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Journal of Scientific and Engineering Research, 2024, 11(6):1-9

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Experimental analysis of performance characteristics of a single shell two tube pass heat exchanger

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Abstract In industries there are various processes in which heat transfer takes place such as a nuclear power plant or chemical processing units. There is a need for transfer of heat from one fluid to the other. This can be done very efficiently with the help of heat exchangers. Heat exchangers are the devices which exchange heat between two or more fluid streams at different temperatures. Present study focuses on the working, constructional details and heat recovery of a single shell and two tube pass heat exchangers. This internship is intended to analyse the performance of heat exchangers by optimizing the parameters such as hot and cold fluid flow rates to obtain the maximum heat transfer rate. In the present study, we analyzed the setup theoretically at various hot fluid inlet temperatures, mass flow rate of hot fluid and mass flow rate of cold fluid to analyse the various parameters such as outlet temperature of hot fluid, outlet temperature of cold fluid, inner side heat transfer coefficient, outer heat transfer coefficient, overall heat transfer coefficient, effectiveness, NTU of a single shell and two tube pass heat exchangers.

Keywords performance characteristics, heat transfer coefficient, heat exchanger, NTU

1. Introduction

1.1 Background:

The process of heat exchange between two fluids that are at different temperatures and separated by a solid wall occurs in many engineering applications. The device used to implement this exchange is termed a heat exchanger and specific application may be found in space heating and air conditioning, power production, waste heat recovery and chemical processing. There are various parameters which governs the heat exchange process some of which are mass flow rates of hot and cold fluid and inlet conditions of the hot and cold fluid. Depending upon the variance of these parameters, dependent variables such as effectiveness, heat transfer coefficient, and the outlet temperatures of the hot and cold fluid vary.

2. Literature Review

2.1 Introduction to Heat Exchangers

Heat exchangers are devices used to transfer heat between two or more fluid streams at different temperatures. Heat exchangers find widespread use in power generation, chemical processing, electronic cooling, air conditioning, refrigeration and automotive applications. It can also be defined as equipment which transfers energy from a hot fluid to a cold fluid with maximum rate and minimum investment and running cost.

2.2 Various Types of Heat Exchangers

Direct Contact Heat Exchangers: In a direct contact or open heat exchanger the exchange of heat takes place by direct mixing of hot and cold fluids and transfer of heat and mass takes place simultaneously. The use of such units is made under conditions where mixing of two fluids is either harmless or undesirable. Eg. Cooling Towers, Jet Condensers

Indirect Contact Heat Exchanger: In this type of heat exchanger the heat transfer between two fluids could be carried out by transmission through wall which separates the two fluids. This type includes regenerators and recuperators.

Parallel Flow Heat Exchanger: In parallel flow heat exchanger the two fluid streams travel in same direction. The two streams enter at one end and leave at the other end.

Counter Flow Heat Exchanger: In counter flow heat exchanger the two fluid streams travel in opposite direction. The hot and cold fluid enters at opposite ends. This type of heat exchanger gives maximum heat transfer for a given surface area.

Cross flow Heat Exchanger: In this type of heat exchanger the two fluids cross one another in space usually at right angles.

Concentric Tube Heat Exchanger: In these type two concentric tubes are used each carrying one of the fluids. The direction of flow may be parallel or counter flow.

Shell and Tube Heat Exchanger: This type of heat exchanger one of the fluids flow through a bundle of tubes enclosed by a shell. The other fluid is forced through a shell and it flows over the outside surface of the tubes.

Multiple Shell and Tube Pass Heat Exchanger: The shell side fluid is forced to flow back and forth across the tube by baffles. Multiple tube passes exchangers are those which reroute the fluid through tubes in the opposite direction.

Compact Heat Exchanger: They have very large surface area per unit volume of the exchanger. These are generally employed when heat transfer coefficient associated with one of the fluids is much smaller than the other fluid.

Condensers: In a condenser the condensing fluid remains at constant temperature throughout the exchanger while the temperature of colder fluid gradually increases from inlet ton outlet. The hot fluid loses latent part of the heat which is accepted by the cold fluid.

