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Experimental Investigation of plate heat exchanger using Nanofluids

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Abstract - *There is a great need to work on the working fluids of heat exchanging devices in addition to their design. This experimental research work was based on the comparison between water and copper oxide nanofluids in gasket type (PHE) plate heat exchanger. The PHE pattern of plate was chevron type and the base fluid used for nanofluids was water. Three volume concentrations of 0.1, 0.3, and 0.5 were utilized and the nanoparticles size was 50nm. Convective heat transfer and thermo physical characteristics were studied at different flow rates keeping the initial conditions same. It was observed that the heat transfer capacity was increased with increasing concentration up to certain limit. Enhancement of 52% was observed in heat transfer capacity at the concentration of 0.3% as compared to pure water. Afterwards with further increase in concentration it showed a declining trend. It was also observed that with the increase of concentration density and friction was increased*.

Key words: Copper oxide, Nanofluids, plate heat exchanger, heat transfer, Nanoscale.

1 INTRODUCTION:

The evolution in technological field as well as the intensification in industrial processes has justified the ever increasing demand of more effective heat exchanging systems. Therefore the scientific persuade is not only concerned with the advancement in industrial equipment designs but also with the enhancement in the thermal properties of the working fluids used in them. The innovation regarding equipment design came forward with an effective and compact device called Plate Heat Exchanger (PHE), having modulated surfaces. PHE normally consists of a set of thin corrugated stainless steel or titanium plates having ports or holes at their top corners which provides a passage for the two fluid mediums between which the heat is to be transferred. These plates are converged between a fixed frame plate and a movable pressure plate which are later compressed by using tightening bolts. PHEs are fabricated either in a gasketed or in a welded/brazed models. In a gasket PHE the flow passages for the both heat exchanging mediums are kept sealed with the help of bordering gaskets. The corrugations on the plates helps to create turbulence inside the fluid flow channels and also improves the mechanical strength of the plate pack [1, 2]. Such type of devices having high surface density and possessing a flow arrangement that has successive flow partitions and reattachments within the narrow PHE paths has shown enhanced heat transfer capability. On the other end, sophistication due to modulated surfaces also become the cause of frictional losses, which makes the design of PHE a possible problem that must be accommodated between greater heat transfer and the pumping power required [3]. The demand of such a working fluid that yields greater performance than the conventional one has attracted the scientific interest towards the nanofluids, i.e., engineered colloidal suspension of solid nanoparticles having an average dimensions of 1-100nm in certain base fluids like water, ethylene glycol and engine oil [4, 5, 6]. The research work being done in this area has proved that the thermal conductivity of these newly introduced fluids is greater than the simple base fluids having a significant dependence upon particles size, shape, type and concentration [6]. It must also be mention that although the enhancement in the thermo physical properties of base fluid due to nanofluids is evident but it does not affirm that these fluids would also yield high performance from plate heat exchanger [4]. Nguyen experimentally investigated the heat transfer in PHE and reported an enhancement in the heat transfer rates [7], Pantzali et al also studied the effects using CuO nano fluids in the similar apparatus, both experimentally and numerically, and confirmed the later mentioned behavior [8].

In this study the authors have tried to give an overview of the performance of the Herringbone type PHE while using CuO nanofluid as a coolant, with the help of experimental investigation and later compared the results with the base fluid.

2 Preparation of Nanofluids

Nanofluids were prepared by two step method in this research work. Nanoparticles were bought from Hengqiu Graphene technology, China and the net particle size of copper oxide nanoparticles were 50nm. Three concentrations were prepared by using magnetic stirrer and ultrasonic bath. First placed the water in a beaker and put the measured amount of nanoparticles in a beaker. Magnetic sterification was allowed for about an hour and then place the beaker in the sonicator bath and sonication process was run for 4-5 hours. At one time only two beakers were placed in a sonicator so that the water level in the sonicator bath did not exceed the upper limit. The techniques used for stabilization and homogenization are mentioned in literature [9]. Small amount of CTAB (Cetyl trimethyammonium bromide) was added to achieve good suspension of nanoparticles. Efforts were made to homogenize the suspension, so that it remained in a stable condition for a long period.

