

# Experimentation on Augmenting Heat Transfer Characteristics of (Ethylene Glycol + Water) Mixture in A Combined (Pipe in Pipe and Shell & Tube) Heat Exchanger



M.P.V.L.Prasanna, P.Ravindra Kumar, B.Emmanuel, K.Lakshmi Prasad

**Abstract:** In this research work, the design of pipe in pipe, shell-and-tube and combined heat exchanger (previously mentioned types were combined to consider as one unit) has been made. These three heat exchangers have been utilized for two kinds of flows i.e., parallel as well counter flow types individually. The design of combined heat exchanger takes been proposed with the idea of increasing the heat transfer area and to understand the behavior of various parameters involved by comparing with the individual heat exchangers. 75:25 aqueous Ethylene Glycols, have been used as the working fluid in all three heat exchangers of counter as well parallel flow conditions. Total quantity of working fluid is 12 liters, in which 6liters of fluid is used as cold fluid and the other half is used as hot fluid. As a result, overall heat transfer coefficient ( $U$ ) has been increased with increase of mass flow rate. Highest overall heat transfer coefficient value observed as  $1943\text{w/m}^2\text{-k}$  at highest mass flow rate (within the considerations of this work) of  $0.145\text{ kg/s}$ . The highest decrement in LMTD recorded for  $0.0425$  to  $0.145$  increase of mass flow rate is  $49.32\%$  in shell-and-tube heat exchanger of parallel flow arrangement. The highest effectiveness is observed for pipe in pipe counter flow heat exchanger case, which is  $0.39$  at a mass flow rate of  $0.145\text{kg/s}$ .

**Keywords:** Pipe in pipe heat exchanger, shell-and-tube heat exchanger, combined heat exchanger, parallel flow, counter flow, ethylene glycol mixture, mass flow rate, LMTD, overall heat transfer coefficient ( $U$ ), effectiveness ( $\epsilon$ ).

## I. INTRODUCTION

Device, utilizing in exchanging of heat between two fluids, whose temperatures are not same is the heat exchanger.

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In a large portion of the heat exchangers utilized in our everyday life there will be no immediate contact between the two liquids. In different terms device helps in recoup heat amid the two flow patterns of a process. The transfer of heat among air and heat exchanger is immaterial contrasted with between liquids. Be that as it may, these would be utilized both in heating just as cooling process. Heat transfer from the hot liquid to cold liquid is done through wall surface, which isolates the working liquids flows through it. As long as convection heat transfers consistently within is constrained.

The name heat exchanger is utilized, just when with at very least two liquid flows are operated. General examples are car radiators, steam boilers situated in thermal power plants, condensers exploited for the refrigerators. The material selection affects working fluids or vice-versa.

The inter-dependency of working fluid and heat exchanger material represents the importance of temperature withstanding criteria in heat exchanger design.

## II. II REVIEW OF LITERATURE

R. Dharma lingam et al., [1] Designed and conducted tests on shell-and-tube besides tube-in-tube heat exchangers to found transfer of heat characteristics associated with Nano fluid. Concluded, coefficient of heat transfer is high for higher Reynolds number i.e., 1200. However in case of Nano fluid there is an increase of 9.31% compared to water in shell and tube heat exchanger. P.B.DeHankar et al., [2] fabricated double pipe heat exchanger. Hypothetical and test esteems for parameters Reynolds number, friction factor as well the rate of mass flow extent between (0.02– 0.033) Kg/sec. There is a very small difference between  $h_{\text{expt}}$  &  $h_{\text{theo}}$ , so easily assumed that the theoretical equations for transfer of heat, friction factor and ' $K = 6.552 \times 10^{-4}$ ' were found from Wilson chart ( $1/U$  i vs.  $1/Re$  0.8) hold true for test arrangement. Xiaoke Li, Changjun Zou et.al., [3] Concluded benefits of heat transfer and suggested water/EG-based SiC Nano fluids taken probable applications for energy systems, which indicated promising capability in this kind of Nano fluids investigation on further heat transfer characteristics. J. Bala Bhaskara Rao & V. Ramachandra Raju [4] Carried-out the experiment using heated fluid in inner tube side and chill fluid inside shell side with 600 circular tubes at orientation 25 % baffle cut. Drop in pressure as well rate of Heat transfers were calculated for 4000–20000 Reynolds numbers.

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Vindhya Vasiny Prasad Dubey et.al., [5] Using ANSYS 14.0, steady state thermal analysis has done to justify designed simplified shell and tube model, which is based on kern's method to cool temperature from  $55^{\circ}\text{C}$ - $45^{\circ}\text{C}$  with the help of room temperature conditioned water. Folaranmi Joshua [6] designed and constructed a tube in tube type heat exchanger, which has been utilized for counter stream arrangement is considered. By using water as working fluid, obtained 73.4% efficient heat exchanger in comparison with designed one and resulted coefficient of overall heat transfer is  $711\text{W}/\text{m}^2\text{K}$ .

