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Comparative Analysis of Different Fluids in One Shell Pass And Two Tube Heat Exchanger

J.E. Igwe* and C.S. Agu
Department of Mechanical Engineering, College of Engineering and Engineering Technology, Michael Okpara University of Agriculture Umudike, Abia State, Nigeria

ABSTRACT: *The comparative analysis and performance evaluation of various proportions of ethylene-glycol and silicon carbide using one – shell – two tube heat exchanger in counter flow arrangement were conducted. Matlab software was used to evaluate the LMTD, NTU, overall heat transfer coefficient U, and effectiveness of the fluids. The various working fluids used in the experiment are water, water-ethylene glycol 100%,water-ethylene glycol 50%, water-ethylene glycol 25%, water - Sic 1%, and water - Sic 2%. It was observed that the water - Sic 2% had the highest heat transfer rate of 225.3206 W/m^2 ^{o}C and highest efficiency of 57.08% as base fluid for cooling, resulting to higher efficiency of the system.*

Keywords: *Ethylene-glycol, heat exchanger, fluids, shell and performance evaluation.*

I. INTRODUCTION

Most industrial processes involve heat transfer and more often, it is required that these heat transfer processes be controlled. Heat transfer is the term used for thermal energy from a hot to a colder body. Heat transfer always occurs from a hot body to a cold one, as a result of the second law of thermodynamics. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped but can only occur through three ways which are conduction, convection and radiation or any combination of that (Rajput, 2000). Though study has also shown that phase change is accompanied with thermal energy transfer.

Theoretically on a microscopic scale, thermal energy is related to the kinetic energy of the molecules. The greater a material's temperature, the greater the thermal agitations of its constituent molecules. Then the regions containing greater molecular kinetic energy will pass this energy to regions with less kinetic energy. Thus, when an object or fluid is at a different temperature than its surroundings or another body, heat transfer will occur in such a manner that the body and the surroundings or surrounding body reach thermal equilibrium.

A heat exchanger is equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running costs. It is a device used for affecting the process of heat exchange between two fluids that are at different temperatures. Heat exchangers are useful in many engineering process like those in refrigerating and air conditioning systems, power systems, food processing systems, chemical reactors and space or aeronautical applications [7]. In heat exchangers the temperature of each fluid changes as it passes through the exchangers, and hence the temperature of the dividing wall between the fluids also changes along the length of the heat exchanger. Heat exchangers are designed to deliver certain heat transfer rate for a certain specified conditions of flow rates and temperature. To get substantial heat transfer area from a double pipe exchanger, it must be long. The result is a high pressure drop, increased pumping costs, and large amounts of metal. This means we need a more compact arrangement that still simulates counter current flow. The Shell and Tube exchangers are used when a process requires large amounts of fluid to be heated or cooled and are suited for higher-pressure applications [9].

There are many different types or designs of shell and tube heat exchangers to meet various process requirements. U-tube type heat exchanger has only one tube sheet and as each tube is free to move with respect to shell, the problem of the differential movement is eliminated. Tubes can be cleaned mechanically, in applications where the tube side fluid is virtually non-fouling fluid. The advantage of U-tube heat exchanger is, as one end is free the bundle can expand or contract in response to the stress differentials. The disadvantage of U-tube construction is that the inside of the tube cannot be cleaned effectively since the U bends require flexible end drill shafts for cleaning [10]. Figure 1 is the diagram of a typical heat exchanger.

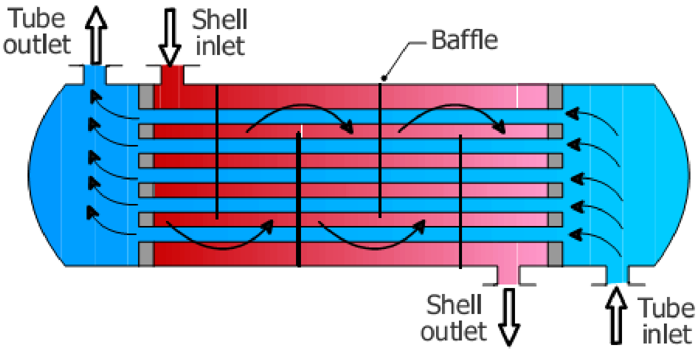

Figure 1: 1-Shell 2-Tube Pass Heat Exchanger

Shell and tube exchangers come in two pass and four pass models standards, and multi-pass custom models. Shell and Tube heat exchangers use baffles on the shell side fluid to accomplished mixing or turbulence. Without the use of baffles, the fluid can become stagnant in certain parts of the shell. A comprehensive treatment of heat exchanger design would involve many factors besides the heat transfer design would involve many factors besides the heat transfer analysis like size, weight, structural length, pressure drop and cost is beyond our scope.