Evaporators: In this case the boiling fluid (cold fluid) remains at constant temperature while the temperature of hot fluid gradually decreases from inlet to outlet.

3. Methodology

To attain the objectives of said work, initially a theoretical model has been developed to analyse the performance of shell and tube heat exchanger and practical study has been carried out on setup in the laboratory. Details of the study are covered in below section

3.1 Theoretical Analysis:

The goal of heat exchanger design is to relate the inlet and outlet temperatures, the overall heat transfer coefficient and the geometry of the heat exchanger to the rate of heat transfer between the two fluids. The two most common heat exchanger design problems are those of rating and sizing.

We will begin first, by discussing the basic principles of heat transfer for a heat exchanger. We may write the enthalpy balance on either fluid stream to give:

$$Q_c = m_c(h_{c2} - h_{c1})$$
$$Q_h = m_h(h_{h1} - h_{h2})$$

For constant specific heats with no change of phase, we may also write

$$Q_c = m_c c_{pc}(T_{c2} - T_{c1})$$
$$Q_h = m_h c_{ph}(T_{h1} - T_{h2})$$

There are two methods for the analysis of heat exchangers. One is known as the Logarithmic Mean Temperature Difference Method and the other is Effectiveness- Number of Transfer Units Method.

In the LMTD Method all the temperatures such as cold fluid inlet, cold fluid outlet, hot fluid inlet, hot fluid outlet is known. With the help of these temperatures total heat transferred between the two fluids is calculated.

In the second method the inlet temperatures of the hot and cold fluid are known and the outlet temperatures of the hot and cold fluid is found out. After calculating the unknown temperatures, the total heat transferred is calculated based on enthalpy balance.

In our study we have varied the inlet temperatures of the hot fluid from 40°C to 90°C and then we have varied the mass flow rates of the hot fluid and cold fluid. We have then analysed the theoretical results

3.1.1 Logarithmic Mean Temperature Difference Method (LMTD Method)

Logarithmic Mean Temperature Difference is defining as the temperature difference which, if constant, would give the same rate of heat transfer as actually occurs under variable conditions of temperature difference. This method is used when both the inlet and outlet conditions are specified.

Assumptions:

1. The overall heat transfer coefficient U is constant.
2. The flow conditions are steady.
3. The specific heats and mass flow rates of both fluids are constant.
4. There is no loss of heat to the surroundings, due to the heat exchanger being perfectly insulated
5. There is no change of phase either of the fluid during the heat transfer.
6. The changes in potential and kinetic energies are negligible.
7. Axial conduction along the tubes of the heat exchanger is negligible.

The logarithmic mean temperature difference is derived in all basic heat transfer texts. It may be written for a parallel flow or counter flow arrangement. The LMTD has the form:

Where Δ T1 and ΔT2 represent the temperature difference at each ends of the heat exchanger, whether parallel or counter flow. The LMTD expression assumes that the overall heat transfer coefficient is constant along the entire flow length of the heat exchanger. If it is not, then an incremental analysis of the heat exchanger is required. The heat transfer rate for a Cross flow heat exchanger may be written as,

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$$

$$Q = FUA\Delta T_{LMTD}$$

3.1.2 ε - NTU Method :(Effectiveness- Number of Transfer Units Method)

Effectiveness- NTU Method: The effectiveness or number of transfer unit methods was developed to simplify a number of heat exchange design problems. Effectiveness is defined as the ratio of actual transfer rate to the maximum possible heat transfer rate if there were infinite surface area. Heat exchanger effectiveness depends on whether the hot fluid or cold fluid is a minimum fluid. This method is employed when the inlet temperatures of the hot and cold fluid are known and the outlet conditions are not known.

The effectiveness or number of transfer unit methods was developed to simplify a number of heat exchange design problems. Effectiveness is defined as the ratio of actual transfer rate to the maximum possible heat transfer rate if there were infinite surface area. Heat exchanger effectiveness depends on whether the hot fluid or cold fluid is a minimum fluid.

