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INVESTIGATION OF HEAT TRANSFER CHARACTERISTICS OF A WATER TO WATER HEAT EXCHANGER: AN EXPERIMENTAL APPROACH

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Abstract:-*Heat exchanger is a device that transfers heat from one fluid to another or from or to a fluid and the environment. The heat transfer characteristics, logarithmic mean temperature difference (LMTD), heat exchanger efficiency were determined experimentally of a water to water tube heat exchanger in this investigation. In this case, heat transfer took place between water to water at different temperatures and the respective features were determined for parallel and counter flow arrangement. Readings of different temperatures at different sections of the tube heat exchanger were taken and temperature profiles of the parallel and counter flow were plotted using the experimental data. It was observed that, the overall heat transfer coefficient and heat exchanger efficiency for counter flow was almost 10% and 20% greater than that of the parallel flow heat exchanger. Hence, counter flow heat exchanger arrangement proved to be more advantageous for greater heat recovery.*

Keywords: Water to water heat exchanger, Parallel flow, Counter flow, Heat transfer characteristics, Temperature profiles

1. INTRODUCTION

Heat exchangers are devices that facilitate heat transfer between two or more fluids at different temperature. Many types of heat exchanger have been developed for using at varied levels of technological sophistication and water to water heat exchanger is one of them.

A heat exchanger can be defined as any device that transfers heat from one fluid to another or from or to a fluid and the environment. Whereas in direct contact heat exchangers, there is no intervening surface between fluids, in indirect contact heat exchangers, the customary definition pertains to a device that is employed in the transfer of heat between two fluids or between a surface and a fluid [1].Various heat exchanger applications are available such as boiler, condenser, water heater, automobile radiator or cooling coil, refrigeration, air conditioning etc. Hence, analysis of different heat exchangers has become a prime concern in heat transfer science.

Different types of classification of heat exchangers available in engineering practice are widely discussed on Froas and Ozisik [2] Walker [3] and Kakac, Shah, and Bergles [4]. Heat exchangers can be classified based on the transfer process, compactness, construction type, flow arrangement and heat transfer mechanism [5], [6]. Heat exchanger performance is one of the most vital term in heat research field because of its vast range of applications. Numerous researches have been done already about the performance of heat exchanger.

Dubey et al. [7] investigated the performance of a shell and tube type heat exchanger under the effect of varied operation condition was analyzed and it was seen that the computational results were almost same compared with the experimental results. Kara et al. [8] made a computer based design model for a shell-tube heat exchanger. In that exchanger single phase fluid flows on both shell and tube side. According to the conclusion of that paper, circulating cold fluid in shell side and hot fluid in tube side is advantageous. The heat transfer characteristics of a tube-tube heat exchanger (TTHE) was conducted by Rane et al. [9]. Work of Lunsford [10] is very informative in increasing the heat exchanger efficiency. Yao et al. [11] conducted an experiment on heat transfer enhancement of water to water shell and tube heat exchanger assisted by power ultrasonic. Alam et al. [12] investigated the heat transfer characteristics of an air to water heat exchanger both numerically and experimentally.

Nevertheless, there were a few researches done on water to water heat exchanger and as a matter of fact numerous researches are being conducted on the heat transfer characteristics of the heat exchangers. In this experimental study the heat transfer characteristics of a water to water heat exchanger were determined experimentally. Increasing the heat transfer efficiency and plotting the temperature profiles for the parallel and counter flow heat exchanger is one of the most important concern regarding the enhancement of heat transfer auxiliaries in heat transfer science.

2. EXPERIMENTAL METHOD

The experimental setup of the water to water heat exchanger where heat transfer takes place between two liquids (water) is as shown in the Fig. 1.The apparatus is a concentric pipe heat exchanger. The direction of water was reversed to study both parallel and counter flow condition where air temperature, water flow rate were taken constant except the air velocity. The overall heat transfer coefficient can be determined for the heat exchanger either directly or by considering the heat transfer coefficient of the water to tube and tube to water separately. The apparatus was a series of tubes where heat transfer took place between the hot and cold fluids and in Fig. 1 a simplified form has been shown with one tube.

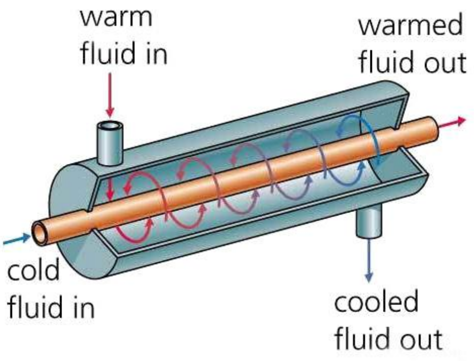

Fig. 1: Illustration of simple water to water tube Heat Exchanger

The archetypical problem that any heat exchanger solves is that of getting energy from one fluid mass to another, as we see in Fig. 2. A simple or composite wall of some kind divides the two flows and provides an element of thermal resistance between them. There is an exception to this configuration in the direct-contact form of heat exchanger [13].

