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Influence of nanoparticles on the effectiveness of heat exchanger and associated pressure drop

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Abstract— **Heat exchanger is the essential device for almost all the industrial process heating and cooling equipment. Heat is transferred from one fluid to other by the mode of convection and conduction through the wall of the heat exchanger. Effectiveness of heat exchanger depends on the overall heat transfer coefficient. Heat transfer coefficient of pure water, Al_2O_3-water, CuO-water, and Fe_2O_3-water nanofluids has been studied.**

This paper addresses experimental results of the transient and turbulent region of forced convective heat transfer of water based nanofluids compared to that of distilled water. Four different concentrations of nanofluids in the range of 0.5% to 2% by mass have been prepared for Al_2O_3, CuO and Fe_2O_3. These nanofluids of different concentrations flows through counter flow heat exchanger. Different parameters affecting the heat transfer characteristics were studied and the influence of each parameter is noted. The overall heat transfer coefficient has been calculated with respect to associated pressure drop.

Index Terms— **nanofluids, heat exchanger, Heat transfer, concentration, Heat transfer coefficient, nanoparticle**

Nomenclature—

C_p	Specific heat of the fluid	J/Kg. K
μ	Dynamic Viscosity	Pa.s
ρ	Density	kg/m^3
F	Friction factor	Dimensionless
ϕ	Volume fraction of nanoparticles	Dimensionless
ϕ_v	Volume fraction percentage	Dimensionless
ϕ_m	Mass concentration percentage	Dimensionless
R_e	Reynolds Number	Dimensionless

Subscripts

f	fluid
nf	Nanofluid
np	Nanoparticle
bf	Base fluid (water)
v	Volume concentration parentage
m	Mass concentration parentage
w	Water

I. Introduction

Nano fluid is made by dispersing the nano particles in the base fluid. Nano fluids are diluted liquids with suspended nano particles. Exponential growth of nano technology led to do the research work in the field of heat exchangers. The thermal behavior of nano fluids could provide a basis for enhancement of heat transfer.

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Sandeep kumar *et.al.*[1] studied the pressure drop and heat transfer enhancement characters. The results showed that the thermal conductivity increases with both temperature and concentration. But the viscosity and density is increasing with concentration and decreasing with temperature. Om Shankar Prajapati, and A. K. Rajvanshi [2] was investigated experimentally the turbulent flow forced convection heat transfer of Al_2O_3-water nanofluid inside annular tube with variable wall temperature. Experimental results emphasized the enhancement of heat transfer due to the nanoparticle presence in the fluid.

Mostafa Jalal *et.al.* [3] Investigated the improvement of heat transfer of a heat sink by using CuO-water nanofluid. The influence of each parameter affecting the heat transfer characteristics were studied and presented. S.Senthilraja *et.al.* [4] studied the thermal conductivity of Al_2O_3/water, CuO/water and Al_2O_3–CuO/water hybrid nanofluid were investigated experimentally. The two step method was adopted to prepare the hybrid nanofluid. Three different volume concentrations of nanofluids (0.05, 0.1 & 0.2%) were prepared by dispersing Al_2O_3 and CuO nanoparticles in wter.

Yimin Xuan and, Qiang Li [5] presented a procedure for preparing a nanoliquid which is a suspension consisting of nanophase powders and a base liquid by means of the procedure.

W.H. Azmi *et.al.* [6] presented a report on enhancement in heat transfer coefficients in combination with structural modifications of flow systems namely, the addition of tape inserts. Experiments are undertaken to determine heat transfer coefficients and friction factor of TiO_2/water nanofluid up to 3.0% volume concentration at an average temperature of 30^0C.

1.1 Literature on heat exchangers with nanofluids

It has become a common phenomenon to use the nanofluids in all varieties of heat exchangers. Thermal properties of all liquid coolants used today as heat exchange fluids exhibit average thermal conductivity except liquid metals. As an example, water is roughly three times lesser than that of copper. We generally enhance the heat transfer by creating turbulence, increasing area, etc., which will be limited by the inherent restriction of the thermal conductivity of the fluid. Thus, it is logical that efforts will be made to increase the thermal conduction behavior of cooling fluids. Using the suspension of solids is an option that came to mind more than a century ago.