If the cold fluid is the minimum fluid, then effectiveness is defined as

$$\varepsilon = \frac{C_h(T_{h1} - T_{h2})}{C_{min}(T_{h1} - T_{c1})}$$

And if the hot fluid is minimum fluid then effectiveness is defined as

$$\varepsilon = \frac{C_c(T_{c2} - T_{c1})}{C_{min}(T_{h1} - T_{c1})}$$

Thus, we may now define the heat transfer rate as

$$Q = \varepsilon C_{min}(T_{h1} - T_{c1})$$

It is now possible to develop expressions which relate the heat exchanger effectiveness to another parameter referred to as the number of transfer units (NTU). The value of NTU is defined as:

$$NTU = \frac{UA}{C_{min}}$$

For convenience the Effectiveness –NTU relationships are given for a simple double pipe heat exchanger for parallel flow and counter flow:

Parallel Flow

$$\varepsilon = \frac{1 - exp[-NTU(1 + C_r)]}{1 + C_r}$$

$$NTU = \frac{-ln[1 - \varepsilon(1 + C_r)]}{1 + C_r}$$

Counterflow

$$\varepsilon = \frac{1 - exp[-NTU(1 - C_r)]}{1 + C_r exp[-NTU(1 - C_r)]}\ , when\ C_r < 1$$

$$\varepsilon = \frac{NTU}{1 + NTU}\ , when\ C_r = 1$$

The Effectiveness –NTU relationships are given for a single shell two tube pass heat exchanger

$$\varepsilon = \frac{2}{1 + C^* + (1 + C^{*2})^{1/2} \frac{1 + exp\,[-NTU(1 + C^{*2})^{1/2}]}{1 - exp\,[-NTU(1 + C^{*2})^{1/2}]}}$$

3.2 Experimental Setup:

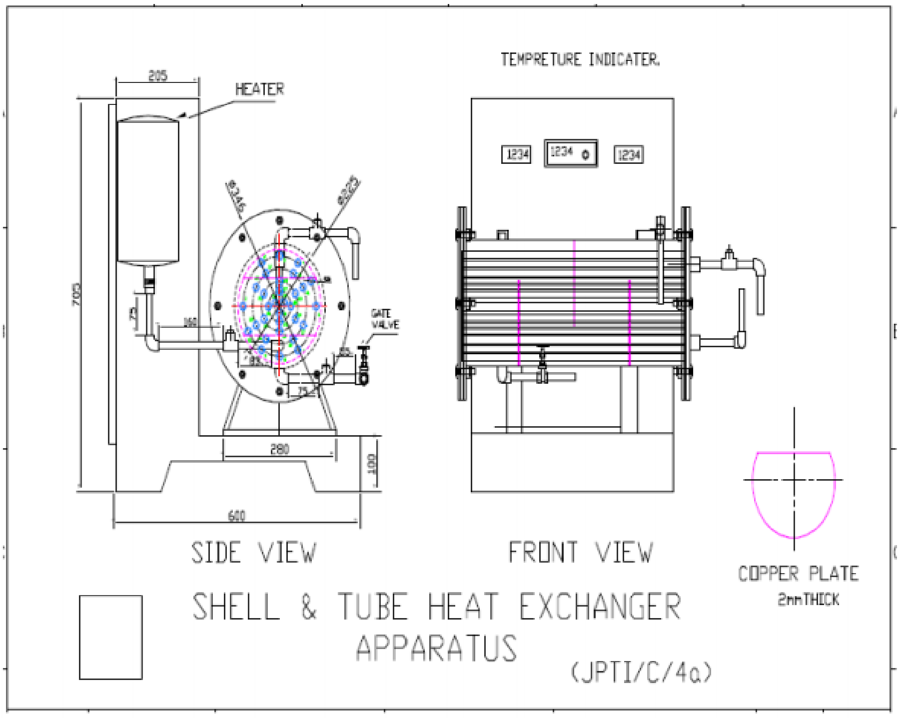

Figure 3.1: Experimental Setup

3.2.1 Experimental Setup Specification:

The below data gives us the specifications of the single shell and two tube pass heat exchangers on which the experiment was performed.

