of layouts are considering [2]. Mukharji investigated the effect of pressure drop on performance of shell and tube heat exchanger. The author also discussed the design parameter for checking the effectiveness of shell and tube heat exchanger. Computer software is used to optimize the thermal design parameter [3]. Ayub had calculated the heat transfer coefficient of shell and tube heat exchanger by new chart method in a TEMA style [4]. Haran proposed to analysis the shell and tube heat exchanger by using two type of fluid (Water and oil type). For high pressure operation, mainly medium weighted shape of shell and tube heat exchanger is used. Pro- E is used to design the performance parameter of such type of heat exchanger and thermal analysis is done by ANSYS software. Result is compared with theoretical formulae [5]. Babu and Munawarb had been used the genetic algorithms to determine the cross-sectional area of shell and tube heat exchange [6]. Gopichand et al. had analyzed the thermal aspect of a counter flow of water-oil type shell and tube heat exchanger [7].

On the basis of above mention literature review, it is observed that most of the research described the thermal analysis and design aspect of shell and tube heat exchanger. The present paper aim is to investigate the influences of different parameters on Shell and tube heat exchanger.

Shell and Tube Heat Exchangers consists of a number of tubes, which is situated inside the shell. In such type of heat exchanger, there is flexibility to varying the temperature and pressure reading to determine the result. It is more popular heat exchanger and widely used in industry. Figure 1 illustrates a schematic diagram of shell & tube heat exchanger. During the exchange of heat through shell walls, one fluid flow through the tubes and other fluid is flow over the tubes. The fluids can be flow either in same direction i.e parallel flow arrangement or opposite direction i.e counter flow arrangement to transfer of the heat.

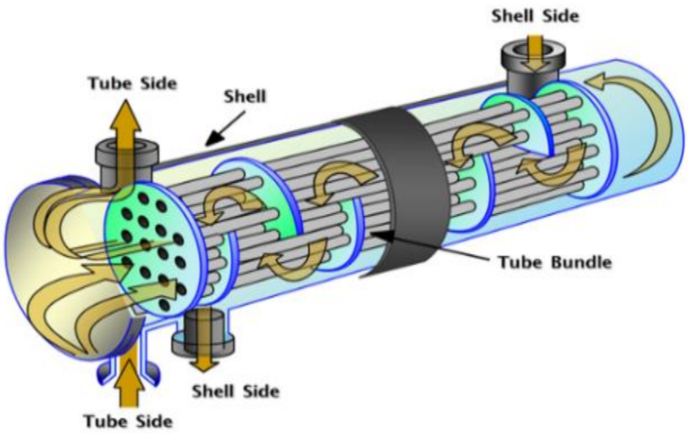

Fig 1: Schematic Diagram of Shell & Tube Heat Exchanger

2. Fabrication

Fabrication of shell and tube heat exchanger was a complicated process and even though our work has explained below: According to design data for dimension of shell and tube heat exchanger, the tube materials were purchased. Initially, the dimensions of the shell was marked on the sheet metal. So the sheet metal is cut of required shape. After that, the metal sheet is rolled into a cylindrical form of radius 71 mm. TIG welding is done to join the ends. In such a way, the shell type heat exchanger is constructed. During the fabrication of heat exchanger, copper tube has to be folded into a helical form. For supporting process, the spiral type tube is placed on the either sides of the shell. For the measurement of mass flow rate of fluid, the inlet and outlet passage hole is formulated. Due to improper bending of spiral copper tube, there is problem for measurement of different parameter. So construction of shell and tube heat exchanger is according to design parameter properly. Different mounting arrangement is attached to given heat exchanger for proper functioning. Emersion rod is attached to given configuration for heating of cold fluid. Temperature sensor is attached for measurement of temperature of hot and cold fluid. Rotameter is used for measurement of mass flow rate of fluid.

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3. Selection of Process Parameter and Range

Diameter of the inner tube di = 8 mm
Diameter of the outer tube do= 9 mm
No. Of tubes: 64
Thickness of the shell: 0. 5mm
Length of tubes: 260 mm
External diameter of the Shell: 142mm
Internal diameter of the Shell: 134 mm
Length of Shell: 230 mm
Number of turns on the tube N= 6

3.1 Flow calculations

Inlet temperature of hot fluid T_{h1} =65°C
Exit temperature of hot fluid T_{h2} =51°C
Inlet temperature of cold fluid T_{c1} =29°C
Exit temperature of cold fluid T_{c2} = 41°C
Specific heat of hot fluid c_h=4180J/kg K
Specific heat of cold fluid c_c=4180J/kg K
Overall heat transfer coefficient U=1600W/Km^2

3.2. Numerical Analysis

A number of methods are used for designing of Shell and tube heat exchangers. In general, Kern's method or Bell-Delaware method are used for designing and analysis of heat exchanger. For design aspect, Kern's method is mostly used. But Bell-Delaware method is more accurate for finding the effectiveness and mass flow rate. Basically conservative results are obtained by both methods. Heat transfer coefficient can be calculated by the help of non-dimensional number like grashoff number, Reynolds number and Nusselt number. In this paper, shell and tube heat exchanger with counter flow of fluid is consider and the temperature of hot fluid is changed from 65^0 C to 45^0 C . For calculation of different parameter of result, Kern's method is used.

