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Fabrication and Experimental Analysis of Heat Transfer Characteristics of Acetone /Water by using Tube in Tube and Shell and Tube Heat Exchanger

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Abstract*: Cooling is essential to maintain the required efficiency and reliability in a wide range of products such as automobiles, high and medium cogeneration power plants, high power laser systems. Part of heat load amplification and the heat fluxes induced by more industrial products, cooling is one of the industry's main technical problems such as manufacturing, transport and in microelectronics. The main content of the paper is to study the LMTD (logarithmic mean temperature difference), Heat transfer Coefficient and Effectiveness (ε) of combined heat exchanger using acetone/water mixture as a function of a different mass flow rates. This paper deals with the experimental study on the three different heat exchangers like tube in tube, shell and tube and combined (tube in tube & shell and tube) heat exchanger with acetone/water mixture mostly to check the elevation of convective heat transfer coefficient, LMTD, effectiveness, overall heat transfer coefficient. This experimentation work give a summary of, the experimental study of the forced convective heat transfer and flow characteristics of a 25% acetone consisting of 75% water. Acetone/water mixture flow in to a parallel, counter direction in the tube in tube, shell and tube heat exchanger and combined heat exchanger under laminar flow conditions. A maximum increase in the coefficient of convective heat transfer of 58.4% and an effectiveness of 48.5% is recorded. However, combined heat exchanger provides better heat transfer characteristics than parallel and counter flow tubular and shell and tube heat exchanger due to the multi-pass flow of acetone/water. The overall heat transfer coefficients, Reynolds number, logarithmic mean temperature difference, the effectiveness of the acetone/water are also studied and the results are presented in tabular columns and figures.

***Keywords:* Acetone/water, LMTD, Overall heat transfer coefficient, Effectiveness, Nusselt number and Reynolds number.**

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I. INTRODUCTION

Heat exchangers are equipment that affects the heat exchange process between two fluids at distinct temperatures. These heat exchangers are usually categorized according to the method of transferring them. Tube in tube & shell and tube thermal exchangers are mainly used among all kinds of heat exchangers. Based on fluid flow, these heat exchangers are again categorized. They are sort of parallel flow, type of counter flow and sort of cross flow. In this experiment, we will manufacture and combine a tube in a fixed tube type tube heat exchanger & shell and tube heat exchanger. Using thermocouples, the efficiency and heat transfer coefficient of the fixed tube in tube Heat exchanger & shell and tube is produced at varying temperatures. Either hot or cold fluid occupies the annular space and other fluid moves through the internal tubes in tube & shell and tube heat exchanger. If a fluid flows in the direction of the other fluid, the flow is said to be parallel and if the fluid flow is contrary to the direction of another fluid flow, the flow is said to be counter flow.

II. LITERATURE SURVEY

A broad variety of research is already being performed to study the flow and heat transfer features in Tube in tube & shell and tube heat exchangers. The type of fluid flow is responsible for enhancing heat transfer in the Tube in tube & shell and tube. Due to the type fluids like nanoparticles and high cost fluids to increase heat transfer rate. By this literature to make project by reduction of cost by using organic solvent instead of nanofluids.

The option of using as process heat transfer fluid the acetone / water combination is explored thermally. In addition, the acetone / water mixture thermal transfer features will be experimentally studied using the test facility, which is manufactured based on the calculation of the design. The implant of tube in tube and shell and tube in the test section used to conceive the forced convection, which will improve the heat transfer rate. Baskar, Karthikeyan-2013 [1]. The results are also responsive to the baffle cut selection, for this shell and tube heat exchanger 25% baffle cut gives slightly improve the results, Durgesh Bhatt, Priyanka M Javhar-2014[2], they carried out a Shell and Tube Heat Exchanger Performance Analysis It is noted that by altering the value of one variable, we can achieve distinct outcomes by maintaining the remaining variable as constant.

Based on this consequence, we can optimize the heat exchanger type tube in tube, shell and tube and combined heat exchanger design. Less is the spacing of the baffle, more is the passing of the shell side, greater the transfer of heat, but at the expense of the fall in stress.

In this work 25% of baffle cut are used. The tube-baffle leakage and bypass streams play a significant part in explaining the heat exchanger's performance factor of single segmental baffle shell and tube heat exchanger. Saurabh Sharma-2017 [3].