S. No.	Geometry	Value
1	Tube material	Copper
2	Conductivity of Tube	386 W/m-K
3	Inner diameter of tube	13 mm
4	Outer diameter of tube	16 mm
5	Length of tube	0.5 m
6	Number of tubes	32
7	Number of passes	2
8	Number of Baffles	4
9	Tube Layout	Triangular
10	Pitch	0.03 m
11	Baffle Spacing	0.1 m

4. Results and Discussion

The following matrix has been generated by varying the inlet temperature of the hot fluid from 40°C to 90°C. Along with this, in the first case the flow rate of the hot fluid has been kept constant and the flow rate of the cold fluid has been varied and the results were obtained.

Table 4.1: Performance parameters of shell and tube heat exchanger with discharge of hot fluid constant and cold fluid varying and inlet temperature of hot fluid 40°C

$T_{hi(°C)}$	$q_{h\ (lpm)}$	$q_{c\ (lpm)}$	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	$T_{ho(°C)}$	$T_{co(°C)}$	$Q_{(W)}$
40	1	1	234.0843	105.1930	67.7119	0.7880	35.8206	34.1458	288.8275
		2	234.0843	147.8176	83.1448	0.9676	34.6810	32.6382	367.5868
		3	234.0843	179.1420	92.2146	1.0731	34.0979	31.9516	407.8803
		4	234.0843	204.6574	98.5385	1.1467	33.7311	31.5546	433.2290
		5	234.0843	233.8071	104.8313	1.2200	33.4294	31.3036	454.0837

Table 4.2: Performance parameters of shell and tube heat exchanger with discharge of cold fluid constant and hot fluid varying and inlet temperature of hot fluid 40°C

$T_{hi(°C)}$	$q_{h\ (lpm)}$	$q_{c\ (lpm)}$	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	$T_{ho(°C)}$	$T_{co(°C)}$	$Q_{(W)}$
40	1	1	234.0843	105.1930	67.7119	0.7880	35.8206	34.1458	288.8275
	2		294.9277	105.1930	73.0793	0.8436	37.5100	34.9401	344.1629
	3		337.6079	105.1930	76.0098	0.8775	38.2201	35.2969	369.0189
	4		371.5856	105.1930	77.9858	0.9003	38.6118	35.5083	383.7465
	5		400.2785	105.1930	79.4570	0.9173	38.8605	35.6516	393.7283

Table 4.3: Performance parameters of shell and tube heat exchanger with discharge of hot fluid constant and cold fluid varying and inlet temperature of hot fluid 50°C

$T_{hi(°C)}$	$q_{h\ (lpm)}$	$q_{c\ (lpm)}$	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	$T_{ho(°C)}$	$T_{co(°C)}$	$Q_{(W)}$
50	1	1	236.9745	105.1930	68.0072	0.7946	41.5993	38.3003	578.2543
		2	236.9745	147.8176	83.5905	0.9767	39.3060	35.2831	736.1092
		3	236.9745	179.1420	92.7631	1.0838	38.1329	33.9084	816.8589
		4	236.9745	204.6574	99.1651	1.1586	37.3951	33.1136	867.6466
		5	236.9745	233.8071	105.5408	1.2331	36.7884	32.6108	909.4113

Table 4.4: Performance parameters of shell and tube heat exchanger with discharge of cold fluid constant and hot fluid varying and inlet temperature of hot fluid 50°C

$T_{hi(°C)}$	$q_{h\ (lpm)}$	$q_{c\ (lpm)}$	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	$T_{ho(°C)}$	$T_{co(°C)}$	$Q_{(W)}$
50	1	1	236.9745	105.1930	68.0072	0.7946	41.5993	38.3003	578.2543
	2		298.5691	105.1930	73.3521	0.8468	44.9928	39.8947	689.3311
	3		341.7763	105.1930	76.2675	0.8804	46.4206	40.6099	739.1553
	4		376.1735	105.1930	78.2322	0.9031	47.2083	41.0332	768.6442
	5		405.2206	105.1930	79.6945	0.9200	47.7087	41.3198	788.6134