The amount of heat transfer was limited by the heat transfer fluids used. In order to maximize the heat transfer characteristics traditional fluids like oils and ethylene glycol are used further to increase and/or enhance the thermal conductivity of traditional fluids, the solid particles are suspended into the base fluids in heat exchangers .

[1] Performed an experimental analysis to study heat transfer of Nano fluids in a shell and tube heat exchanger. The Nano fluids used were TiO2/water and Al2O3/water under turbulent flow conditions the effect of Peclet number were investigated. This results Nano particle addition to the base fluids enhances the heat transfer coefficient. [2] have determined the thermal balance equations in order to transient distribution of temperature in the core wall and both the unmixed gasses. The aim is the development of quite general exact analytical solution for transient two dimensional temperature distribution for wall and both gasses in cross flow heat exchanger with neither gas mixed. [3] carried out an experimental study in which he compared the performance of Nano fluid based on direct absorption of solar thermal system (DASC) with that of a conventional one. The results obtained revealed that the efficiency increased of an order of 4-6% on using CuO when compared to water. Furthermore, the CuO Nano fluid with 0.005% volume fraction possess 2 –2.5 % of efficiency improvement than 0.05% volume fraction. According to [5], an experimental study has been carried out on the flow and convective heat transfer characteristics of water based Al_2O_3 Nano fluids flowing through a circular tube of 1.812 mm inner diameter with the constant heat flux in fully developed laminar regime. Water-based Al2O3 Nano fluids with various volume fractions ranging from 0.01% to0.3% are manufactured by the two-step method, the heat transfer coefficient

of water-based Al2O3 Nano fluids was increased by 8% at 0.3 to l% under the fixed Reynolds number compared with that of pure water and the enhancement of the heat transfer coefficient is larger than that of the effective thermal Conductivity at the same volume concentration.

[4] investigated on applicability of Nano fluids in high flux solar collectors. Experiments on a laboratory-scale Nano fluid dish receiver suggest that up to 10% increase inefficiency is possible-relative to a conventional fluid- if operating conditions are chosen carefully for 0.125% volume fraction of graphite. [8] investigated the thermal head contribution from heat exchanger when thermally induced natural circulation of fluid occurs. The objective of this research work is to compare the different fluids in one shell pass and two tube heat exchanger

II. MATERIALS AND METHOD

The experimental set up consists of one shell that is fabricated from steel pipe with nominal IPS diameter up to 12 in. Shells are fabricated by rolling steel plate. It is apparent that higher heat transfer coefficient results when a liquid is maintained at a state of turbulence. Two baffle plates are inculcated to the tube bundle. Condenser tubes are made up of brass. The brass having a high thermal conductivity has the capacity to transfer more heat from the hot fluid in shell to the cold fluid in tubes. There are two u-tubes that are kept with square pitch. The tube sheets inserted at ends of the tubes in order to avoid the instability of tubes in the shell and to provide support to withstand pressures.