This research work summarizes the experimental study of the forced convective heat transfer and flow characteristics of a 25% acetone consisting of 75% water. Acetone/water mixer flowing in a parallel, counter direction in tube in tube, shell and tube heat exchanger and combined heat exchanger under laminar flow conditions to find the overall heat transfer coefficient, logarithmic mean temperature difference(LMTD) and effectiveness of the heat exchanger.

III. EXPERIMENTAL SETUP

The experimental set-up is fabricated in such a way that it is consisting of tube in tube section and shell and tube section heat exchanger. Both heat exchangers are interconnected with PU (Polyurethane) tubes as required flow arrangements like the parallel and counter flow and combination of the heat exchanger is called Combined HE (Heat Exchanger) as shown in Fig.1. It is tested at various Mass Flow rates. The PU (Polyurethane) tubes are flexible and reusable as per our test requirement for flow arrangements like the parallel flow and counter flow in tube in tube heat exchanger, Shell and tube heat exchanger and Combined HE (Heat Exchanger). The left side tank is cold tank; right side tank is hot tank. The Hot tank is equipped with a heater inside to heat and supply of acetone / water to the heat exchangers at different temperatures. At room temperature, tank on the left side is normal acetone / water that are cold acetone / water.

Fig. 1.Combined Heat Exchanger (Tube in tube + Shell and tube) Experimental setup

Thus, cold acetone/water is passed through the heat exchangers, which leads to an increase in heat transfer between the hot acetone/water in the inner tube and the cold acetone/water which surrounds the outer tube in Tube in Tube heat exchanger, the cold acetone/water in the inner tube and the hot acetone/water which surrounds the outer tube in shell and tube heat exchanger. The heat exchangers shown in this experimental setup are parallel and counter flow heat exchanger and shell and tube heat exchanger. The hot fluid flow and cold fluid flow are controlled by flow regulating valve and fluid flow is measured by measuring jar with respect to time. Taken by a three different mass flow rates of acetone/water with 2 liters jar with respect to time 2litres/14sec, 2litres/28sec and 2litres/42sec to be calculated as 0.142 kg/sec, 0.0714 kg/sec and 0.0476 kg/sec respectively. The hot tank is provided with a heater and stirrer. The stirrer helps in maintaining the upper surface temperature and the lower surface temperature in constant state. The 2 tanks each are of the capacity of 6 liters.

This guarantees continuous water flow to the piping netwo rks. Individual heat exchangers are operated one by one i.e. Tube in tube, shell and tube & combined HE. In this setup, the four regulator valves are used. The 5 tubes are used in shell and tube is with 4 mm in diameter and 600 mm in length. The diameter of inside shell in shell and tube is 76 mm and 600 mm in length. The heat exchanger area is the same all the same. The diameter of outer tube is 82 mm in tube heat exchanger, and length is 600 mm. In tube in tube heat exchanger, inner tube of Tube is 21 mm in diameter and 600 mm in length. The heat exchangers are of the same range and under the same conditions are operated at the same flow rates. Table on which the experimental set-up is made by 900 x 1500 mm in size. Type of pipe that is used in experimental-setup is a 19.05mm inside diameter of (PU) Polyurethane pipe.

In this project, we are using Acrylic fiberglass tube for outer tube of both Tube in tube & shell and tube. It is like a transparent glass tube, which is observing floating of the fluid flow inside the shell. Acrylic fiberglass tube dimensions are 82 x 3 mm, 76mm inner diameter and 600mm in length.

IV. METHODOLOGY

The heat exchangers are designed normally by using either Kern's method or Bell-Delaware method. Kern's method is mostly used for the preliminary design and provides conservative results whereas; the Bell-Delaware method is more accurate method and can provide detailed results. It can predict heat transfer coefficient with better accuracy. In this paper we have designed as fixed tube type heat exchanger to cool the water from 70 to 40 by using acetone/water at room temperature.

A. For Tube in tube Heat Exchanger, shell and tube heat exchanger and for combined heat exchanger

- Firstly the acetone/water is heated to the required temperature with an immersion heater.
- Then supply the hot acetone / water in inside of the tube and cold acetone/water is supplied to outer tube.