Sarit Das *et.al.* [7] presented an exhaustive review on nanofluid heat transfer and suggests a direction for future developments. Chidanand K Mangrulkar andVilayatrai M Kriplani [8] reviewed several research articles and presented a comprehensive data on nanofluid heat transfer. Various factor affecting the thermal conductivity of Nanofluids at different conditions has been studied by B.Kirubadurai *et.al.* [9]. The researchers have tried to increase the heat transfer rate by considering thermal conductivity of Nano fluid. They have observed that the conductivity is increased with increasing concentration of metal particles within critical limit. It is affected by shape, size, clustering, collision, porous layer, melting point of nanoparticle. They have proved that the controlling these parameters will increase the thermal conductivity of nano fluid.

Alpesh Mehta *et.al.* [10] studied the effect of nano fluids on compact heat exchanger by using ε –NTU rating numerical method on turbo-charged diesel engine of type TBD 232V-12 cross flow compact heat exchanger radiator with unmixed fluids. Comparative study of Al_2O_3 mixed with pure water, nano fluids as coolant is carried out. Xinwei Wang [11] carried out the work using Al_2O_3 and CuO nano particles measuring approximately 20 nm are dispersed in distilled water, ethylene glycol, engine oil, and vacuum pump fluid. Thermal conductivities of the fluids are measured by a steady-state parallel-plate technique. Several theoretical models for computing effective thermal conductivity of composite materials are used to explain the thermal conductivity increase in these fluids.

A nanofluid of CuO nanoparticles and distilled water has been prepared and its heat transfer characteristics have been studied through square cupric duct in laminar flow under uniform heat flux by Zeinali Heris *et.al.* [12]. Experiments revealed that a remarkable enhancement in heat transfer coefficient is achieved compared to the base fluid. Moreover, it has been reported that heat transfer coefficient enhances with increasing nanofluid flow rate as well as concentration of nanoparticles in the nanofluid especially at high flow rates.

M.Saeedinia *et.al.* [13] investigated the heat transfer and pressure drop of nanofluids flow in horizontal coiled wire inserted tube at constant heat flux. The nanofluid is prepared by dispersion of CuO in base oil. Particle volume fraction ranging from 0.07% to 0.3% is used. Convective heat transfer coefficient of water, Cu-water, Al-water, Al_20_3-water and $Ti0_2$-water of 2% nanoparticle concentration has been calculated for counter flow heat exchanger by Hasanuzzamana *et.al.* [14]. It has been proved that the effectiveness of heat exchanger depends on the convection heat transfer coefficient of the fluid. Forced convective heat transfer in a water based nanofluid has experimentally been compared to that of pure water in an automobile radiator by V. L. Bhimani *et.al.* [15]. Five different concentrations of nanofluids in the range of 0.1-1 vol. % have been prepared by the addition of TiO_2 nanoparticles into the water.

Thermal performance analysis of a counter flow heat exchanger is performed by varying the composition of nanofluids used, which is a mixture of coolant and iron particles by Raman Chouda [16]. An experimental analysis has been performed on counter flow heat exchanger. The volume fraction of coolant varies from 0-2.0% by mass. Experimental results such as heat transfer rates, overall heat transfer coefficient, and heat exchanger effectiveness have been calculated to assessing the performance of heat exchanger.

1. Preparation of nanofluids

Alumina (alpha-Al2O3), Fe_2O_3 and CuO nanoparticles are used for the preparation of nanofluids. Distilled water is used as base fluid. Work is done on four mass concentration percentages of nanoparticles such as 0.5%, 1%, 1.5% and 2%. For all the three types of nano metal particles, we use the same mass percentage.

Nanofluid is prepared by two step process. First, weigh the exact amount of nanoparticles as per weight fraction with the help of digital weighing machine. Three types are of same quantity of nanoparticles are prepared and added surfactants, Tween-80, to one solution, C-Tab to another nano fluid, and Span-80 to another beaker. Place these beakers on magnetic stirrer one by one and put the stirrer bit into the beaker. Switch on the stirrer at full speed and ran it for one hour for proper mixing. In the same manner, the samples are prepared by using other two nanoparticles with 1% mass concentration. Kept all the nine beakers without disturbing them for 72 hours as shown in figure 2.1 and finalized the surfactant to be used for preparation of nanofluids.

(a) With Span-80 (b) With Tween-80 (c) With C-Tab

Figure 2.1: Samples of Nanofluids after 72 Hrs.

Bulk amount of nanofluid is prepared by using a custom made mechanical stirring setup after finalization of suitable surfactant. For thorough mixing of the nanoparticles, the stirring is made at different speeds until the homogeneous nanofluid is formed.