A separate partition has been created with a non-conducting material in between the cold fluid inlet and cold fluid outlet sections in order to avoid the mixing of fluids. The various working fluids used in this experiment are water, pure ethylene glycol, and 50% of ethylene glycol, 25%ethylene glycol, 1% volume fraction of Sic and 2% volume fraction of Sic with water as base fluid. The working fluid silicon carbide Nano fluid is used with the advantages of having low density with high thermal conductivity among the ceramic compounds. It is comparatively cheap and commercially available. The colour of nanoparticles is grey and black. With the cheap potential availability the black coloured 100nm sized have been used for the preparation of Nano fluid. The thermal conductivity of the Nano fluid increases when compared with the base fluid. The Nano fluids are prepared by two-step method by the ultra sonicator and the stirrer breakdown the aggregates of the nanoparticles. The suspension and addition of surfactants help in adjusting the PH value of Nano fluids. The adjustment of Nano fluids prevented the reaggregation of nanoparticles and improved the stability of Nano fluids. The Nano fluid is prepared by stirring for 8 hours and the settlement of the particles is avoid for five hours. Always the hot fluid water is kept used in the shell with a temperature of331K. On the other side the tube side various working fluid sare varied and those are water, pure ethylene glycol, 50%,25%volume concentrations of ethylene glycol and 1%,2% volume concentrations of Sic with water as base fluid are allowed at a temperature of 300K.

2.1 Determination Of Models

The models adopted in the evaluation of different parameters were as suggested by [7]

2.1.1 Heat Transfer Rate (Q)

The heat transfer rate was determined from the expression

$$Q = \dot{m}_k \ X \ c_{pk} \ X \left(T_{K1} - T_{K2}\right) = \dot{m}_k \ X \ c_{pk} \ X \left(T_{C2} - T_{C1}\right) \quad (1)$$

2.1.2 Effective logarithmic mean temperature difference (LMTD)

$$\theta_m = \frac{\left(T_{K1} - T_{K2}\right) - \left(T_{C2} - T_{C1}\right)}{\left[In\left(\frac{T_{K1} - T_{K2}}{T_{C2} - T_{C1}}\right)\right]} \quad (2)$$

2.1.3 Logarithmic mean temperature difference correction factor (F)

The correction factor is a function of the shell and tube fluid temperatures. This factor uses two dimensionless temperature ratios as shown in equation 3

$$P = \frac{\left(T_{C2} - T_{C1}\right)}{\left(T_{K1} - T_{C1}\right)} \quad (3)$$

Where P = ratio of cold fluid temperature difference and hot fluid temperature difference.

$$R = \frac{\left(T_{K1} - T_{K2}\right)}{\left(T_{c2} - T_{C1}\right)} \quad (4)$$

Where R = ratio of hot fluid temperature difference and cold fluid temperature difference.
The correction factor, F is estimated from charts using calculated value of P and R

2.1.4 Overall heat transfer coefficients (U)

The overall heat transfer coefficient is evaluated from equation 5

$$U = \frac{Q}{AF(\theta_m)}, \ A = \frac{Q}{AF(\theta_m)} \quad (5)$$

Where Q = Heat transfer rate in the heat exchanger
A = Surface area
F = correction factor of logarithm mean temperature difference
θ_m = Logarithmic mean temperature difference.

2.1.5 Velocity of the Exit Temperature of Hot (V)

The velocity of the exit temperature is given by the following expression

$$V = \frac{4\dot{m}}{\rho A} \qquad (6)$$

2.1.6 Capacity Ratio R,

The capacity ratio is computed using the equation stated below

$$R = \frac{\dot{C}\min}{\dot{C}\max} \qquad (7)$$

2.1.7 Number of transfer units

The number of the transfer units was obtained from equation 8

$$NTU = \frac{UA}{C_{\min}} \qquad (8)$$

2.1.8 Reynolds Number

The Reynolds Number was deduced from equation 9

$$\mathrm{Re} = \frac{4\dot{m}}{\Pi \mu D} \qquad (9)$$

2.1.9 Heat exchanger effectiveness (ε_H)

Effectiveness of a heat exchanger was calculated from equation 10

$$\varepsilon_H = \frac{1 - \exp[-NTU(1-R)]}{1 - R\exp[-NTU(1-R)]} \qquad (10)$$

III. RESULTS AND DISCUSION

3.1 Results

The results of this research work was presented in table 1 – 3 and figure 1-6

Table1: Thermal Properties of Working fluid

Fluids	Density (kg/m^3)	Heat capacity (J/KgK)	Viscosity (Ns/m^3)	Thermal conductivity (W/mK)
Water	998	4182	0.001003	0.600
Ethylene glycol (pure)	1180	2470	0.0014	0.253
Ethylene glycol (75%)	1077	3412	0.0028	0.253
Ethylene glycol (25%)	1040	3856	0.0017	0.2353
Sic-water (1%)	1015	4812	0.001	0.661
Sic-water (2%)	1037	4812	0.001	0.680