- Experiment is repeated for different mass flow rates and at each flow rate the temperature value of hot acetone/water inlet noted down the readings of inlet and outlet temperatures in the observation table.
- After getting the values in the observation table, calculate the required parameters using mathematical expressions in tube in tube heat exchanger.
- First parallel flow observations were taken and then interchanged the pipe connections to carry out the same procedure for counter flow arrangement.

B. Objective in selection of Acetone as a fluid in heat exchanger

Acetone is generated and disposed of by ordinary metabolic processes in the human body. It usually occurs in blood and urine. It is produced in greater quantities by people with diabetes. Reproductive toxicity testing shows that it can cause reproductive issues with low potential.

Ketogenicicdiets that boost ketone bodies in the blood (acetone, β-hydroxybutyric acid and acetocytic acid) are used to combat epileptic assaults in babies and kids with recalcitrant refractory epilepsy.

Fig. 2.Preparation of acetone/water mixing

C. Preparation of Acetone Water Mixture

It is an important stage undertaker while mixing both fluids by using measuring jar mix the 25% of acetone liquid and 75% of water by measuring with 2-liter jar 0.5 liters acetone and 1.5 liters water as shown in the figure 2. The properties of the mixture (acetone / water) as shown in Table I.

Table- I: Properties of mixture (acetone / water) fluid

S.No	Property	Liquid Acetone-water mixture fluid
1.	Specific heat (c), J/kg-K	3678
2.	Thermal Conductivity (k), W/mk	0.4975
3.	Density (ρ), kg/m^3	947.5
4.	Thermal diffusivity (α), m^2/s	1.351×10^{-7}

D. Mathematical Modeling

First, to find the values of certain unknown temperature values, we consider the energy balance. The equation of the energy balance can be provided as:

$$Q=m_1c_1\,(T_1-T_2) = m_2c_2\,(T_2-T_1) \qquad (1)$$

Then consider the value of the LMTD expression:

$$\Delta T_m= (\Delta T1 - \Delta T2) / \ln(\Delta T1/\Delta T2) \qquad (2)$$

Where $\Delta T_1= T_1-T_2,\ \Delta T_2= T_2-T_1$

Then by using the amount of heat transfer formula, we can get the heat transfer quantity:

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

Intended to find the Effectiveness of heat transfer by the following:

$$\varepsilon=Q/\,(C_{min}*\,(T_1-t_1)) \qquad (4)$$

Add the Empirical correlation for Nusselt Number:

$$Nu=3.66+\frac{0.668\,{}^{D}\!/\!{}_{L}\,Re_D Pr}{1+0.04\left({}^{D}\!/\!{}_{L}\,Re_D Pr\right)^{0.67}} \qquad (5)$$

Reynolds Number based on diameter with respect to mass flow rate:

$$Re_D= (4m) / (\pi D\mu) \qquad (6)$$

V. RESULTS AND DISCUSSION

Initially, the experimental setup is verified for any defects by allowing the water to flow in the heat exchanger. Then, acetone/water is used as the fluid to exchange the heat. The inlet and outlet temperature of the hot and cold fluid is measured using K type thermocouple and the temperature indicator. This is like digital thermometer.

Experimentation was used to measure the hot fluid inlet temperature and the hot fluid outlet temperature, the cold fluid inlet temperature and the cold fluid outlet temperature at distinct Mass flow rates. Based on the mass flow rate and several parameters, the Reynolds number (Re) was calculated, Several parameters such as Overall heat transfer coefficient (U), Logarithmic mean temperature difference (LMTD), Effectiveness (ε), Convective heat transfer coefficient (h) W / m^{2}k and was calculated using equations.