Karthik Silaipillayarputhur & Hassan khurshid [7] has been reviewed shell and tube heat exchanger design. In that, prominent explanatory procedures, for example, log mean temperature contrast (LMTD) and effectiveness number of transfer units ( $\epsilon$ -NTU) were considered for analysis. Regarding considered case in this, both LMTD and  $\epsilon$ -NTU methods yield the equivalent same outcome results.

Kanade Rahul H et al., [8] investigated the impact of inner aluminum in counter flow Double Pipe Heat Exchanger (DPHE) utilizing computational liquid unique examination (CFD). Quarter round baffles kept in staggered arrangement actuated better performance and brought about 2.70% high rate of heat transfer when contrasted with semi-round baffles. Sk M.Z.M Saqueeb ali et al., [9] Dealt with the heat exchanger of double pipe type performance rate of with various materials. CFD analysis is done by using ANSYS. He got high temperature profile at outlet in case of Aluminum besides copper now comparison with steel material. Vishal H Acharya [10] investigated on different reviews regarding heat exchangers of shell and tube aimed at different parameters. Explained procedure for designing heat exchanger and modeled for different parameters using CFD analysis.

Ala Venkata Rao, Srivalli Gollamudi [11] has done numerical simulation, proper pressure effect and heat transfer coefficient correlations for various sizes of longitudinal circular and square strip are considered with different flow rates under the stormy stream. Transfer of heat from hot fluid raises by increasing mass flow rate and Reynolds number. There is further enhancement with insertion of the square and circular stripes with different sizes. The pressure drop is augmented with enlarged rate of mass flow and size of stripes. N.A.usri et al.[12], conducted tests by varying the volume concentrations in nanoparticles of  $\text{Al}_2\text{O}_3$  immersed happening 60:40 water and mixture of ethylene glycol at various mass flow rates using force convection heat transfer setup. Finally, concluded that as the volume concentration of nanoparticles increasing, the Nusselt number is increasing. There exists larger heat transfer coefficient, as larger the Nusselt number,. It remained seen that as stacking of nanoparticles suspended within base liquid expanded, Coefficient of heat move is likewise higher. The Literature survey regarding research has gone through modeling of individual tube in tube and shell-and-tube heat exchangers, through which different flows has been analyzed. Hybrid flow (combination of two different flows) has been proposed in few journals. But, it is little difficult in calculations part of hybrid flow. So, proposal of designing a hybrid heat exchanger (combination of heat exchangers) has come out from the idea of hybrid flow. Finally, this report has been designed and analyzed the hybrid heat exchanger (combination of tube in tube and shell-and-tube heat exchanger) for individual flows (parallel & counter flow).

### III. III PREPARATION OF 75:25 WATER-ETHYLENE GLYCOL MIXTURES

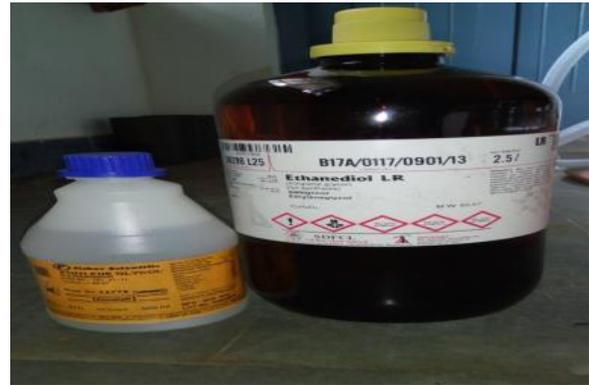


Fig. I. Ethylene Glycol

The coolant named ethylene glycol is illustrated in Fig. I, which has been used to mix with the water to utilize as a working fluid in the fabricated heat exchangers represented in Fig. I, II, III. The mixing of ethylene glycol to the water is not a difficult task, as properties of ethylene glycol are similar to of water. So, as mentioned in title, working fluid is the mixture of 75% water and 25% ethylene glycol. i.e., 3 liters ethylene glycol is mixed with 9liters of water directly to make 12 liters working mixture, to prepare working fluid. After mixing, two each of 6 liters of fluid is to be filled in two separate steel tanks for hot and cold fluid.

Color and odor of mixture remains identical to water.

Hot working fluid obtained by using heater to heat water as well stirrer utilized in mix up the liquid evenly. Cold liquid is nothing but mixture available by the side of room temperature.