II. Experimental apparatus

An experimental setup, counter flow heat exchanger used to measure the heat transfer coefficient. It consists of Concentric tube Heat Exchanger, Instant Water Heater, Instant Water cooler, Submerged pump, Thermocouples, Rotameters, Pressure gauges, Regulating valves.

A photograph of experimental set up of counter flow heat exchanger used to measure heat transfer coefficient is shown in Fig.3.1. The control valves regulate the flow rate of both hot and cold fluids flowing through the concentric tubes. The concentric tube is applied with a layer of asbestos insulation to minimize any heat losses from outer surface of outer pipe.

Figure 3.1: Photographic view of Experimental setup

1.1 *Evaluation of Thermophysical Properties of Nanofluids*

Thermal and physical properties of nanofluids will change with mass concentration of nanoparticles. It is assumed that the surfactant influence on properties is neglected, since the mass concentration when compared with the base fluid is very less. Several researchers did experimentation and presented the properties. Most of the relations have been taken from the reference [17] and the reference [18].

The specific heat of nanofluids for various nano particle mass concentrations is estimated by using the equation [17].

$$C_{pnf} = C_{Pnp}\,\phi + (1-\phi)\,C_{Pbf} \qquad (3.1)$$

Where, C_P= Specific Heat and ϕ = Volume fraction of nanoparticles

Volume concentration is defined as the fraction of space of the total suspension occupied by the suspended material, and is often used instead of mass concentration. Therefore, in the present study, the volume concentration was determined from the specified mass concentration at the dispersed fluid by the following equation [17] as shown below:

$$\phi_v = \frac{1}{\left(\frac{100}{\phi_m}\right)\left(\frac{\rho_{np}}{\rho_{bf}}\right)+1} \times 100(\%) \qquad (3.2)$$

Where, ϕ_m is the mass concentration in percentage
ρ_{bf} = Density of base fluid and ρ_{np} is the density of nanoparticles
Once the volume concentration is determined, the density of the dispersed nanofluid can be determined from relation [17] as:

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi\rho_{np} \qquad (3.3)$$

Viscosity of the nanofluid can be calculated by using Einstein's classical equation [19] as shown below:

$$\mu_{nf} = (1+2.5\phi)\mu_w \qquad (3.4)$$

Where, μ_w is the dynamic viscosity of water
For nanofluids, friction factor (*F* can be calculated by using Guangthongusk and Wongwise Correlation [20] as:

$$F = 0.961\, R_e^{-0.375}\phi_v^{0.052} \qquad (3.5)$$

III. Results and Discussions

Experiments have been carried out in counter flow heat exchanger with pure water and studied the pressure drop and associated overall heat transfer coefficient. With the same flow conditions, the experiments are being conducted for nanofluids with different mass concentrations and presented the result.

Figure 4.1 represents the increase of pressure drop with different percentages of nanoparticle mass concentration in the base fluid. When the experiment is done with pure water at a particular flow rate, the pressure drop is observed approximately 3.2kPa. When the water is added with Alumina, copper oxide and iron oxide nanoparticles, the pressure drop for all the three fluids are different.

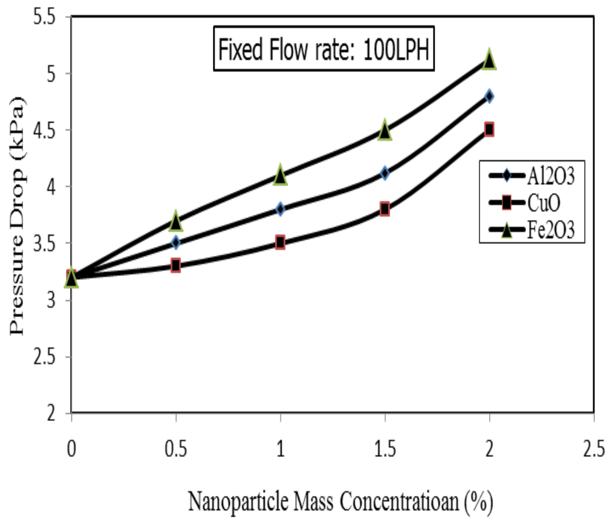

Figure.4.1: Variation of pressure drop with different mass fraction in the base fluid

It has been observed that the Fe_2O_3 is having the highest pressure drop followed by Al_2O_3 and less pressure drop with CuO. Nevertheless, when compared with pure water, the pressure drop for nanofluids at a particular flow rate is relatively more. The reason may be as the Fe_2O_3 nanofluid density is more compared with Al_2O_3 and CuO.