For the calculation of hot and cold fluid temperature, energy balance equation is used. Mathematically energy balance equation may be written as:

$$Q = m_C \times C_C \times \Delta T_C = m_h \times C_h \times \Delta T_h \qquad (1)$$

The expression of LMTD can be written as:

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{Ln(\Delta T_1/\Delta T_2)} = \frac{(T_{h1} - T_{C2}) - (T_{h2} - T_{C1})}{Ln((T_{h1} - T_{C2})/(T_{h2} - T_{C1}))} \qquad (2)$$

The amount of heat transfer has been calculated by following equation:

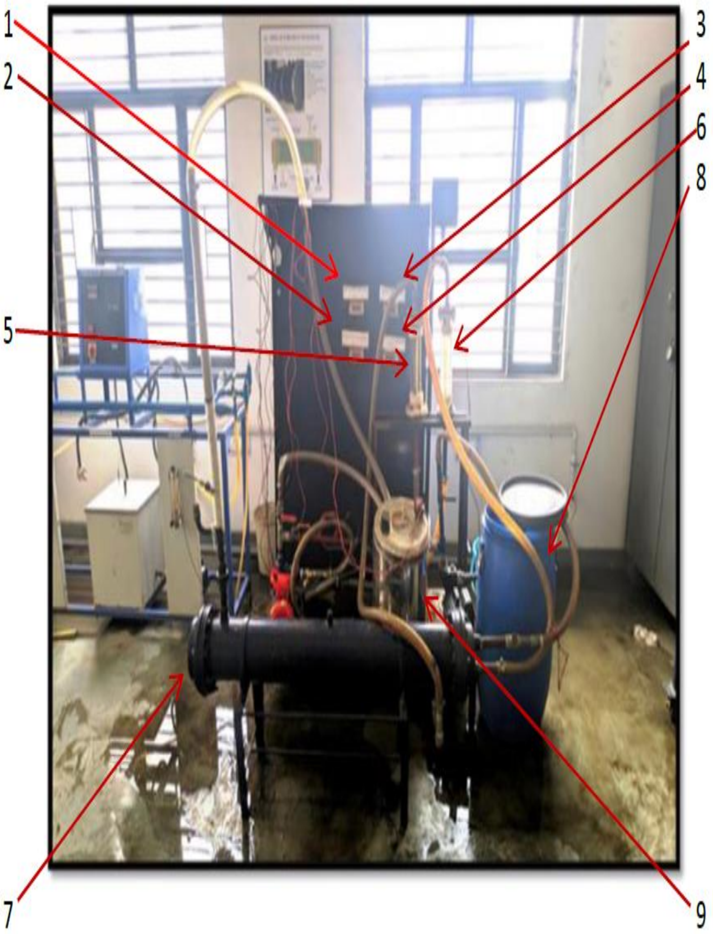
$$Q = UA\Delta T_m \qquad (3)$$

The Effectiveness of heat exchanger is calculated by the following empirical relation:

$$\in = \frac{C_{\max} \times (T_{h1} - T_{h2})}{C_{\min} \times (T_{h1} - T_{C1})} \qquad (4)$$

3.3 Experimental Setup And Observations

A shell and tube heat exchanger with two-pass was constructed and observation is taken. The observation was conducted and effectiveness of shell and tube heat exchanger has been determined by changing the mass flow rate of cold fluid. Fig 2 shows the schematic diagram of Experimental Set-up of Shell & Tube Heat Exchanger. During the observation, input and output temperatures of hot fluid and cold fluid, mass flow rate, and velocity of fluid is measured. The reading of different measured value is represented in Tables 1 and 2.