Working fluid temperatures were recorded using thermocouple sensors by placing in liquid.

### IV. IV DESIGN AND METHODOLOGY OF HEAT EXCHANGERS

Generally, design for any system or component includes few initial assumptions. Then, only designing of components will be completed. In the same manner, assumptions to be made for design of heat exchangers are as follows:

- The entire system can be considered as isobaric;
- There will be no chance of heat exchange into surroundings. Since, the unit is adiabatic.
- Throughout the heat exchanger, thermo-physical nature as well coefficients of heat transfer will be constant.

Entire design of heat exchangers were based on formulae obtained from journals mentioned in literature survey as well assumptions made for coefficient of overall heat transfer.

Almost all formulae obtained from journals were taken from standard kern's method.

**A. Mathematical Modeling and Design Of Pipe In Pipe Heat Exchanger:**

From heat exchanger design, major concentration takes away by finding overall heat transfer coefficient (U). Design formula to find coefficient of overall heat transfer [4] is

$$U = \frac{Q}{A(\Delta T)} \text{ W/m}^2\text{K} \quad (1)$$

The basic formula for finding rate of heat transfer [1] is

$$Q = UA (\Delta T) W \quad (2)$$

The energy balancing equation for heat exchanger [16] is

$$m_c c_c (T_{C2} - T_{C1}) = Q = m_h c_h (T_{H1} - T_{H2}) \quad (3)$$

The area of fluid flow [6] is

$$A = (\pi/4)[(D_o^2 - D_i^2)] m^2 \quad (4)$$

The logarithmic mean temperature difference ( $\Delta T$ ) varies in counter besides parallel flow

For parallel flow

$$(\Delta T)_p = \frac{(T_{H1} - T_{C1}) - (T_{H2} - T_{C2})}{\ln [(T_{H1} - T_{C1}) / (T_{H2} - T_{C2})]} \quad (5)$$

For counter flow,

$$(\Delta T)_c = \frac{[(T_{H1} - T_{C2}) - (T_{H2} - T_{C1})]}{\ln [(T_{H1} - T_{C2}) / (T_{H2} - T_{C1})]} \quad (6)$$

The inner tube dimensions will be obtained from equation [21] is

$$1/(UA) = [1/(h_i A_i)] + [\ln(r_o/r_i)/2\pi KL] + [1/h_o A_o] \quad (7)$$

The Effectiveness ( $\epsilon$ ) is

$$\epsilon = \frac{Q_{actual}}{Q_{max}} \quad (8)$$

Rate of actual heat transfer ( $Q_{actual}$ ) will calculated from (3) Maximum possible heat transfer ( $Q_{max}$ ) will be Either

$$Q_{max} = m_h c_h (T_{H1} - T_{C1}) \text{ or } Q_{max} = m_c c_c (T_{H1} - T_{C1}) \quad (9)$$

The heat transfer rate (Q) can be obtained from

$$Q = \epsilon C_{min} (T_{H1} - T_{C1}) W \quad (10)$$

The designed values or specifications of the pipe in pipe heat exchanger were mentioned inside Table- I

**Table- I: Specifications of the pipe in pipe heat exchanger**

Outer tube material	Acrylic fiberglass
Outer pipe ID	76 mm
Outer pipe OD	82 mm
Outer pipe length	600 mm
Inner pipe material	Copper

Inner pipe ID	19.5 mm
Inner pipe OD	22 mm
Length	1000mm

**B. Mathematical Modeling and Design Of Shell And Tube Heat Exchanger:**

The design procedure for shell-and-tube and pipe in pipe heat exchangers are almost same up to the outer shell design. Whereas the inside arrangement of shell additionally require the following formulae:

Overall heat transfer coefficient,

$$U_o = \frac{(1/A_o)}{\left(\frac{1}{h_i A_i}\right) + \frac{\ln(d_o/d_i)}{2\pi k L} + \left(\frac{1}{h_o A_o}\right)} \quad (11)$$

Where  $A_i = \pi d_i N_t L$  and  $A_o = \pi d_o N_t L$  (12)

Number of tubes,  $N_t = \frac{\pi D_i L_i}{\pi d_i l_i}$  (13)

Triangular pitch,  $P_t = 1.25 d_o$  (14)

Baffle spacing,  $B = 74 d_o^{0.75}$  (15)

The following below Table-II is representing the heat exchanger design specifications of shell-and- tube type.