As a curiosity, we have changed the flow rate of nanofluids of all the three types and observed the pumping loses at different mass concentrations. It has been found that more pressure losses are associated with increase of mass concentration percentage of nanofluids. The tendency is almost similar for all the three types of nanofluids which are shown in figures 4.2 to figures 4.5.

From the nature of graphs, the pumping losses are less for pure water when compared with the flow of nanofluids. At low concentration, the pressure drop is lower. As the concentration is increasing, the losses are also increasing with increase of flow rate. But the tendency is same for all the fluids at all concentrations. It is evident from the graphs that more pressure losses are associated with iron oxide nanofluids. Lowest is with CuO nanofluid. This is because of more specific weight of Fe_2O_3 than CuO.

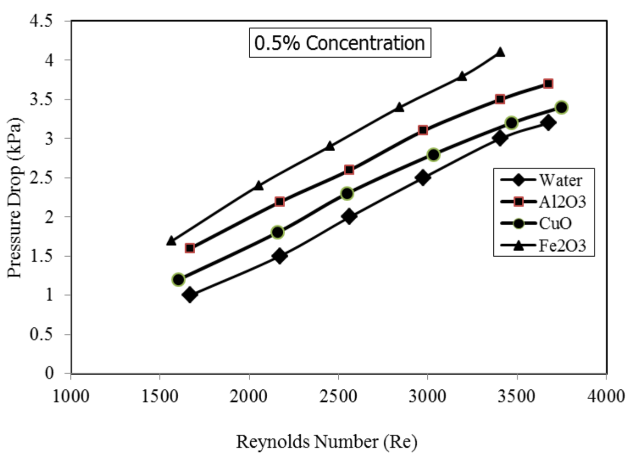

Figure.4.2: Variation in pumping losses with flow rate at 0.5% mass concentration

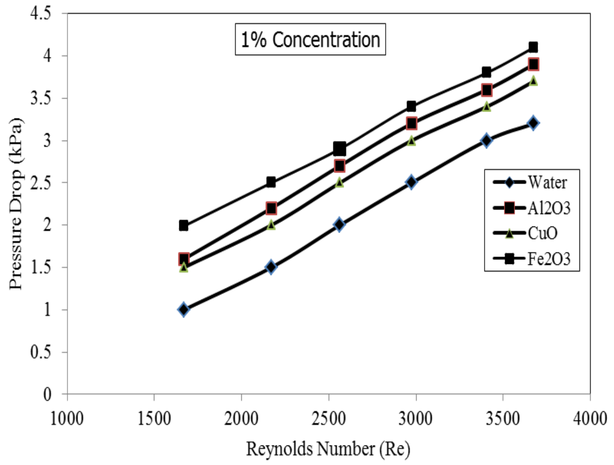

Figure.4.3: Variation in pumping losses with flow rate at 1% mass concentration

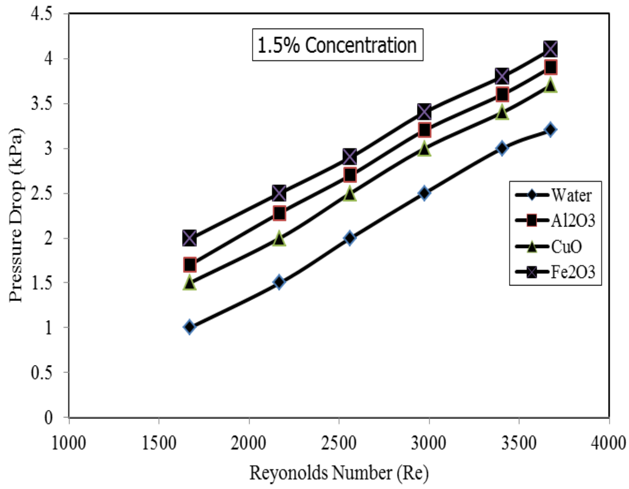

Figure.4.4: Variation in pumping losses with flow rate at 1.5% mass concentration