3 Experimental setup:

An effective and comprehensive system was used to study nanofluid in PHE. In this setup nanofluids was used as coolants. Heat transfer oil Shell S_2 was cooled by water and then with different concentrations of Nanofluid. Oil temperature set at 75 C̊ with water and nanofluids temperatures were maintained at 30 C̊ for inlet conditions. The experimental rig shown in Fig 1 and the schematic diagram in Fig 2. Besides using four temperature and pressure gauges at inlet and outlet of heat exchanger, thermocouples were also used to measure the inlet temperature of oil and nanofluid. One temperature sensor was also used in electric heater to maintain oil temperature. Two centrifugal type pumps were used with flow control valves. Flow rates were maintained within a range of 8 to 11 l/min with the help of digital flow meters.

Table 1: Specification of Plate Heat Exchanger

Design Temperature	90 / 90 c̊
Design pressure	7.5 / 7.5 Bar
Number of Plates	25
Heat transfer area	0.3 m^2
Dimension of plates	5 * 18 inch
Plate thickness	0.5 mm
Pattern of Plates	Chevron

4 Calculations:

The mathematical relation for the calculation of density was presented by Pak and Chao [10] and the data is calculated by this equation, which is described as:

$$\rho nf=(1-\phi)\ \rho_{f}+\phi\rho_{p} \qquad 1$$

ρnf is the nanofluid density, ρ_f is the base fluid density, ρ_p is the nanoparticles density and ϕ is the volume concentration of particles.

The relation for heat capacity for nanofluid was proposed by Xuan and Roetzel [11] and the values were calculated by using this equation:

$$Cp_{nf} = (1-\phi)\ Cp_f + \phi\ Cp_p \qquad 2$$

Cp_{nf} is the nanofluid heat capacity, Cp_f is the base fluid heat capacity and Cp_p is the nanoparticles heat capacity.

The rate of heat transfer was calculated by the equation as follows:

$$Q = mC_p\,(T_1-T_2) \qquad 3$$

Q is the rate of heat transfer, m is the mass flow rate, T_1 is the inlet and T_2 is the outlet of fluid.

The formula for the calculation of thermal conductivity was presented by Yu and Choi [12]. The relation can be expressed as:

$$K_{nf} = K_f\,\frac{(K+2K_f-2\phi(K_f-K)}{(K+2K_f+\phi(K_f+K)} \qquad 4$$

K_{nf} is the nanofluid thermal conductivity, K_f is the thermal conductivity of base fluid and K is nanoparticles thermal conductivity.

The log mean temperature difference for the plate heat exchanger was calculated by the equation as follows:

$$\Delta T_{LM}=\frac{(Th_{in}-Tc_o)-(Th_o-Tc_{in})}{Ln\frac{(Th_{in}-Tc_0)}{(Th_o-Tc_{in})}} \qquad 5$$

ΔT_{LM} is the log mean temperature difference, Th_{in}, Th_o is the inlet and outlet of hot fluid. Tc_{in} and Tc_o is the inlet and outlet of cold fluid.

Overall heat transfer coefficient was calculated by the formula:

$$U = \frac{Q}{A\Delta Tlm} \qquad 6$$

U is the overall heat transfer coefficient, A is the heat transfer area and Q is the heat transfer rate.