Table- II: Experimental Results of Acetone / Water fluid of Parallel flow by varying mass flow rate

Parallel flow heat exchanger arrangement									
Mass flow rate (kg/sec)	Tube in tube			Shell and tube			Combined heat exchanger unit		
	LMTD (°C)	(ε)	h (W/m^2K)	LMTD (°C)	(ε)	h (W/m^2K)	LMTD (°C)	(ε)	H (W/m^2K)
0.142	9.2	0.18	145.7	12.24	0.25	151.82	13.89	0.485	154.79
0.0714	10.08	0.16	114.35	14.83	0.23	116.36	15.62	0.45	118.99
0.0476	11.39	0.145	98.71	16.62	0.19	100.56	17.32	0.423	105.31

Table- III: Experimental Results of Acetone / Water fluid of Counter flow by varying mass flow rate

Counterflow heat exchanger arrangement									
Mass flow rate (kg/sec)	Tube in tube			Shell and tube			Combined heat exchanger unit		
	LMTD (°C)	(ε)	h (W/m^2K)	LMTD (°C)	(ε)	h (W/m^2K)	LMTD (°C)	(ε)	h (W/m^2K)
0.142	9.98	0.241	147.93	11.28	0.301	152.98	12.31	0.386	156.36
0.0714	11.23	0.19	118.32	13.16	0.231	121.36	14.19	0.273	125.18
0.0476	13.31	0.132	102.21	15.02	0.164	107.15	16.21	0.22	109.23

Table- IV: Experimental Results of Acetone / Water fluid of Parallel flow by varying Reynolds number

Parallel flow heat exchanger						
Reynolds number (Re)	Tube in tube		Shell and tube		Combined heat exchanger unit	
	LMTD (°C)	**U (W/m^2K)**	**LMTD (°C)**	**U (W/m^2K)**	**LMTD (°C)**	**U (W/m^2K)**
1948	9.2	352.32	12.24	644.65	13.89	674.41
979	10.08	175.91	14.83	321.87	15.62	336.77
653	11.39	117.27	16.62	214.56	17.32	224.51

Table- V: Experimental Results of Acetone / Water fluid of Counter flow by varying Reynolds number

Counterflow heat exchanger						
Reynolds number (Re)	Tube in tube		Shell and tube		Combined heat exchanger	
	LMTD (°C)	**U (W/m^2K)**	**LMTD (°C)**	**U (W/m^2K)**	**LMTD (°C)**	**U (W/m^2K)**
1948	9.98	433.09	11.28	445.38	12.31	888.1
979	11.23	216.2	13.16	229.91	14.19	443.2
653	13.31	144.13	15.02	158.62	16.21	295.35

The LMTD of acetone and water mixed fluid in the tube in tube, Shell and tube and combined Heat exchanger concerning the Mass flow rate (m) which varies from 0.04076 to 0.1420 kg/sec in the parallel flow heat exchanger as shown in Figure 3.

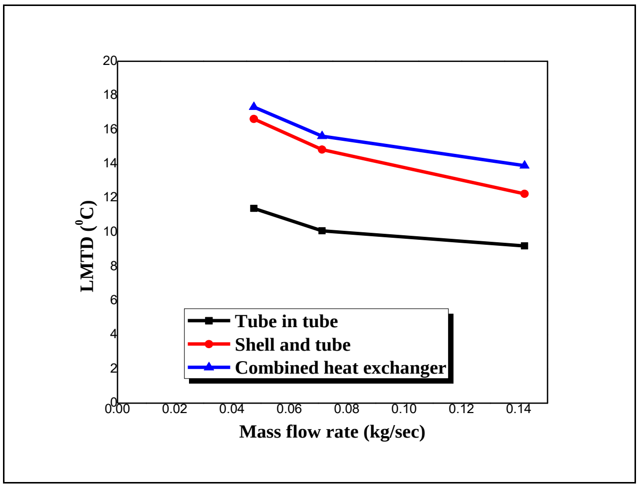

Fig. 3.Variation of the mass flow rate vs. LMTD in the parallel-flow arrangement for three heat exchangers

The increase in LMTD of mass flow rate at 0.142 kg/sec is observed to be 50.97% in combined heat exchanger compared with Tube in tube Heat exchanger. The combined Heat exchanger is 13.48 % more than Shell and tube Heat exchanger by using an acetone and water mixture fluid.