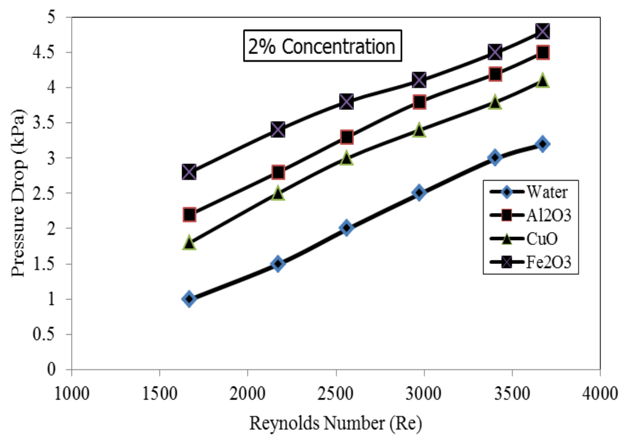

Figure.4.5: Variation in pumping losses with flow rate at 2% mass concentration

Overall heat transfer coefficient mainly depends on the properties of fluid, heat transfer area and the temperature difference between cold and hot fluids. It is assumed that when the nanoparticles are added to the base fluid, the thermal properties may change and the thermal conductivity will increase.

Enhancement of overall heat transfer coefficient is evident when the mass concentration is increasing. This is due to the increase of thermal conductivity of nanofluid. The increase of heat transfer coefficient may also due to the increment of specific heat capacity of the fluid.

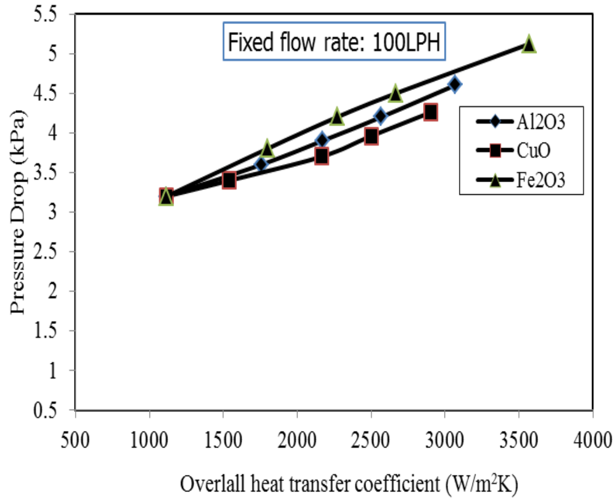

Figure.4.6: Flow losses with overall heat transfer coefficient at different mass concentrations at a constant flow rate

Increase of overall heat transfer coefficient at the cost of pressure drop at a fixed flow rate of both coolant and nanofluid is observed in the figure 4.6. It is seen that the overall heat transfer coefficient is increasing with nanoparticles concentrations.Fe_2O_3 is having linear variation when compared with CuO. More pressure drop is observed in Fe_2O_3 nanofluid than Al_2O_3. Low drop is with CuO. The reason for this behavior is that the Fe_2O_3 is heavier than the Al_2O_3 and CuO.

IV. Conclusions

Nanofluids are prepared by two-step process i.e. dispersing the nanoparticles into base fluids. A custom built stirrer is used to disperse the particles properly and to minimize particle agglomeration to get a uniform stable suspension. C-Tab is used for Al_2O_3 & Fe_2O_3 as a surfactant, to maintain stability and proper dispersion. Tween 80 is used as a surfactant for CuO.

All the three nanoparticles are used for preparing the nanofluids with distilled water as a base fluid. These are prepared with the help of surfactants with nanoparticle mass percentage of 0.5 %, 1.0%, 1.5% and 2.0%. The nanofluids kept stable for 72 hours to test for sedimentation

Density of nanofluids is increasing when compared with distilled water and it also increases with increase in particle concentration at a particular temperature. But as temperature increases density decreases.

The temperatures and pressure drops of nanofluids are measured at steady state by using an experimental setup at different flow rates.

Results show that the overall heat transfer coefficient for 0.5%, 1.0%, 1.5% and 2.0% concentration percentage nanoparticles of all the three types at a particular flow rate is higher than that of pure base fluid (water)**.**

As the concentration percentage is increasing, the heat transfer coefficient and hence the heat transfer rate is attractive when compared with the pumping losses.

The heat transfer rate increment is better in case of Fe_2O_3 when compared with Al_2O_3 and CuO. But the pumping loses are more or less same for all the three nanofluids

We can conclude that the pressure drop of nanofluid is more than that of water and is increasing with increase in nanoparticle concentration. But the increment in pressure drop is lesser when compared to the achieved enhancement in overall heat transfer coefficient.

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