Table 4.5: Performance parameters of shell and tube heat exchanger with discharge of hot fluid constant and cold fluid varying and inlet temperature of hot fluid 60°C

T_{hi}(°C)	q_h (lpm)	q_c (lpm)	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	T_{ho}(°C)	T_{co}(°C)	Q(W)
60	1	1	239.0869	105.1930	68.2201	0.8004	47.3412	42.4552	867.7111
		2	239.0869	147.8176	83.9124	0.9845	43.8848	37.9280	1104.6347
		3	239.0869	179.1420	93.1597	1.0930	42.1173	35.8650	1225.7927
		4	239.0869	204.6574	99.6184	1.1688	41.0059	34.6721	1301.9709
		5	239.0869	233.8071	106.0544	1.2443	40.0924	33.9175	1364.5857

Table 4.6: Performance parameters of shell and tube heat exchanger with discharge of cold fluid constant and hot fluid varying and inlet temperature of hot fluid 60°C

T_{hi}(°C)	q_h (lpm)	q_c (lpm)	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	T_{ho}(°C)	T_{co}(°C)	Q(W)
60	1	1	239.0869	105.1930	68.2201	0.8004	47.3412	42.4552	867.7111
	2		301.2306	105.1930	73.5486	0.8491	52.4512	44.8547	1034.8755
	3		344.8230	105.1930	76.4531	0.8826	54.6032	45.9299	1109.7857
	4		379.5268	105.1930	78.4096	0.9052	55.7908	46.5658	1154.0862
	5		408.8328	105.1930	79.8653	0.9220	56.5452	46.9962	1184.0660

Table 4.7: Performance parameters of shell and tube heat exchanger with discharge of hot fluid constant and cold fluid varying and inlet temperature of hot fluid 70°C

T_{hi}(°C)	q_h (lpm)	q_c (lpm)	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	T_{ho}(°C)	T_{co}(°C)	Q(W)
70	1	1	240.9263	105.1930	68.4035	0.8061	53.0461	46.6089	1157.0857
		2	240.9263	147.8176	84.1900	0.9921	48.4176	40.5716	1472.9769
		3	240.9263	179.1420	93.5020	1.1018	46.0517	37.8203	1634.4509
		4	240.9263	204.6574	100.0099	1.1785	44.5646	36.2295	1735.9410
		5	240.9263	233.8071	106.4983	1.2550	43.3429	35.2229	1819.3205

Table 4.8: Performance parameters of shell and tube heat exchanger with discharge of cold fluid constant and hot fluid varying and inlet temperature of hot fluid 70°C

T_{hi}(°C)	q_h (lpm)	q_c (lpm)	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	T_{ho}(°C)	T_{co}(°C)	Q(W)
70	1	1	240.9263	105.1930	68.4035	0.8061	53.0461	46.6089	1157.0857
	2		303.5481	105.1930	73.7178	0.8510	59.8849	49.8185	1380.6854
	3		347.4758	105.1930	76.6127	0.8844	62.7676	51.2556	1480.8053
	4		382.4466	105.1930	78.5621	0.9069	64.3590	52.1049	1539.9728
	5		411.9781	105.1930	80.0121	0.9237	65.3699	52.6793	1579.9907

Table 4.9: Performance parameters of shell and tube heat exchanger with discharge of hot fluid constant and cold fluid varying and inlet temperature of hot fluid 80°C