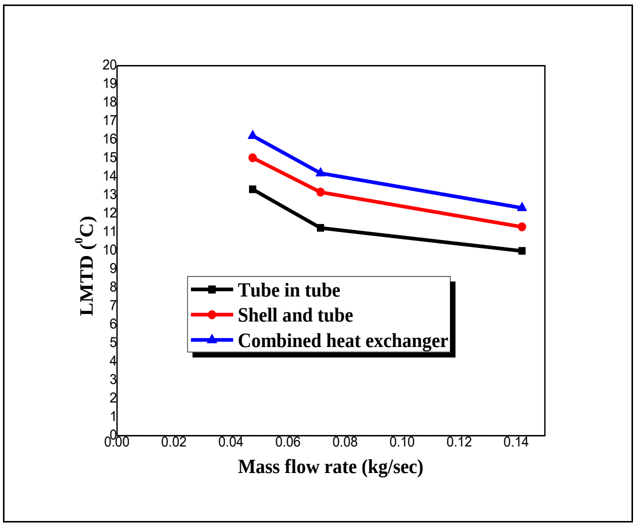

Fig. 4.Variation of the mass flow rate vs. LMTD in the counter-flow heat exchanger for three heat exchangers

The LMTD of acetone and water mixed fluid in a tube in tube, Shell and tube & combined Heat exchanger concerning the Mass flow rate (m) which varies from 0.04076 to 0.142kg/sec in the counter flow heat exchanger as shown in Figure 4. The increase in LMTD of mass flow rate 0.142 kg/sec is observed to be 23.34% in Combined Heat Exchanger, when comparing with tube in tube Heat Exchanger. The combined heat exchanger is 9.13 % increment than shell and tube heat exchanger by using an acetone and water mixture fluid.

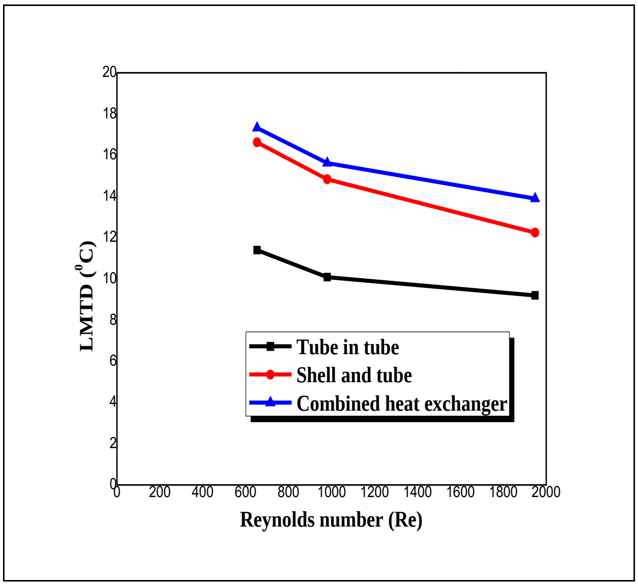

Fig. 5.Variation of Reynolds number vs. LMTD in parallel flow arrangement for three heat exchangers

Figure 5 Shows the variation of Re and its LMTD in parallel flow arrangement of Tube in tube heat exchanger, Shell and tube heat exchanger & Combined heat exchanger. The combined HE is 50.97% increasing in LMTD at Reynolds number 1948 when comparing with Tube in tube heat exchanger by using acetone/water. The combined heat exchanger claims 13.48% in comparison of shell and tube.

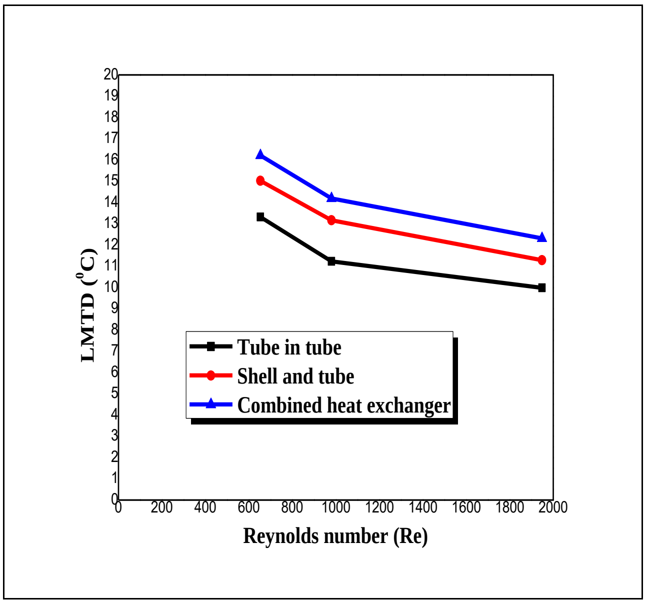

Fig. 6.Variation of Reynolds number against LMTD in the counter-flow heat arrangement for three heat exchangers

In Figure 6 Observe the variation of LMTD concerning Reynolds number in counter-flow arrangement of Tube in tube heat exchanger, Shell and tube heat exchanger & combined heat exchanger. The combined HE is a 23.34% increment in LMTD at Reynolds number 1948 when comparing with Tube in tube and 9.13% with the comparison of shell and tube by using acetone/water fluid.