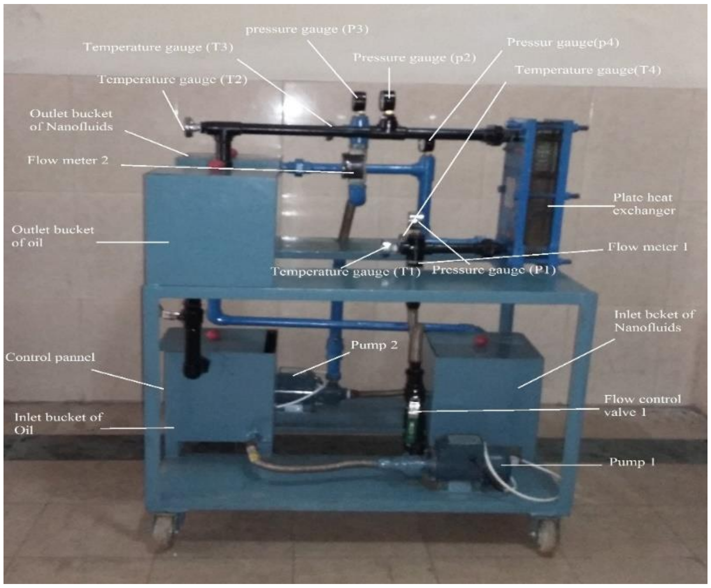

Figure 1 Experimental setup

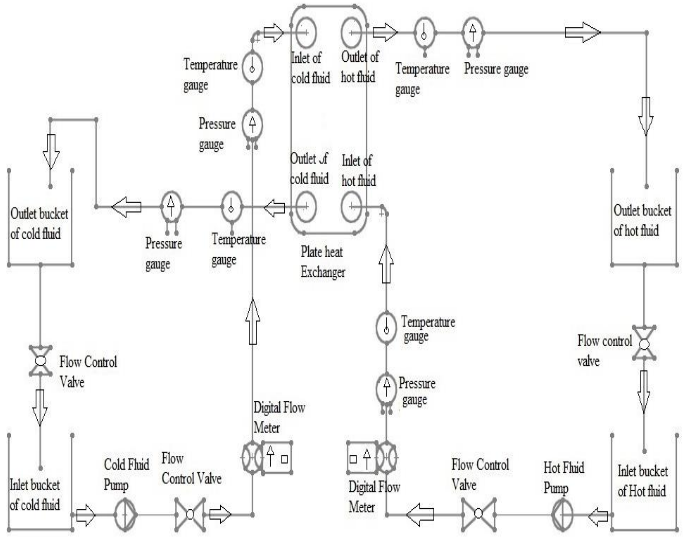

Figure 2 Schematic diagram

Viscosity of nanofluid was calculated by Drew and Passman [13].The equation is valid for less than 5% volume concentration.

$$\mu_{nf} = (1+2.5\phi)\,\mu_w \qquad 7$$

μ_{nf} is the viscosity of nanofluid and μ_w is the viscosity of water.

The Nusselt number was calculated by using the Dittus Boelter equation. The validity of the equation decreases with large temperature difference between two fluids.

$$Nu_D = 0.023ReD^{0.8}Pr^n \qquad 8$$

D is circular inside diameter, pr is the prandtl number.For heating n=0.4, For cooling n=0.3

Reynold number [14] was calculated as:

$$R = \frac{VD}{v}$$

9

v is the kinematic viscosity and V is velocity of fluid

$$v = \frac{\mu}{p}$$

10

prandtl number [15] was calculated as:

$$Pr = \frac{\mu_{nf}}{\alpha_{nf}}$$

11

α_{nf} is the thermal diffusivity and is given by

$$\alpha_{nf} = \frac{knf}{Pnf * Cp}$$

12

Heat transfer coefficient is calculated as:

$$H = \frac{mCp\Delta T}{A(T_f - T_w)}$$

13

T_f is the fluid temperature and T_w is the wall temperature.

5 Results and Discussion

As the concentration of nanofluids increases the heat transfer rate also increases, but this trend is maintained only up to a certain concentration of nanofluids i.e., at 0.30%, it was maximum, but with the further increase in concentration, heat transfer rate declines, at the same flow rate. It is clear that as the amount of nanofluids was increased up to 0.50% the heat transfer rate increases at start but then falls to the rate same as at 0.1%, keeping the flow rate constant 11 liters per minute.

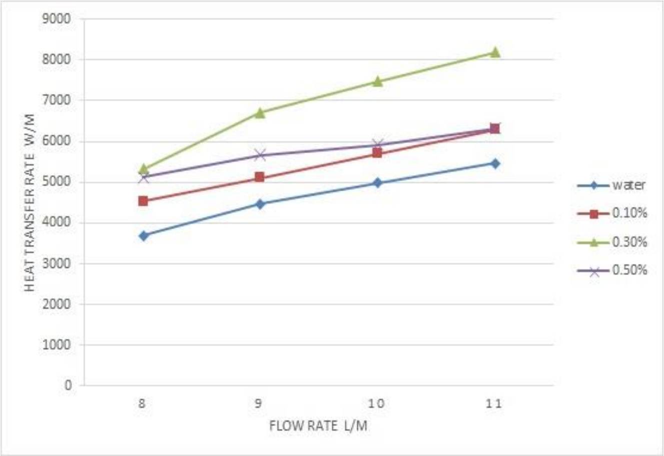

Chart 1. Heat transfer rate at different flow rates

It is obvious that the addition of nanoparticles in the base fluid would make it denser so density varies directly with respect to the concentration of nanofluids as shown in chart 2.