1. Hot Fluid Inlet Temperature Sensor
2. Hot Fluid Outlet Temperature Sensor
3. Cold Fluid Inlet Temperature Sensor
4. Cold Fluid Outlet Temperature Sensor
5. Hot Fluid Rotameter
6. Cold Fluid Rotameter
7. Shell and Tube Heat Exchanger with 2 pass
8. Cold Fluid storage tank
9. Hot Fluid Storage Tank

Fig 2: Experimental Set-up of Shell & Tube Heat Exchanger

4. Results and Discussion

The experiment was performed on shell and tube type heat exchanger for determination of heat transfer performance. During the observation, the mass flow rates of hot fluid as well as flow rate of cold fluid had been changed. Initially the mass flow rate of the hot fluid is taken as constant and the mass flow rate of the cold fluid is varied. During observation, the temperature of hot fluid is taken as 64^{0}C and 65^{0}C. During the observation different mass flow rate of cold fluid such as 0.168, 0.182, 0.196, 0.21, 0.238 and 0.252 kg/sec is taken. For each mass rate of hot fluid, the LMTD had been calculated.

Table1: Mass flow rate and temperature of hot and cold fluid at inlet and outlet

S. NO.	Mass flow rate of hot fluid (lph)	Mass flow rate of cold fluid (lph)	Mass flow rate of hot fluid (kg/sec)	Mass flow rate of cold fluid (kg/sec)	Hot water inlet temp. (°C)	Cold water inlet temp. (°C)	Hot water outlet temp. (°C)	Cold water outlet temp. (°C)	θ1 (°C)	θ2 (°C)	LMTD (°C)
1	500	600	0.14	0.168	65	29	51	40.67	24.333	22	23.147

2	500	650	0.14	0.182	65	28	50	39.54	25.461	22	23.688
3	500	700	0.14	0.196	65	28	48	40.14	24.857	20	22.340
4	500	750	0.14	0.21	64	28	45	40.67	23.333	17	19.999
5	500	800	0.14	0.224	64	27	47	37.63	26.375	20	23.040
6	500	850	0.14	0.238	64	27	51	34.65	29.352	24	26.586
7	500	900	0.14	0.252	64	27	52	33.67	30.333	25	27.580

Table2: Variation of total heat transfer, effectiveness, NTU, Prandtl number and Nusselt number

S. NO.	Q (Total Heat Transfer) kW	Velocity (m/sec)	Reynolds Number	C_h	C_c	Effectiveness	NTU	Prandtl Number	Nusselt Number
1	8.232	0.8355	7510	0.588	0.7056	0.4666	0.628608	0.0062508	6.3763
2	8.82	0.9052	8136	0.588	0.7644	0.5270	0.74871	0.0062508	6.7979
3	9.996	0.9748	8762	0.588	0.8232	0.6432	1.03070	0.0062508	7.2131
4	11.172	1.0444	9388	0.588	0.882	0.7916	1.56861	0.0062508	7.6225
5	9.996	1.1140	10014	0.588	0.9408	0.7351	1.32853	0.0062508	8.0264
6	7.644	1.1837	10640	0.588	0.9996	0.5972	0.90955	0.0062508	8.4252
7	7.056	1.2533	11266	0.588	1.0584	0.5837	0.87655	0.0062508	8.8194

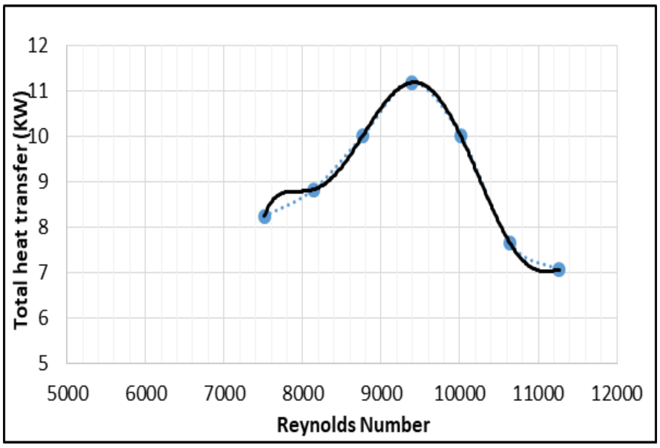


Fig 3: Variation of Overall heat transfer with Reynold's number

Fig. 3 shows the variation of total heat transfer with Reynold's number. From the graph, it is seen that, initially total heat transfer has been increased with increase of Reynold's number and after that heat transfer decreases. Heat transfer is mainly dependent on thermal conductivity of tube material and convective heat transfer of fluid. When the value of Reynold's number will increase then the nature of fluid will be changed from laminar to turbulent and Flow velocity of fluid has been also increased. Therefore the rate of heat transfer between the fluids will rapidly increase. Further increase of Reynold's number , which ultimately decreases heat transfer rate, due to less time of contact between fluid and tube material. The thickness of the boundary layer deceases with increase in Reynolds number. Hence the value of temperature gradient will increase leading to lower heat transfer.