T_{hi}(°C)	q_h (lpm)	q_c (lpm)	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	T_{ho}(°C)	T_{co}(°C)	Q(W)
80	1	1	242.2776	105.1930	68.5371	0.8111	58.7223	50.7568	1446.0573
		2	242.2776	147.8176	84.3925	0.9987	52.9166	43.2102	1840.6177
		3	242.2776	179.1420	93.7518	1.1095	49.9504	39.7713	2042.2058
		4	242.2776	204.6574	100.2957	1.1869	48.0868	37.7830	2168.8599
		5	242.2776	233.8071	106.8224	1.2641	46.5564	36.5250	2272.8647

Table 4.10: Performance parameters of shell and tube heat exchanger with discharge of cold fluid constant and hot fluid varying and inlet temperature of hot fluid 80°C

T_{hi}(°C)	q_h (lpm)	q_c (lpm)	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	T_{ho}(°C)	T_{co}(°C)	Q(W)
80	1	1	242.2776	105.1930	68.5371	0.8111	58.7223	50.7568	1446.0573
	2		305.2506	105.1930	73.8409	0.8524	67.2990	54.7802	1726.3554
	3		349.4247	105.1930	76.7288	0.8858	70.9174	56.5808	1851.7947
	4		384.5917	105.1930	78.6730	0.9082	72.9155	57.6443	1925.8865
	5		414.2888	105.1930	80.1190	0.9249	74.1850	58.3633	1975.9766

Table 4.11: Performance parameters of shell and tube heat exchanger with discharge of hot fluid constant and cold fluid varying and inlet temperature of hot fluid 90°C

T_{hi}(°C)	q_h (lpm)	q_c (lpm)	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	T_{ho}(°C)	T_{co}(°C)	Q(W)
90	1	1	243.1126	105.1930	68.6192	0.8157	64.3673	54.8918	1734.1280
		2	243.1126	147.8176	84.5169	1.0047	57.3815	45.8378	2206.7344
		3	243.1126	179.1420	93.9054	1.1163	53.8146	41.7131	2448.0420
		4	243.1126	204.6574	100.4716	1.1944	51.5747	39.3286	2599.5830
		5	243.1126	233.8071	107.0219	1.2723	49.7361	37.8200	2723.9641

Table 4.12: Performance parameters of shell and tube heat exchanger with discharge of cold fluid constant and hot fluid varying and inlet temperature of hot fluid 90°C

T_{hi}(°C)	q_h (lpm)	q_c (lpm)	h_i W/m^2-K	h_o W/m^2-K	U W/m^2-K	NTU	T_{ho}(°C)	T_{co}(°C)	Q(W)
90	1	1	243.1126	105.1930	68.6192	0.8157	64.3673	54.8918	1734.1280
	2		306.3027	105.1930	73.9165	0.8533	74.6910	59.7330	2071.3987
	3		350.6291	105.1930	76.8001	0.8866	79.0505	61.8990	2222.2946
	4		385.9172	105.1930	78.7411	0.9090	81.4586	63.1779	2311.3923
	5		415.7167	105.1930	80.1845	0.9257	82.9889	64.0422	2371.6092