Table 2: Temperature of fluids

Working fluid (tube side)	Cold fluid inlet (^{o}C)	Cold fluid outlet (^{o}C)	Working fluid (shell side)	Hot fluid inlet (^{o}C)	Hot fluid outlet (^{o}C)
Water	26.7	28.4	Water	58	54.8
Pure ethylene glycol	26.7	28.3	Water	58	54.9
50%ethylene glycol	26.7	28.1	Water	58	55.4
25%ethylene glycol	26.7	28.2	Water	58	55
Sic 1%	26.7	29.6	Water	58	54.7
Sic 2%	26.7	29.7	Water	58	54.8

Table 3: Reynolds number and thermal effectiveness of the fluids

S/N	FLUID	Q_c (W)	Q_h (w)	LMTD (^{o}C)	U W/m^{2}c	Velocity X10^{-5}	Cmin W/^{o}C	Cmax W/^{o}C	R	NTU	Reynolds No.	Effectiveness (%)
1	Water	507.8102	2542.7	2.3715	145.0060	4.8467	298.7119	794.5800	0.3759	0.7168	362.6447	47.48
2	ethylene glycol 100%	282.2835	2462.3	2.2679	84.2887	4.0992	176.4272	496.3000	0.3555	0.7055	259.8090	47.19
3	ethylene glycol 75%	341.1973	2065.9	1.9385	119.1921	4.4912	243.7123	648.2800	0.3759	0.7222	129.9045	47.71
4	ethylene glycol 25%	413.1396	2383.7	2.1640	129.2847	4.6510	275.4264	732.6400	0.3759	0.6932	213.9604	46.45
5	si-water 1%	996.7635	2662.1	3.0957	218.0424	4.7655	343.7115	914.2800	0.3759	0.9368	363.7327	56.00
6	si-water 2%	1031.1000	2542.7	3.0989	225.3206	4.6644	343.7115	914.2800	0.3759	0.9681	363.7327	57.08

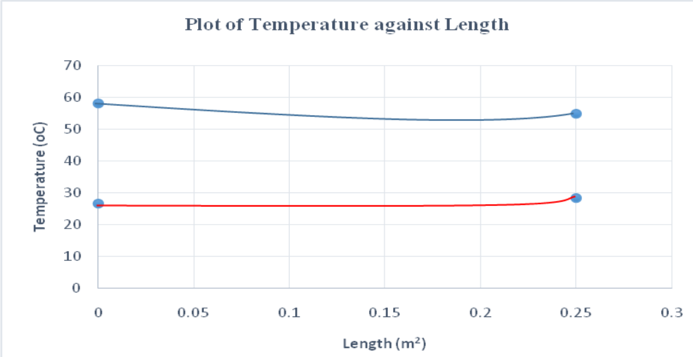

Figure 1 A graph plot of temperature against length shows the flow profile of the working fluids.