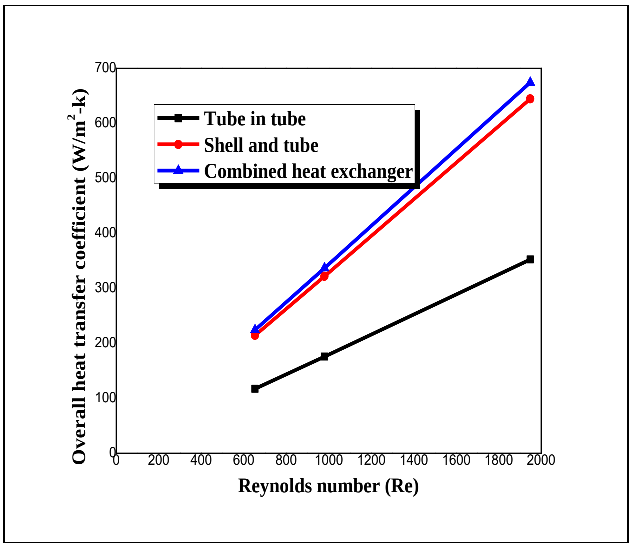

Fig. 7.Variation of Reynolds number against U in the parallel flow arrangement for three heat exchangers

As shown in Figure 7, the Overall heat transfer coefficient of acetone and water mixed fluid in a Tube in tube, shell and tube & combined heat exchanger concerning the Reynolds number 1948 in the parallel flow arrangement. The increase in overall Heat transfer Coefficient is 91.41% of combined heat exchanger compared to tube in tube heat exchanger and 4.61% as to shell and tube by using an acetone and water mixture fluid.

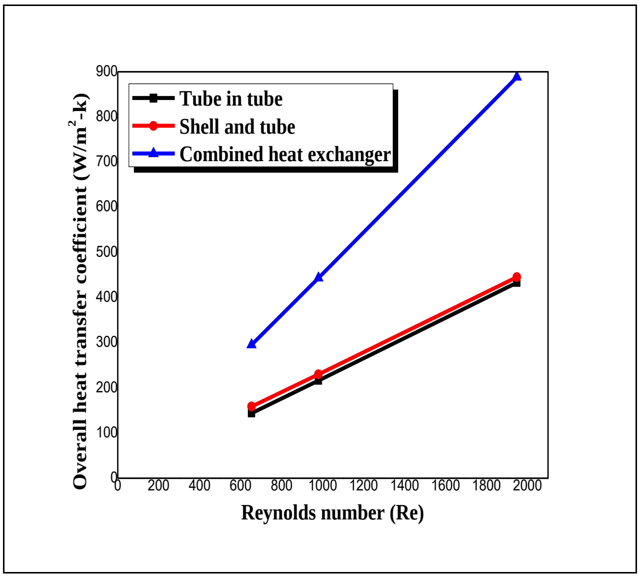

Fig.8.Variation of Reynolds number against U in the counter-flow arrangement for three heat exchangers

As shown in Figure 8, The overall heat transfer coefficient (U) of acetone and water mixed fluid in the Tube in tube, Shell and tube & Combined Heat Exchanger concerning Reynolds number at 1948 in the counter-flow arrangement. The overall heat transfer coefficient values are 888.10 W/m^2K, 445.38 W/m^2K and 433.09 W/m^2K for combined, shell and tube and tube in tube heat exchangers respectively. Increase in overall heat transfer coefficient is 99.40 % of combined heat exchanger.