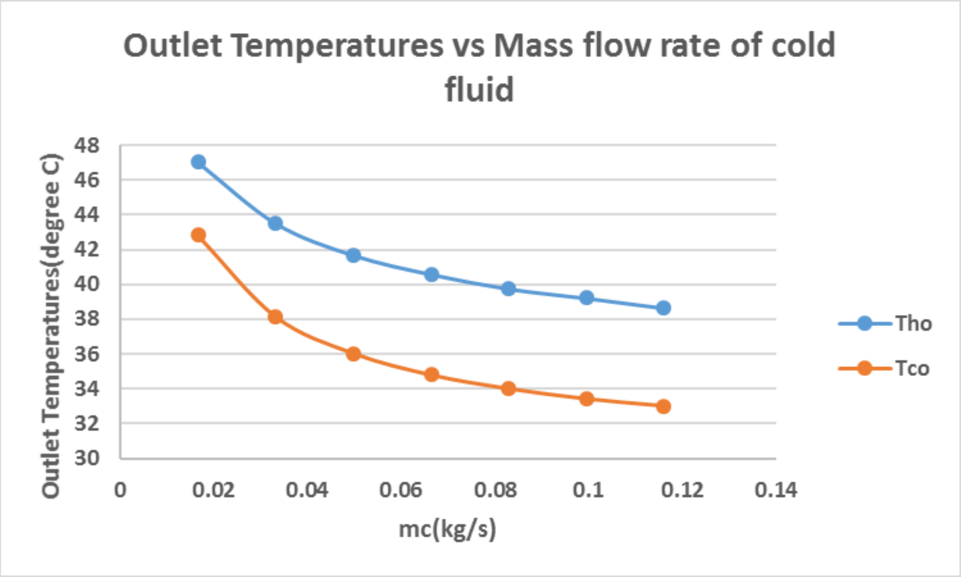

Figure 4.1: Variation of outlet temperature of hot and cold fluid with mass flow rate of cold fluid

The nature of the graphs indicates that as the mass flow rate of the cold fluid increases the outlet temperature of the hot and the cold fluid decreases. This is due to the fact that the heat capacity of the hot and cold fluid should be equal according to the law of conservation of energy. Hence, as the mass flow rate increases the outlet temperature of both the cold and hot fluid decreases.

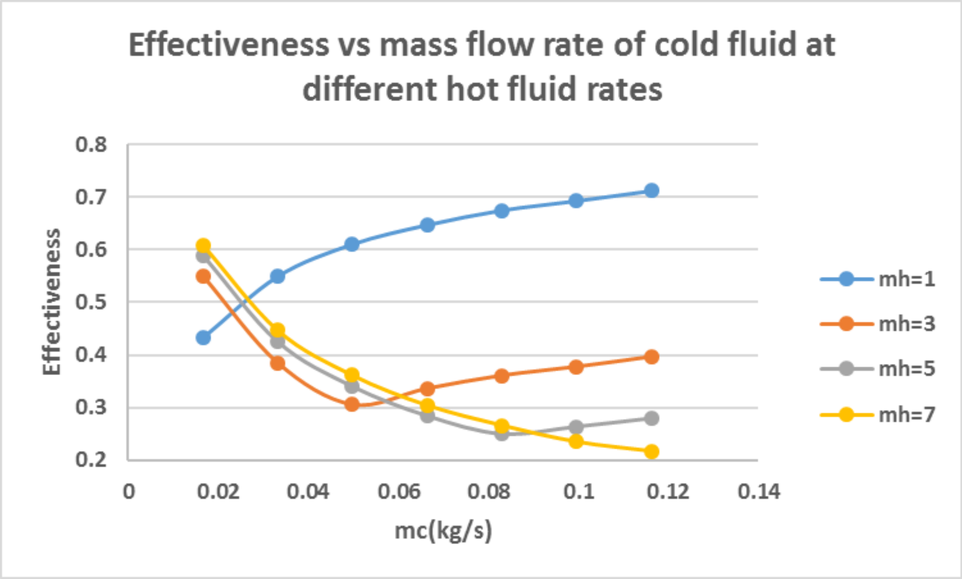

Figure 4.2: Variation of effectiveness with mass flow rate of cold fluid for different hot fluid rates