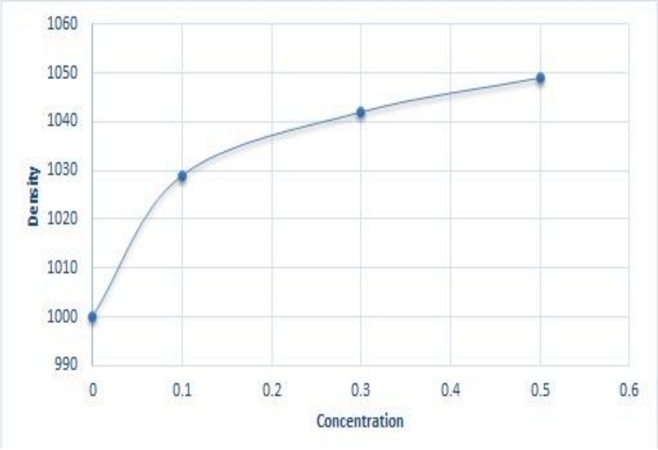

Chart 2. Density of nanofluids at different concentration

It is clear from the chart 3 that specific heat capacity shows a sudden decline as nanofluids are added into the base fluid, and it goes on decreasing with further increase in volume fraction of nanoparticles. So it is also evident from this trend that the heat absorption and drainage will happen more quickly with the use of nanofluids.

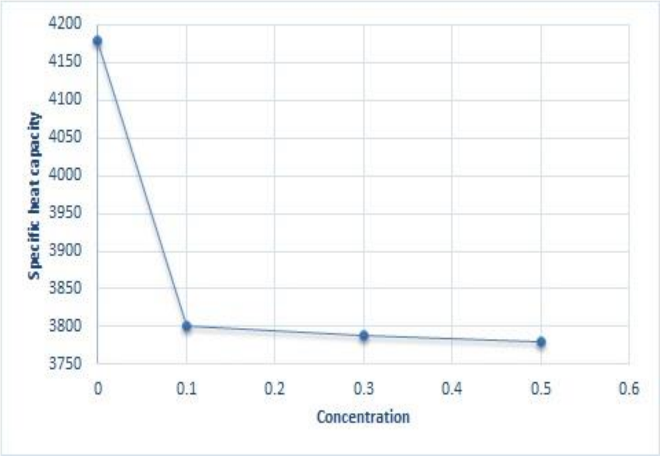

Chart 3. Specific Heat capacity behavior under different concentrations

Overall heat transfer coefficient shows the same behavior as that of heat transfer rate. It increases as the concentration increases until it reaches a maximum value that is achieved at an optimum concentration i.e., 0.30% and then it shows a decreasing trend, chart 4.

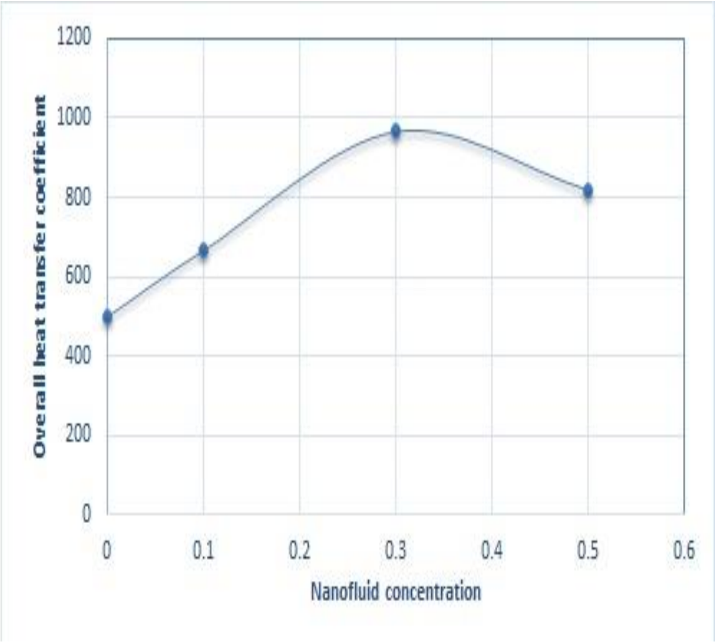

Chart 4. Overall heat transfer coefficient at different concentrations of nanofluids