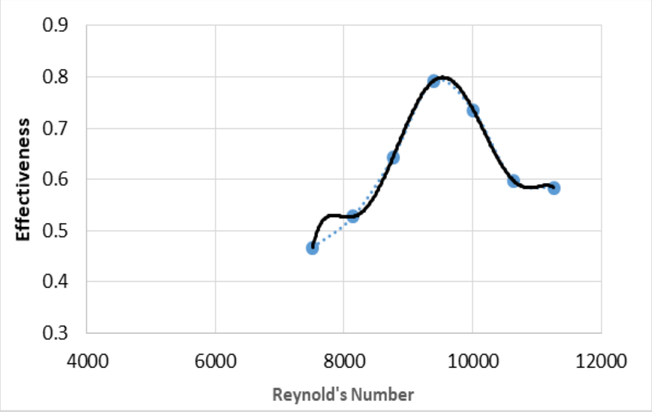


Fig 4: Variation of Effectiveness with Reynold's number

Fig 4 shows the variation of effectiveness with respect to Reynold's number. For enhancement of effectiveness of heat exchanger, Reynold's number can play an important role by increasing velocity and heat transfer between hot and cold fluid . It represents that when Reynolds number increased by 1.28%,then result increasing in effectiveness on tube side by 22%. From the graph, it is observed that initially effectiveness increases with increase of Reynold's number and after that effectiveness decreases due to variation of temperature of hot and cold fluid after mixing. This phenomena has been occurs due to rapid growth of boundary layer after the vicinity of tube surface. And flow will occurs along the center line of tube . therefore velocity is maximum at center line of tube. When the velocity of fluid increases, then momentum of flowing fluid is also increasing along axial direction and then Reynolds number is also increased. Due to interaction between shear stress and mass flow rare, friction coefficient of the tube decreases .At the end of the tube at high Reynolds, fluid has enough time to get the heat. Therefore effectiveness will be decrease further.

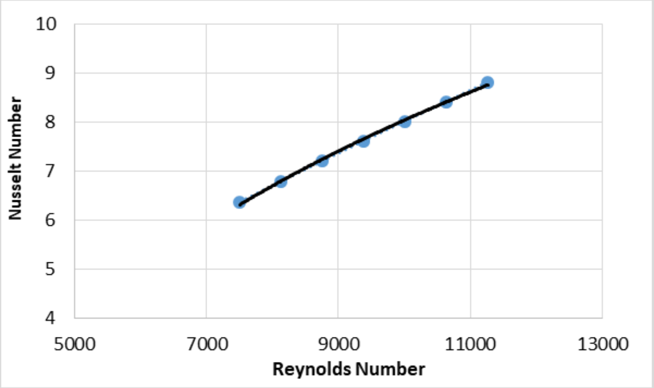


Fig 5: Variation of Nusselt Number with Reynold's number

Fig. 5, shows that variation of non-dimensional number i.e Nusselt number with respect to Reynolds number.Nusselt number show that how much the heat is transferred due to fluid motion as compared to the heat transferred by fluid by the process of conduction. It is also shows that there is linear relation between Nusselt Number and Reynolds Number. With increases of Reynolds Number, the Nusselt number is also increases due to more heat is transfer by convection process as compared to conduction process. Due to difference in aspect ratio, Nusselt number scattered more after the value of Reynolds numbers is above 7500. When the value of Reynolds number is lies between 7500 < Re < 11200, then the wake transition and the shear-layer transition regimes development is more. Mainly there are two factor (i.e temperature and Reynolds number) affecting the Nusselt number highly. Quantitative analysis on the basis of mainsion two factors, it is concluded that there is linear variation between Nusselt number and Reynolds number.

Conclusions

Based on the results presented in this work, the following conclusions have been drawn**.**

1) This analysis investigated the effect of hot fluid temperature, Cold fluid temperature and mass flow rate on total heat transfer and effectiveness for shell and tube heat exchanger.
2) The study concluded that as mass flow rate increases, the total heat transfer rate as well as effectiveness increases. Increasing Reynolds number by 500 from 7000, 8% increasing in heat transfer rate has been observed. While 7% increase in Reynolds number, effectiveness has been increases by 5%.
3) Initially effectiveness of heat exchanger is increases with increases of velocity of flow of fluid and after that effectiveness have been decreases due more heat transfer at high velocity.
4) On the basis of experimental observation, the amount of heat transfer is lies between 7.05 to 11.1 Kw. and the effectiveness of heat transfer is lies between0.46 to 0.79.
5) Shell and tube heat exchanger's effectiveness is maximum at Reynolds Number of 7933.

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