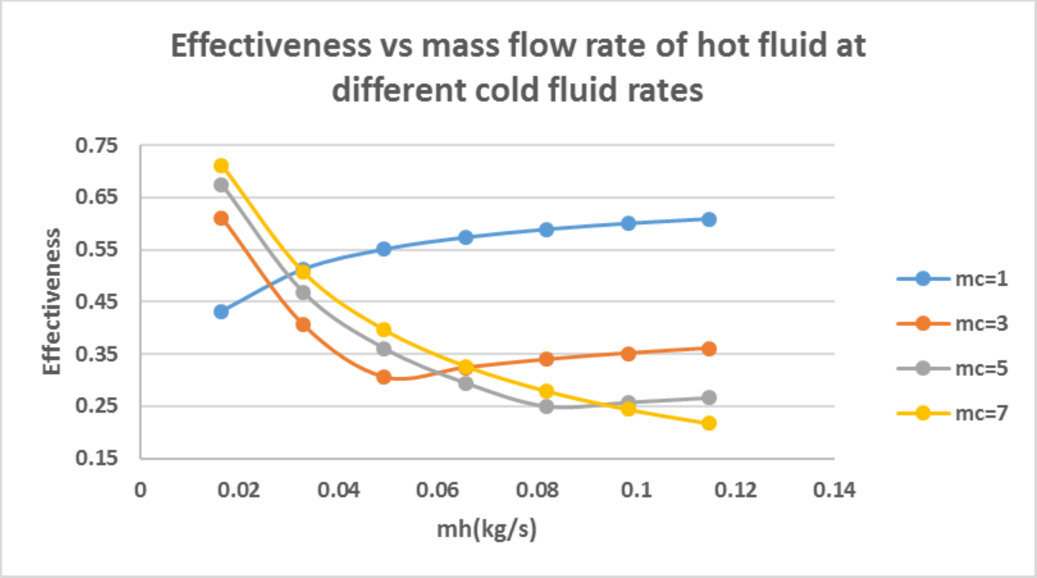

Figure 4.3: Variation of effectiveness with mass flow rate of hot fluid for different cold fluid rates

The nature of the graphs indicates that except for 1kg/s the effectiveness first decreases, reaches a minimum value and then increases again. This is because initially the heat capacity of the hot fluid dominates until a minima is reached. Once that has been achieved the heat capacity of the cold fluid dominates

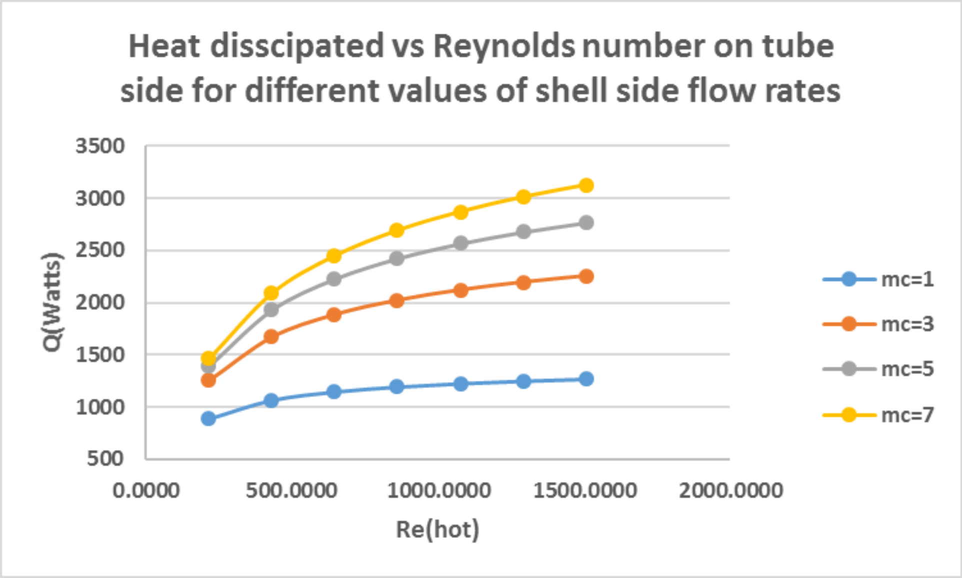

Figure 4.4: Variation of heat dissipated with Reynolds on tube side for different values of mass flow rate of cold fluid

As the Reynolds Number on the tube side increases the heat dissipated or heat load also increases. This is due to the fact that the mass flow rate of any of the hot or cold fluid has a direct correlation with the Reynolds number

5. Conclusion

- Outlet temperature of the cold and hot fluid decreases with an increase in the mass flow rate of the cold fluid
- The effectiveness of the heat exchanger decreases first reaches a minima and then increases for constant mass flow rates of the hot fluid but with varying mass flow rates of the cold fluid.
- The heat recovery of the heat exchanger increases with an increase in Reynolds number of the hot fluid.

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