**Table- II: Specifications for the shell and tube heat exchanger**

Outer shell material	Acrylic fiber-glass
Outer shell dimensions	82x76 mm
Length of the shell	600 mm
Inner tubes material	Copper
No. of tubes	5
Pitch of the tubes	7.5 mm
Inner tubes dimensions	6x4 mm
Inner tubes length	571.5 mm
Baffle spacing	287.5 mm
Type of baffles	Semi-circular(Copper)
No. of baffles	3

The theoretically obtained design values of shell-and-tube as well pipe in pipe type of heat exchangers for counter and counter flow are mentioned in below Table-III

**Table- III: Theoretical design values of heat exchangers**

Type of heat exchanger	m <sub>f</sub>	Re	Parallel flow			Counter flow		
			( $\Delta T$ ) <sub>p</sub> (K)	U (W/m <sup>2</sup> -K)	$\epsilon$	( $\Delta T$ ) <sub>c</sub> (K)	U (W/m <sup>2</sup> -K)	$\epsilon$
Pipe in Pipe	0.1 45	127 1.6	14	1500	0.35	16.75	1500	0.26
Shell and Tube	0.1 45	127 1.6	14.81	1000	0.32	17.03	1000	0.37



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## V. EXPERIMENTAL ANALYSIS

$$Re = \frac{\rho V D}{\mu} \quad (19)$$

### A. Pipe In Pipe Heat Exchanger



Fig. II Pipe in pipe type arrangement

Pipe in pipe arrangement exists shown with Figure II, in which both parallel besides counter flow can be analyzed. The inner copper tube is filled with heated fluid as well as outer acrylic tube filled by cold fluid. Outside shell drilled for 20 mm in the opposite ends to make the cold fluid to pass in and out. As well in the inner copper tube the two ends were connected with pu-tubes, to allow the hot fluid to flow in and out.

#### a. Parallel flow in pipe in pipe heat exchanger:

In this kind, cold liquid was given at right end of outer shell. Whereas hot inlet pipe inserted at right end open of copper tube. The outlets were happened at left end of corresponding openings.

That is how, fluids parallel in direction to each other.

Within this condition, the hot inlet in addition cold inlets were given in one side of their corresponding tubes. From the temperature readings and mass flow rates obtained as mentioned in Table 4. Using LMTD method of calculations "U" will be found, which were as mentioned in the design part of heat exchanger.

The overall heat transfer coefficient (U) from LMTD method

$$U = \frac{Q_{avg}}{A(\Delta T)_p} \quad (16)$$

Table- IV: Recorded observations for parallel flow in pipe in pipe heat exchanger

$m_f$ (kg/sec)	$T_{H1}$ ( $^{\circ}C$ )	$T_{C1}$ ( $^{\circ}C$ )	$T_{H2}$ ( $^{\circ}C$ )	$T_{C2}$ ( $^{\circ}C$ )
0.143	55	30.3	41.3	39.6
0.0719	55	30.9	47.4	36.3
0.0425	55	31.2	49.1	35.8

$$Q_{avg} = \frac{(Q_c + Q_h)}{2} \quad (17)$$

Where,  $Q_c = m_c c_c (T_{C2} - T_{C1})$  and

$$Q_h = m_h c_h (T_{H1} - T_{H2}) \quad (18)$$

Reynolds number

Nusselt number can be calculated as

$$Nu = 0.023 Re^{0.8} Pr^{0.3} \quad (20)$$

The coefficient of convective heat transfer (h) will be obtained using

$$Nu = \frac{hD}{k} \quad (21)$$

#### b. Counter flow in Pipe in pipe heat exchanger:

The temperature readings from pipe in pipe of counter flow heat exchanger were noted shown in Table V, as in case of parallel. But, the inlets of hot and cold fluids were given at opposite ends.

Table- V. Recorded observations of counter flow in pipe in pipe heat exchanger

$m_f$ (kg/sec)	$T_{H1}$ ( $^{\circ}C$ )	$T_{H2}$ ( $^{\circ}C$ )	$T_{C1}$ ( $^{\circ}C$ )	$T_{C2}$ ( $^{\circ}C$ )
0.145	55	40.6	30.2	40.1
0.0719	55	46.4	30.6	37.4
0.0425	55	47.3	30.7	36.7

The overall heat transfer coefficient (U) in this case,

$$U = \frac{Q_{avg}}{A(\Delta T)_c} \quad (22)$$

Further procedure for calculations is same as in the case of parallel flow.

### B. Shell-and-tube heat exchanger:

This kind of heat exchangers are similar to pipe heat exchangers, in addition shell-and-tube consists of more than one inner tube, whose materials usage is similar to pipe in pipe inner tube materials.



Fig. III Shell-and-tube heat exchanger

The shell-and-tube type shown in Figure-III, whose design calculation of outer shell is similar to pipe in pipe heat exchanger. Number of tubes, type of baffle, baffle spacing, and pitch are additional calculations to be made in the inner portion of the shell-and-tube heat exchanger.