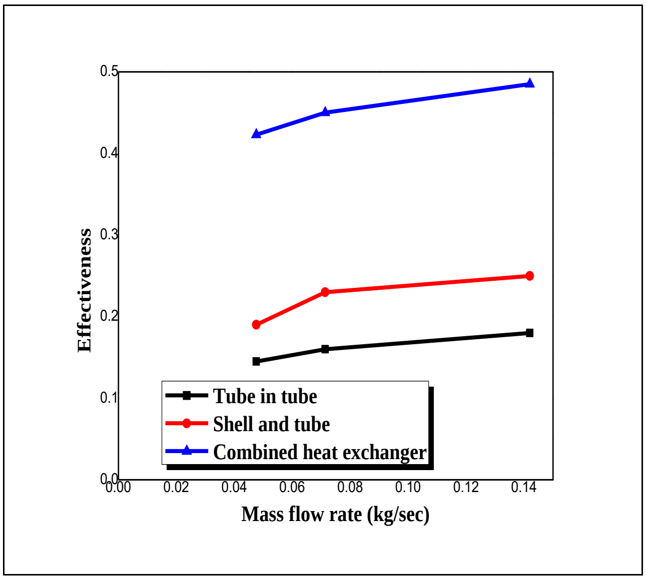

Fig. 9. Variation of effectiveness concerning mass flow rate in the parallel-flow heat exchanger

As shown in Figure 9 Effectiveness in parallel flow by varying three different mass flow rates 0.0476 kg/sec, 0.0714 kg/sec, 0.142 kg/sec to be obtain effectiveness of acetone and water mixture fluid is 14%, 16%, 18%, for Tube in tube Heat Exchanger, 19%, 23%, 25% Shell and tube Heat Exchanger, 42%, 45% and 48.5% for combined tube heat exchanger respectively.

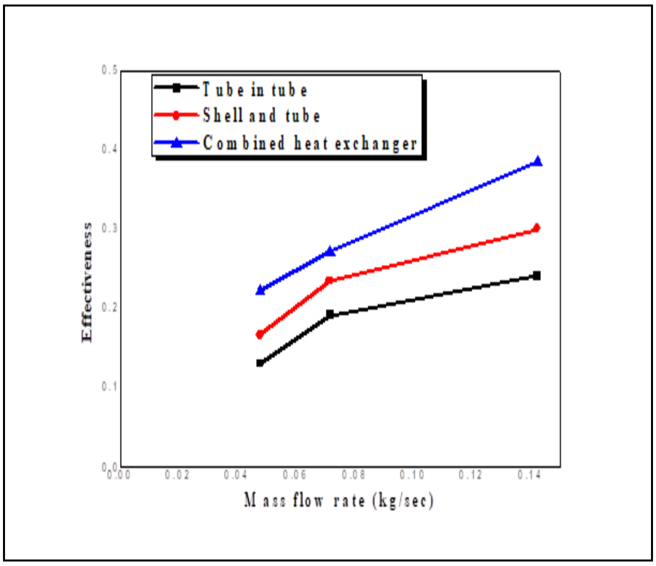

Fig 10: variation of effectiveness concerning the mass flow rate in the counter-flow heat exchanger

From figure 10 Effectiveness in counterflow by varying three different mass flow rates 0.0476 kg/sec, 0.0714 kg/sec, 0.142 kg/sec to be obtain effectiveness of acetone and water mixture fluid is 13.2%, 16.4%, 22% for tube in tube heat exchanger 19.0%,23%,27.3% shell and tube heat exchanger, 24%, 30.1% and 38.6% for combined tube heat exchanger.

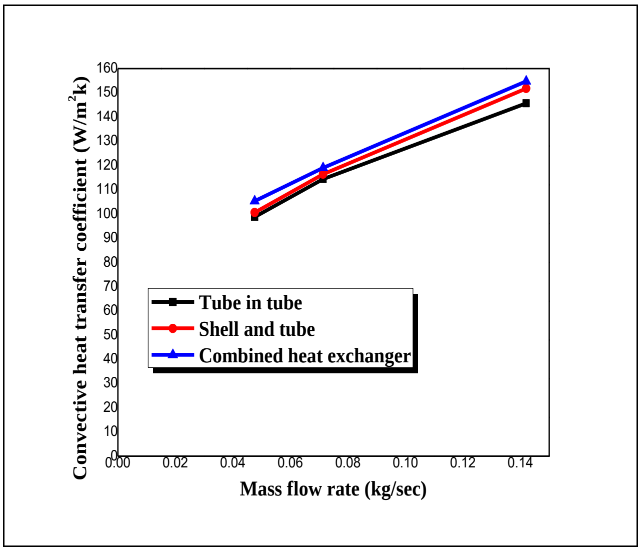

Fig. 11. Variation of Mass flow rate vs. Convective Heat Transfer coefficient in the parallel flow arrangement for three heat exchangers