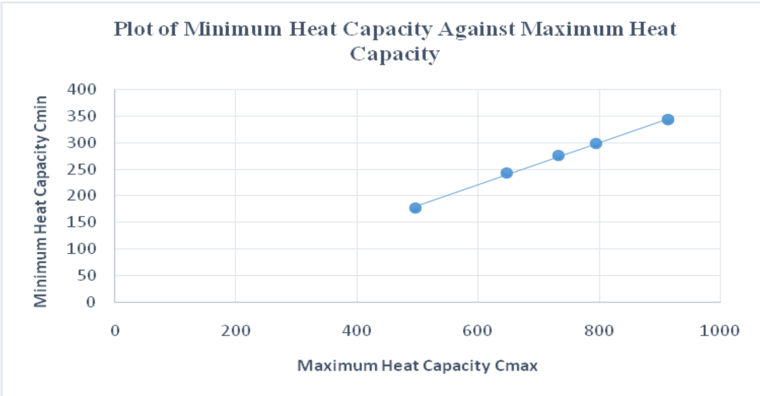

Figure2. Graph of Minimum Heat Capacity against maximum Heat Capacity

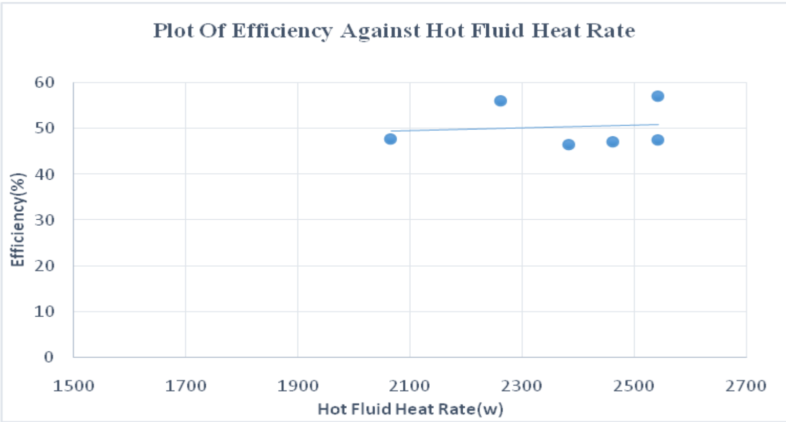

Figure3. Graph of Efficiency against Hot fluid Heat fluid Rate

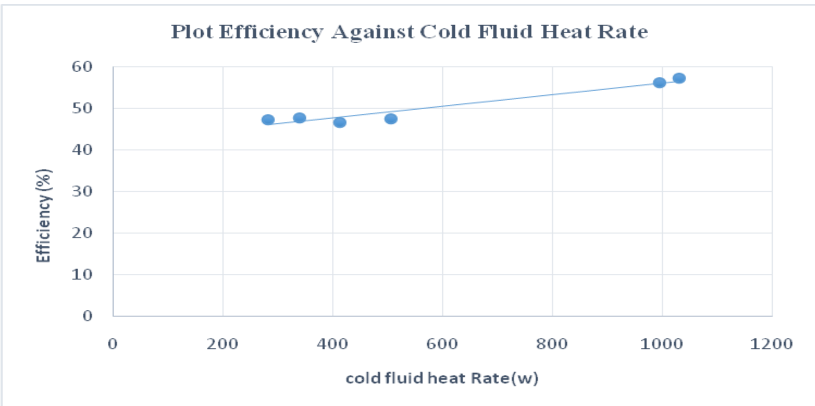

Figure 4. Graph of Efficiency against cold fluid Heat fluid Rate

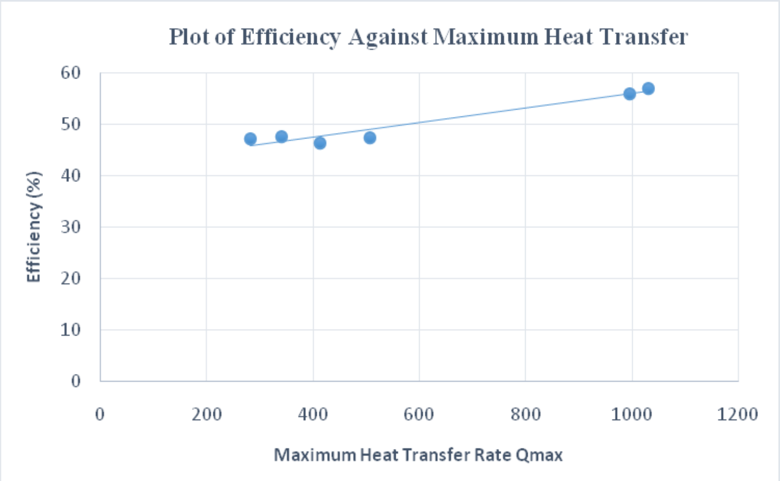

Figure 5. Graph of Efficiency against Maximum Heat Transfer Rate

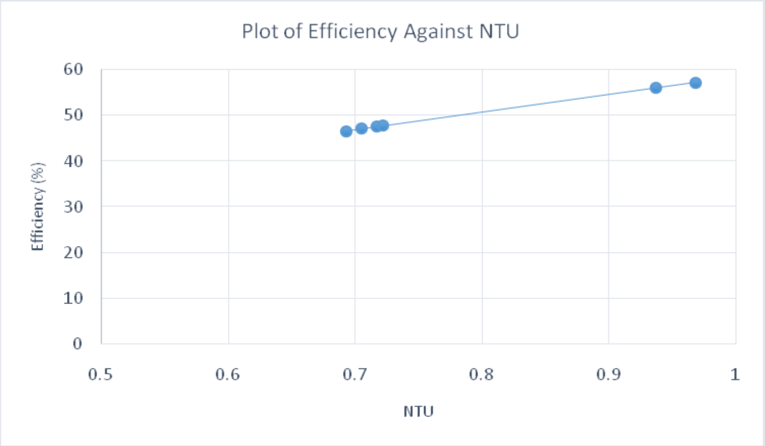

Figure 6. Graph of Efficiency against Number of transfer Units

3.2 Discussion

Table 1 presents the results of the thermal properties of the working fluids. From the table it was observed that water has thermal conductivity of 0.600W/mk, pure ethylene glycol and 75% ethylene glycol recorded the same value of 0.253W/mk thermal conductivity respectively while 25% ethylene glycol had 0.2353W/mk thermal conductivity. Silicon-water at 1% and 2% respectively has average thermal conductivities of 0.661W/mk and0.680W/mk.

Table 2 shows the temperature of the working fluids at the outlet and the shell side of the heat exchanger. The temperature of the hot fluid at the outlet for the different fluids under study range from 54.8 to 55.4^{o}C.

Results of Table 3 indicate that Si-water at 1 and 2% have the same and highest Reynolds Number of 363.7327 respectively with corresponding thermal effectiveness of 56.00 and 57.o8% respectively while ethylene glycol at 25% had the least Reynolds Number of 213.9604 wiyh corresponding thermal effectiveness of 46.45%.

Figure 1 a graph plot of temperature against length shows the flow profile of the working fluids. Showing a harmonic (laminar) which was also proven by the calculated Reynolds Number (Re).

Figure 2 show plot of minimum heat capacity against maximun. The points shows capacity ration R of the various fliuds used in ths experiment. Increase in both heat capacities results to a more efficient capacity ratio; and water-si base(1% and 2%) has its R, at same point.