The temperature readings that are obtained according to varying mass flow rates in parallel flow shell-and-tube heat exchanger are as shown in Table VI.

Rate of mass flows varied are 0.0423, 0.079 and 0.145, which were obtained by adjusting control valves connected to pu-tubes near submergible pumps placed in storage steel tanks.

**Table: VI. Recorded observations for parallel flow in shell and tube heat exchanger**

(m <sub>f</sub> ) kg/sec	T <sub>H1</sub> (°C)	T <sub>C1</sub> (°C)	T <sub>H2</sub> (°C)	T <sub>C2</sub> (°C)
0.145	55	30.3	40	37
0.0719	55	30.9	42	35.8
0.0425	55	31	45.7	34.9

For the same mentioned in Fig. II, temperature readings in counter stream condition were noted happening Table- VII.

**Table- : VII Recorded observations for shell and tube counter stream**

m <sub>f</sub> (kg/sec)	T <sub>H1</sub> (°C)	T <sub>H1</sub> (°C)	T <sub>C1</sub> (°C)	T <sub>C2</sub> (°C)
0.145	55	39.8	30.2	36.3
0.0719	55	43.2	30.4	36.1
0.0425	55	45.3	30.8	35.6

The triangular pitch equivalent diameter is as

$$D_e = \frac{4\left[\left(\frac{\sqrt{3}P_T^2}{4}\right) - \left(\frac{\pi d_o^2}{8}\right)\right]}{\pi d_o/2} \quad (25)$$

Here, in this type, chill liquid has taken on pipes side besides hot fluid flow on shell side.

Reynolds number on behalf of shell side given as

$$Re = \frac{\rho V D_e}{\mu} \quad (23)$$

Nusselt number can be obtained from

$$Nu = \frac{h_o D_e}{k_f} \quad (24)$$

**C. COMBINED HEAT EXCHANGER:**

The term combined heat exchanger itself is explaining that the heat exchanger is in combination with the other.



**Fig. IV Combined heat exchanger**

Coefficient of overall heat transfer is one of major requirements for any heat exchanger considerations. The calculated results of overall heat transfer coefficient were

Here the combined heat exchanger is achieved by connecting the pipe in pipe heat exchanger with the shell-and-tube heat exchanger by using pu-tubes as shown in Fig. IV. The parallel flow in combined heat exchanger is performed by giving hot and cold fluid inlets to the pipe in pipe type and their outlets were connected to inlets of shell-and-tube unit. Inlet temperature readings of combined case were taken at inlets of pipe in pipe heat exchanger as well the outlet readings taken at the outlets of shell-and-tube case. Total temperature readings for Parallel stream case of combined heat exchanger are recorded as shown in below Table- VIII.

**Table- VIII: Recorded observations for parallel flow in combined heat exchanger**

m <sub>f</sub> kg/sec	T <sub>H1</sub> (°C)	T <sub>C1</sub> (°C)	T <sub>H2</sub> (°C)	T <sub>C2</sub> (°C)
0.145	55	29.7	43	35
0.071	55	38.2	47	34.3
0.0425	55	30.4	51	32.1

Whereas coming to connections in this unit, inlets for two of the heat exchangers were given at right end openings by pu-tubes. Outlets for the two individual units considered at left end openings using same pu-tubes, in parallel stream condition. Since, single flow is proposed in this combined heat exchanger. In counter-current stream condition, inlet of hot mixture given at right end opening and cold inlets were given at left end openings. Opposite ends became outlets for fluids. Methodology of flow differs in flow type.

The following Table IX consisting, temperature readings for combined heat exchanger of counter flow condition with varying mass flow rates. The logarithmic mean temperature difference values recorded for different mass flow rates in case of three heat exchangers in Table 10.

**Table- IX: Recorded observations for combined heat exchanger consisting of counter flow**

(m <sub>f</sub> ) kg/sec	T <sub>H1</sub> (°C)	T <sub>H1</sub> (°C)	T <sub>C1</sub> (°C)	T <sub>C2</sub> (°C)
0.145	55	39.8	29.8	37
0.0719	55	40.3	29	34.3
0.0425	55	43	29	32.1

Experimental Results obtained for aqueous ethylene glycol mixture in both counter and parallel flow conditions of the three different heat exchangers mentioned in this report

**Table- X: Logarithmic Mean Temperature Difference for different mass flow rates**

m <sub>f</sub> (kg/sec)	Re	Parallel flow (ΔT) <sub>p</sub> (K)			Counter flow (ΔT) <sub>c</sub> (K)		
		P-I-P	S-T	C-HE	P-I-P	S-T	C-HE
		0.14	12	9	1	1	1
5	71.6	.76	0.38	5.65	3.61	3.64	6.53
0.07	91	1	1	1	1	1	1
19	0.4	2.3	3.64	7.43	5.5	5.65	8.04



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-noted as Table- X, for the parallel and counter stream conditions in case of considered three heat exchangers.