In Figure 11, shows that Tube in tube, shell and tube & combined heat exchanger are slightly a small variation in convective heat transfer rate with respect to mass flow rate. At 0.142 kg/sec mass flow rate combined heat exchanger is 6.23% more heat transfer coefficient than tube in tube. At 0.142 kg/sec Mass flow rate, the Convective heat transfer coefficient is 145.70 W/m^2K.

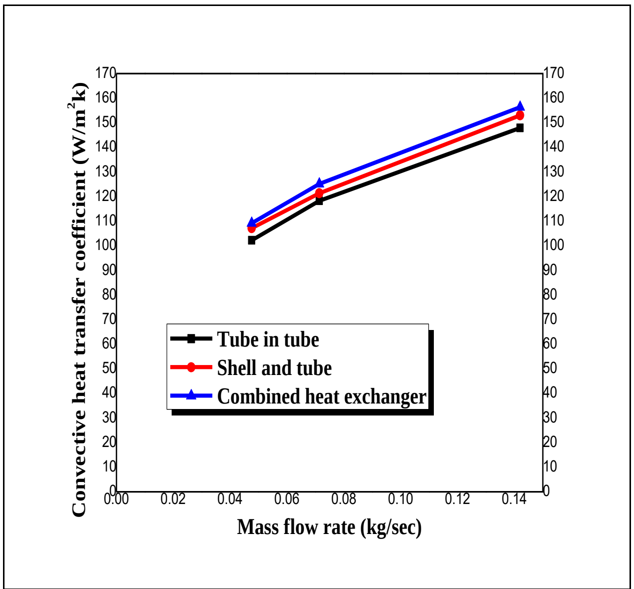

Fig. 12. Variation of the Mass flow rate vs. convective heat transfer coefficient in counter-flow arrangement for three heat exchangers

In this figure 12 A small variations in Tube in tube, Shell and tube & Combined Heat Exchanger. But Mass flow rate increases then convective Heat Transfer rate also increase in order 0.1420 kg/sec, 0.0714 kg/sec and 0.0476 kg/sec the combined heat exchanger is 5.69%, 5.79% and 6.86% with respect to Tube in tube Heat Exchanger.

VI. CONCLUSION

Experimentally studied the Convective Heat Transfer performance and the characteristics of the flow of acetone / water in heat exchangers, Tube in tube, Shell and tube & Combined Heat Exchanger (HE). Experiments were conducted under the conditions of the laminar flow $Re_D < 2300$. The effect of acetone / water and the mass flow rate & Reynolds number of the Heat Transfer performance and the behaviour of the flow of acetone / water in Tube in tube, Shell and tube & Combined Heat Exchanger have been compared by parallel flow arrangement and counter flow arrangement. The combined heat exchanger delivers more heat transfer coefficient enhancements than the Tube in tube & Shell and tube. In this experiment the maximum Heat Transfer rate was observed at 1948 Reynolds number. A maximum enhancement in Convective Heat Transfer coefficient is 156.36 W/m^2K of 58.4% and effectiveness of 48.5% at combined heat exchanger.

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NOMENCLATURES

Nomenclature		Greek symbols	
A	heat transfer area (m^2)	ΔT_m	logarithmic mean temperature difference (°c)
T	temperature (°c)	μ	dynamic viscosity (N s/m^2)
c	specific heat (J/kgK)	ρ	density (kg/m^3)
U	overall heat transfer rate (W/m^2K)	α	thermal diffusivity (m^2/s)
Re	Reynolds number (Dimensionless)	ε	effectiveness
Nu	Nusselt number (Dimensionless)		
h	convective heat transfer coefficient (W/m^2K)		
D	tube diameter (m)		
m	mass flow rate (kg/s)		
T	temperature (°c)		
Q	heat transfer rate (W)		
K	thermal conductivity (W/Mk)		

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