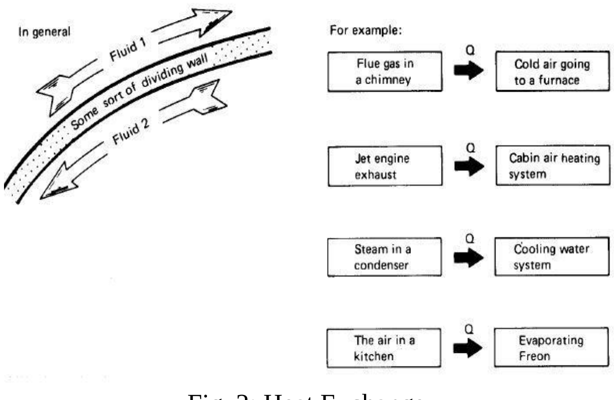

Fig. 2: Heat Exchange

Heat exchangers are generally categorized by the flow of the two fluids in relation to one another. Three categories consist of parallel flow, counter flow, cross flow.In a parallelflow heat exchanger, the fluids pass through parallel to each other. Heat is transferred from the hot fluid to the cold fluid.

Although ordinary heat exchangers may be extremely different in design and construction and may be of the single- or two-phase type, their modes of operation and effectiveness are largely determined by the direction of the fluid flow within the exchanger. The most common arrangements for flow paths within a heat exchanger are counter-flow and parallel flow. A counter-flow heat exchanger is one in which the direction of the flow of one of the working fluids is opposite to the direction to the flow of the other fluid. In a parallel flow exchanger, both fluids in the heat exchanger flow in the same direction [14]. Fig. 3 and Fig. 4 shows the parallel and counter flow arrangement.

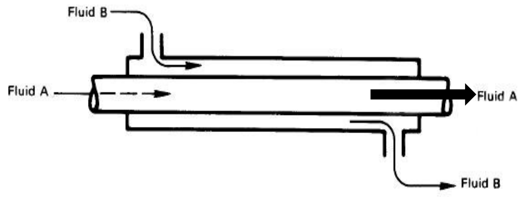

Fig. 3: Schematic arrangement of parallel flow

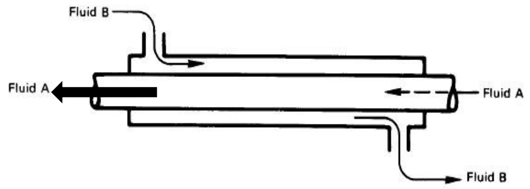

Fig. 4: Schematic arrangement of counter flow

For parallel flow, as shown in Fig. 3, the temperature difference between the two fluids is large at the entrance end, but it becomes small at the exit end as the two fluid temperatures approach each other. The overall measure of heat transfer driving force, the log mean temperature difference is greater for counter flow, so the heat exchanger surface area requirement will be larger than for a counter flow heat exchanger with the same inlet and outlet temperatures for the hot and the cold fluid [15].

A counterflow heat exchanger has the hot fluid entering at one end of the heat exchanger flow path and thecold fluid entering at the other end of the flow path. Counter flow is the most common type of liquid-liquid heat exchanger, because it is the most efficient. A double pipe heat exchanger is usually operated as a counter flow heat exchanger, as shown in Fig. 4.

The temperatures of the hot and cold fluid were taken at several sections including inlet and outlet. Using these data the log mean temperature difference, mass flow rate, overall heat transfer coefficient, heat exchanger efficiency were determined. Then using the obtained results temperature profiles for both parallel and counter flow were plotted and the analysis on the heat exchanger yields to its requirements.

2.1 GOVERNING EQUATIONS

For the analysis of parallel and counter flow heat exchanger, there are some necessary equations and they are as follow [5],

Logarithmic mean temperature difference (LMTD),

(1) $$LMTD = \frac{\Delta t_a - \Delta t_b}{\ln\left(\frac{\Delta t_a}{\Delta t_b}\right)}$$

Overall heat transfer coefficient,

(2) $$U = \frac{Q}{A\Delta t}$$

Where, (3) $$A = 3.14DL$$

Heat exchanger efficiency,

(4) $$\eta = \frac{Q_c}{Q_h}$$

Heat loss by hot water,

(5) $$Q_h = m_h c_{p_h} \Delta t_h$$

Heat gain by cold water,

(6) $$Q_c = m_c c_{p_c} \Delta t_c$$

Using these above mentioned equations, heat transfer characteristics of the investigated heat exchanger were determined in numerical values. Heat exchanger efficiency was determined using the eqn. (4) for which the heat loss by the hot fluid and heat gain by the cold fluid were calculated.