**Table- XI: Overall heat transfer coefficient for three mass flow rates**

$m_f$ (kg/s ec)	Re	Parallel flow			Counter flow		
		U(w/m <sup>2</sup> -k)					
		P -I-P	S- T	C HE	P -I-P	S -T	C HE
0.1 45	12 71.6	92 0	10 17	1 666	1 435	1 846	1 943
0.0 719	91 0.4	89 8.6	94 5.31	1 480	1 347	1 536	1 726
0.0 425	88 0.68	56 5	64 1	1 060	1 229	1 370	1 467

Finding effectiveness is also one of the major resources to understand any heat exchanger. To define, ratio of actual heat transfer to the maximum heat transfer is nothing but effectiveness. The resulted effectiveness for the considered conditions is noted in Table- XII.

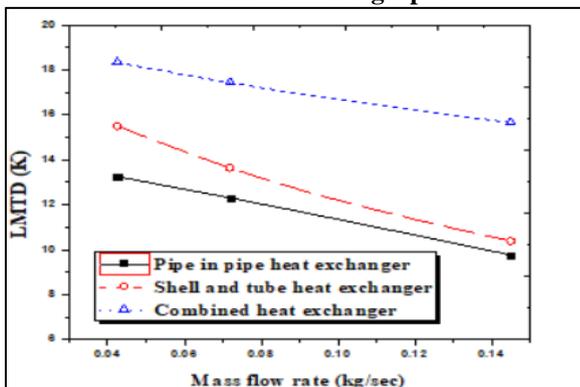
**Table- XII: Effectiveness for different mass flow rates**

$m_f$ (kg/ sec)	Re	Parallel flow			Counter flow		
		$(\Delta T)_p$ (K)					
		P- I-P	S- T	C HE	P- I-P	S- T	C HE
0.14 5	12 71.6	9 .76	1 0.38	1 5.65	1 3.61	1 3.64	1 6.53
0.07 19	91 0.4	1 2.3	1 3.64	1 7.43	1 5.5	1 5.65	1 8.04

## VI. RESULTS AND DISCUSSIONS

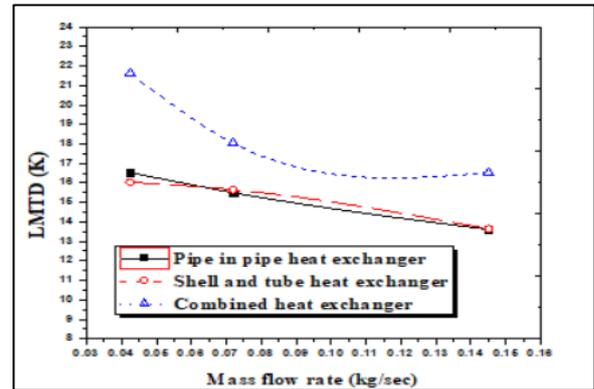
In this report, most of the concentration took part in designing and comparison of three heat exchangers. The comparison is based on various parameters associated to heat transfer process takes place happening designed heat exchangers by varying various rate of mass flows. The obtained experimentation results were presented in

### A. LMTD vs. Mass flow rate graphs:



**Fig. V: variation in LMTD with respect to mass flow rates for co-current stream**

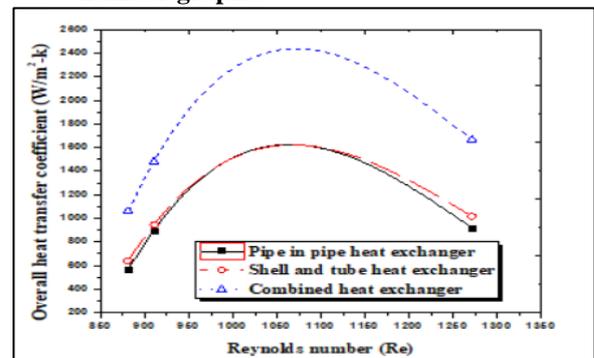
The variation in LMTD with respect to variation in mass flow rate is illustrated in Fig.V. As observed that the LMTD decreases with the increase in mass flow rate in parallel flow in all types.