The power required to pump the nanofluids increases with the increase in the amount of nanofluids in base fluid as shown in the chart 5. But this must also be mentioned here that this minor con of the use of nanofluid is neglected when we compare it with the increased amount of heat transfer rate achieved.

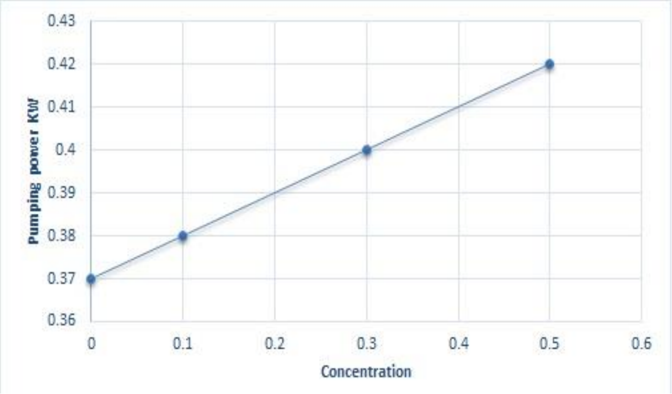

Chart 5. Effect of different concentrations of nanofluids at the pumping power

With the increment in the amount of nanoparticles, the base fluid's viscosity increases and this results in the pressure drop across the outlet with respect to the inlet pressure which is clear from the above chart 6.

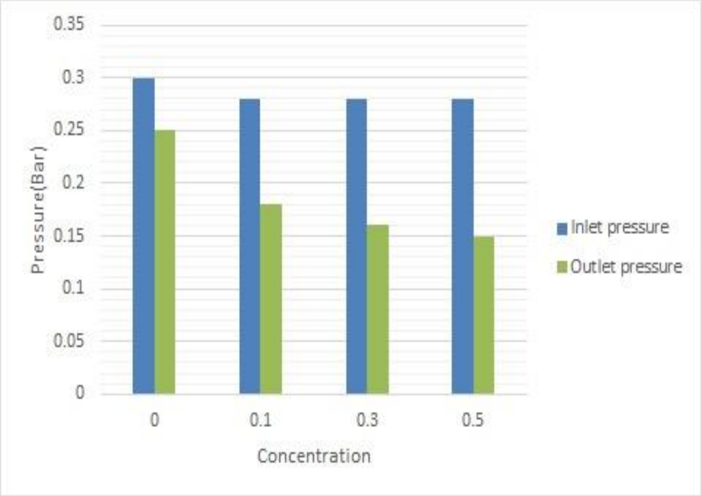

Chart 6. Pressure Drop Due varying concentrations

6 Conclusion:

Performance of a Plate heat exchanger using CuO nanofluids as coolant is observed experimentally under varying conditions and parameters. The effect of concentration, flow rate and pumping power has been determined, which has yield the following results

- Nanofluids can be used as a more efficient working fluid in PHE rather than mostly used water.
- PHE's performance depends upon the surface area, concentration, and flow rate of nano fluids.
- Enhancement of approximately 52% heat transfer rate is observed with the mixing of nanofluids concentration, than the simple fluid (water), but only up to a specific particle fraction i.e., 0.30% in the fluid and afterwards with the further increase a decreasing trend is obtained.
- The same trend is followed in the case of flow rate and heat transfer rate i.e., with the increase of flow rate the heat transfer capability of nanofluids increases and after optimum concentration it declines, if we keep the flow rate constant.
- Enhanced requirement of pumping power is observed for higher concentrations of nanofluids which increases the operational cost but this factor can be easily neglected with the heat transfer obtained.
- As with the use of nanofluids results shows better heat transfer so it can compel to use a smaller plate heat exchanger to achieve the same results, which can effectively not only reduce our capital cost but also the maintenance cost.

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