2.2 EXPERIMENTAL DATA

Several data were taken for the parallel and counter flow arrangement of the heat exchanger. Table 1 and Table 2 illustrate the experimental values taken for parallel and counter flow respectively.

Table 1: Experimental data for parallel flow

Obs.	Fluids	Temperature (°C)						
		Inlet 1	2	3	4	5	6	Out-let 7
1	Hot	40	38	36	35	33	32	32
	Cold	24	27	28	28	29	29	29
	Δt	16	11	8	7	4	3	3
2	Hot	44	43	41	38	35	34	34
	Cold	24	26	27	28	29	30	30
	Δt	20	17	14	10	6	4	4
3	Hot	48	46	44	43	41	40	40
	Cold	24	26	27	29	31	31	31
	Δt	24	20	17	14	10	9	9

Table 2: Experimental data for counter flow

Obs.	Fluids	Temperature (°C)						
		Inlet 1	2	3	4	5	6	Out-let 7
1	Hot	40	39	38	37	36	34	31
	Cold	24	26	26	27	29	30	31
	Δt	16	13	12	10	7	4	0
2	Hot	44	42	41	40	39	38	36
	Cold	24	25	26	28	29	29	35
	Δt	20	17	15	12	10	9	5
3	Hot	48	46	45	43	41	39	35
	Cold	24	27	28	29	31	32	34
	Δt	24	19	17	14	9	7	1

Experimental data for the parallel and counter flow were taken as the temperatures at inlet and outlet with some sections of the tube heat exchanger. Heat transfer took place between hot and cold fluid.

3. RESULT AND DISCUSSION

As the experiment conducted stated above, the required characteristics of the heat exchanger were determined. It was observed that, counter flow was more efficient over parallel flow arrangement. Applying the eqn. (1) through (6) the values of LMTD, overall heat transfer coefficient, heat transfer area, heat exchanger efficiency, heat loss by hot and cold water were determined respectively. Table 3 and Table 4 contains the experimental result determined for parallel and counter flow respectively.

Table 3: Experimental results for parallel flow

1	LMTD	7.77°C
	U	450.45 W/m^2°C
	η	41.67%
2	LMTD	9.94°C
	U	586.85 W/m^2°C
	η	30%
3	LMTD	15.29°C
	U	381.51 W/m^2°C
	η	35%

From the table it can be seen that, the optimum value of logarithmic mean temperature ranges from 7.77°C to 15.29°C and the heat exchanger efficiency ranges from 30% to 41.67%. In parallel flow the flow direction of the hot and cold fluids are same and have same inlet and outlet. Heat transfer takes place between the fluids in the same direction of flow.

Table 4: Experimental results for counter flow

1	LMTD	7.958°C
	U	494.66 W/m^2°C
	η	51.85%
2	LMTD	12.49°C
	U	373.63 W/m^2°C
	η	43.75%
3	LMTD	12.43°C
	U	761.99 W/m^2°C
	η	30.76%

In counter flow, the flow direction of the hot and cold was opposite.

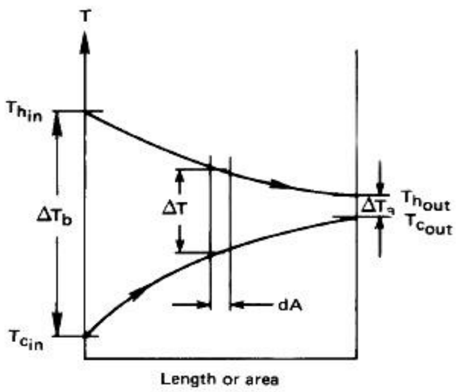

Fig. 5: Standard temperature profile for parallel flow [13]

Regarding the experimental results the temperature profiles for both parallel and counter flow were plotted. Fig. 5 to Fig. 7 represents the temperature profiles for parallel flow.