**Fig. VI Variation in LMTD with respect to different mass flow rates in case of counter flow**

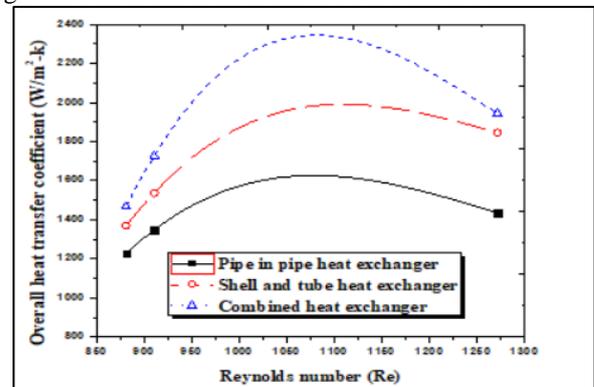
As observed that in the parallel flow, same thing happens in counter flow and it is illustrated in Fig. VI. But when comparing in both cases observed a greater decrease in LMTD in counter flow.

### B. Coefficient of overall heat transfer vs. Reynolds number graphs:



**Fig. VII: Overall heat transfer coefficient with respect to Reynolds number in case of parallel flow**

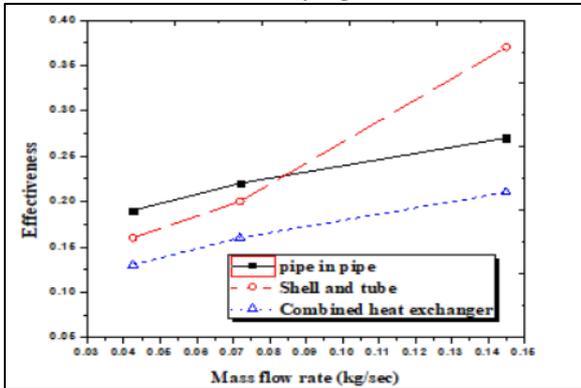
Figure VII representing that in case of parallel flow the overall coefficient of heat transfer increases as there is a raise of Reynolds number. The concave behavior of overall heat transfer coefficient representing that, there is an initial increment and at some Reynolds number, graph has been started and again there is an increment. Compared to both individual graphs, the combined heat exchanger is having higher coefficient of overall heat transfer value.



**Fig. VIII: overall heat transfer coefficient vs. Reynolds number in counter stream condition**

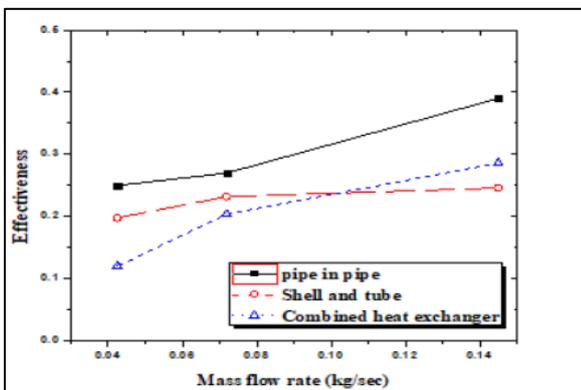
Fig. VIII representing that, the increase of overall heat transfer for counter flow combined heat exchanger is higher compared with parallel stream combined heat exchanger. In counter flow shell-and-tube type, the difference in increment of overall heat transfer coefficient with pipe in pipe heat exchanger is very large.

**C. Effectiveness vs. varying mass flow rates:**



**Fig. IX: variation in effectiveness with respect to mass flow rates of parallel condition**

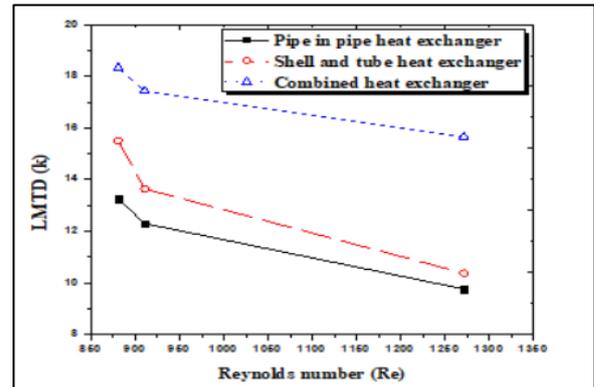
From Fig. IX, the effectiveness is higher for shell-and-tube heat exchanger in parallel flow condition is higher compared to counter flow case. Coming to the effectiveness of combined heat exchanger is gradually increasing with respect to increase in mass flow rate. But, in comparison with remaining individual heat exchangers, the effectiveness was less.