Figure 3 show plot of efficiency against hot water flow rate. It could be seen from the plot profile that water – si 2% base fluid has the highest point. Also, the points of both water – si (1% & 2%) is perpendicular to the X-axis and could be deduced that increase in percentage of silicon can result to increase in an efficiency of the system.

Figure 4 is a plot of efficiency against cold fluid heat rate (Qc). The water – si based fluids has higher points that the other fluids. As such heat gain was higher with the water-si based fluids.

Figure 5 is the plot of efficiency against maximum heat transfer rate (Qmax), With its plot profile showing actual heat transfer (Q); it could be seen that actual heat transfer happened more in water-si based fluids (1% & 2%).

Figure 6 plot efficiency against NTU. As the graph shows that the water-si based fluids has Higher point. An NTu as a measure of system efficiency was proven true i.e the higher the NTU of a fluid the higher the efficiency of a heat exchanger.

The Reynolds Numbers were all found to be less than 2300 i.e Re<2300 as such laminar flow of fluids were proven.

IV. CONCLUSION

The numerical analysis had shown calculated LMTD, NTU, Overall heat transfer coefficient capacity ratio and effectiveness of the working fluids (i.e. water, water-ethylene glycol 100%,water-ethylene glycol 50%, water-ethylene glycol 25%, water - Sic 1%, and water - Sic 2%.) were obtained respectively as follows NTU0.7168, 0.7055,0.7222, 0.6932, 0.9368 & 0.9681; overall heat transfer heat (U) as 145.0060, 84.2887, 119.1921, 129.2847, 218.0424 & 225.3206 and efficiencies as 47.48%,47.19%,47.71%,46.45%,56.00% & 57.08% higher heat transfer rate of 225.3206W/m^{2}C, NTU 0.9681, and efficiency of 57.08% was obtained using water-sic as base fluid for cooling resulting into higher efficiency of the system.

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