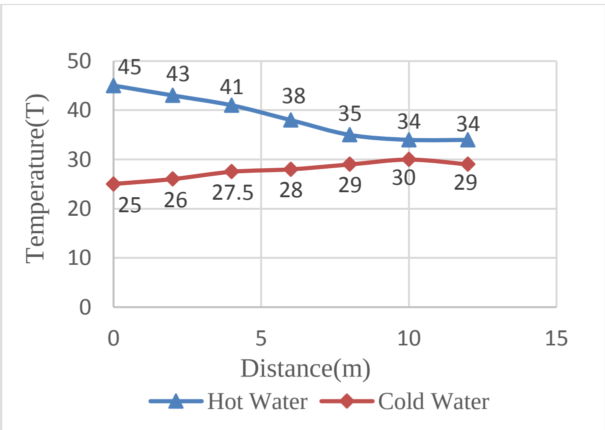

Fig. 6: Temperature profile for parallel flow at section 1

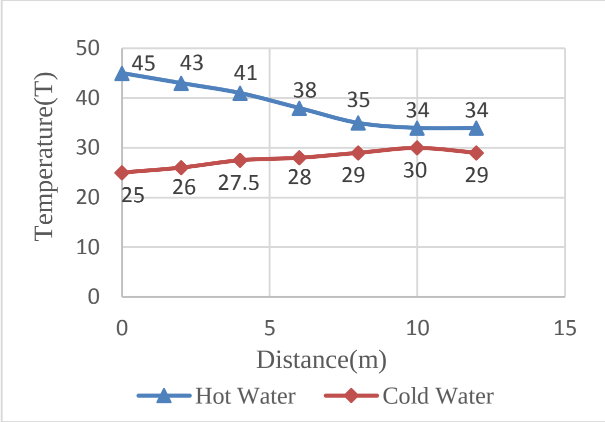

Fig. 7: Temperature profile for parallel flow at section 2

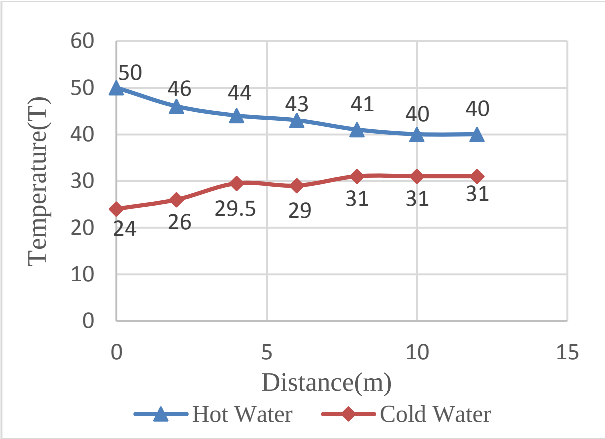

Fig. 8: Temperature profile for parallel flow at section 3

From the graphs of the temperature profiles of parallel flow it can be observed that, heat is rejected by the hot waterand the cold water gains the heat.

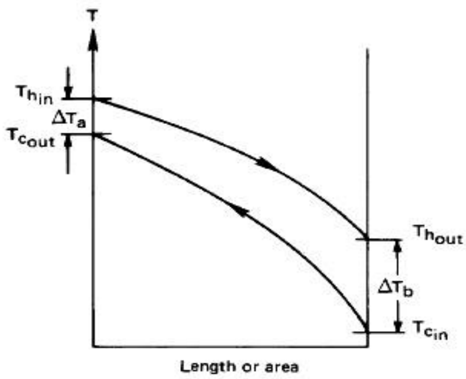

Fig. 9: Standard temperature profile for counter flow [13]

Now for counter flow, the fluid flow directions are opposite to each other. Fig. 8 to Fig. 10 represents the temperature profiles for the counter flow at different sections. The inlet of the hot water is the outlet of the cold water. Similarly, the inlet of the cold water is the outlet of the hot water.