**Fig. X: variation in effectiveness with respect to mass flow rate of counter flow condition**

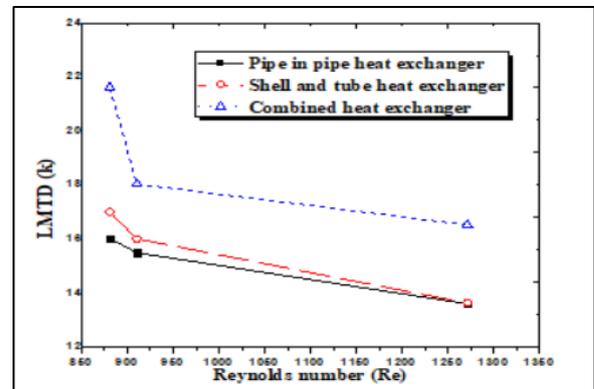
From Fig. X, the higher effectiveness is recorded in pipe in pipe heat exchanger according to Reynolds number of counter stream condition. Finally, the low effectiveness is recorded in heat exchanger of shell-and-tube type according to increase in rate of mass flow. Initially, low effectiveness value with respect to Reynolds number is observed from combined heat exchanger. Later the effectiveness of combined heat exchanger in relation with Reynolds number has been increased for counter flow condition.

**D. LMTD vs. Reynolds number:**



**Fig. XI: Variation in LMTD according to Reynolds number of parallel flow**

From figure 11, the value of LMTD is decreasing with increase in Reynolds number is observed. The LMTD with respect to Reynolds number is higher for combined heat exchanger as observed.



**Fig. XII: variation of LMTD with respect to Reynolds number of counter flow**

From Fig. XII, at larger values of Reynolds number, the difference for variation of LMTD values related to pipe in pipe and shell-and-tube heat exchanger in counter flow condition is almost negligible. But, initially the difference in variation of LMTD values corresponding heat exchanger types of pipe in pipe and shell-and-tube are countable.

**VII. CONCLUSION**

Various parameters corresponding to designed heat exchangers were found and compared with the help of recorded temperatures of their inlets and outlets by using k-type thermocouples. Obtained coefficient of overall heat transfer values corresponding to combined heat exchangers is higher in case of both parallel flow and counter flow. Whereas the effectiveness for the combined heat exchangers are smaller in comparison with individual heat exchangers. Working fluid exploited for this research well suits to cooling purpose.

The few more observations that are obtained from this report are as follows:

# Experimentation on Augmenting Heat Transfer Characteristics of (Ethylene Glycol + Water) Mixture in A Combined (Pipe in Pipe and Shell & Tube) Heat Exchanger

➤ There is a decrement in LMTD with respect to mass flow rate increment in three different heat exchangers for the considered parallel and counter flows. i.e., the highest decrement in LMTD recorded for 0.0425 to 0.145 increase of mass flow rate is 15.5 to 10.38 in shell-and-tube heat exchanger of parallel stream case.

➤ Higher LMTD values were observed for combined heat exchangers i.e., 18.33<sup>o</sup>C in parallel flow condition and 21.62<sup>o</sup>C in counter flow condition at lower mass flow rate (within the considered values) of 0.0425kg/sec.

➤ An increment in overall heat transfer coefficient with respect to increase in mass flow rate is observed. Highest coefficient of overall heat transfer value observed as 1943w/m<sup>2</sup>-k at highest mass flow rate (within the considerations of this work) of 0.145 kg/sec.

➤ Mass flow rate is directly proportional to the Reynolds number. Since  $Re = \frac{\rho V D}{\mu}$ , the velocity (V) is directly proportional to the mass flow rate.

➤ The effectiveness for the combined heat exchangers are less compared to the individual heat exchangers. The larger value of effectiveness is observed in case of counter flow pipe in pipe heat exchanger i.e., 0.39 at the mass flow rate of 0.145 kg/sec.

## NOMENCLATURE

PARAMETER	DESCRIPTION	UNITS
m <sub>f</sub>	rate of fluid mass flow	kg/sec
V	fluid velocity	m/sec
ΔT	Logarithmic Mean temperature Difference	<sup>o</sup> C
T <sub>H1</sub>	Inlet temperature of hot fluid	<sup>o</sup> C
T <sub>H2</sub>	outlet temperature of hot fluid	<sup>o</sup> C
T <sub>C1</sub>	Inlet temperature of cold fluid	<sup>o</sup> C
T <sub>C2</sub>	Outlet temperature of cold fluid	<sup>o</sup> C
Re	Reynolds number	-
Nu	Nusselt number	-
C <sub>h</sub>	Specific heat of the hot fluid	j/ kg-k
C <sub>c</sub>	Specific heat of the cold fluid	j/ kg-k
ρ	Density of the fluid	kg/m <sup>3</sup>
μ	Dynamic viscosity of the fluid	Cp
Q	Heat transfer rate	watt
U	Overall heat transfer coefficient	W/mK
ε	Effectiveness	-

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