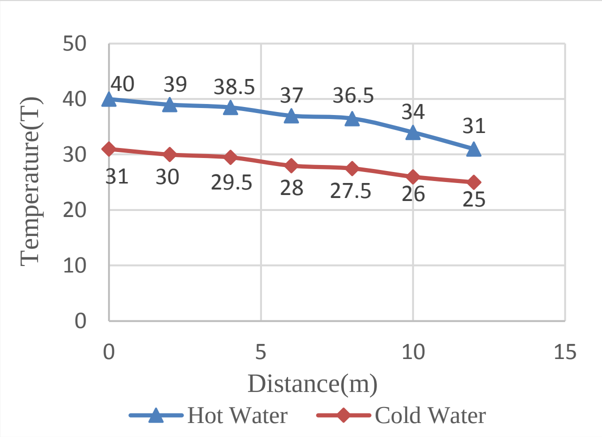

Fig. 10: Temperature profile for counter flow at section 1

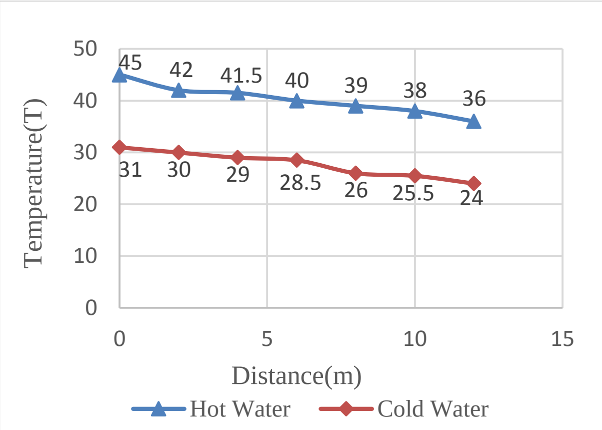

Fig. 11: Temperature profile for counter flow at section 2

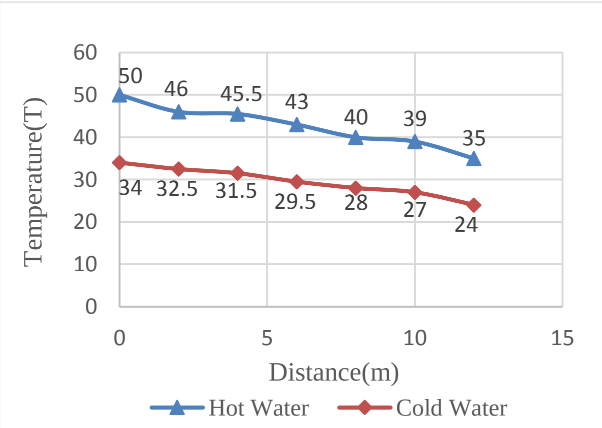

Fig. 12: Temperature profile for counter flow at section 3

From the graphs of the counter flow it can be seen that, the temperature of hot water is gradually falling down due to the rejection of heat and the temperature of the cold water is upward as it gains the heat rejected by the hot water.

If temperature profiles are compared for the above mentioned heat exchangers then it can be easily seen that in counter flow heat exchanger the temp difference between the cold and hot water doesn't vary as much as in parallel flow heat exchanger, due to which entropy generation is lesser and so irreversibility is lesser in counterflow heat exchanger. As it is known that a system closer to reversible system will always have better efficiency than the more irreversible heat exchanger hence, counterflow is obviously more efficient than parallel.

Again if the temperature profiles of both parallel and counter are analyzed then it would be observed that counter flow heat exchanger is more advantageous than parallel flow heat exchanger. In parallel flow arrangement, the outlet temperature of the cold water is always lesser than that of the hot water outlet temperature. Therefore, the heat transfer is restricted by the cold water outlet temperature. On the contrary, for counter flow arrangement, the restriction is relaxed and outlet cold water temperature can exceed outlet hot water temperature. Hence, the heat transfer is restricted by the inlet cold water temperature. Therefore, to achieve greater heat recovery, counter flow heat exchanger is preferred to that of parallel flow heat exchanger.

4. CONCLUSION

The applications of heat exchangers are numerous and boiler, condenser, water heater, automobile radiator or cooling coil, refrigeration, air conditioning etc.are some of the examples of heat exchanger used in the practical world. Basically, heat exchanger exchanges heat between two or more fluids at different temperatures. Heat transfer characteristics of a water to water tube type heat exchanger has been successfully investigated through this experimental analysis. This experimental analysis concludes several decisions as:

a. Temperature profiles plotted for the parallel and counter flow arrangement are relevant.

b. For parallel and counter flow design, counter flow is more advantageous over parallel flow.

c. Heat exchanger efficiency greatly depends upon the mass flow rate of the hot and cold water.

d. Overall heat transfer coefficient increases with decreasing the heat transfer surface area and vice versa.

e. In counter flow heat exchanger, the outlet of cold fluid can be heated above the inlet temperature of hot fluid which provides higher LMTD.

5. ACKOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(°C)
U	Overall heat transfer coefficient	(W/m^2°C)
A	Heat transfer surface area	(m^2)
D	Diameter of the heat exchanger tube	(m)
Q	Heat transfer rate	(Kg/hr)
η	Efficiency	Dimensio-nless
C_{p_h}	Sp. Heat of hot water	(KJ/Kg K)
C_{p_c}	Sp. Heat of cold water	(KJ/Kg k)
Δt_a	Inlet temperature difference	(°C)
Δt_b	Outlet temperature difference	(°C)
m_h	Mass flow rate of hot water	(Kg/hr)
m_c	Mass flow rate of cold water	(Kg/hr)
$LMTD$	Logarithmic mean temperature difference	(°C)