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Influence of Viscosity of nanofluids on heat transfer Rate

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Abstract: Heat exchangers are devices for almost all manufacturing, power production and automobile applications. In this paper, the influence of dynamic viscosity on heat transfer characteristics of pure water and water mixed with copper oxide, Iron oxide and aluminum oxide nanoparticles with different mass concentration in a horizontal circular pipe under constant heat flux condition are studied. All the nanofluids are made in three different mass concentrations i.e. 0.5%, 1.0%, 1.5 % and 2%. Influence of nanofluid temperature on dynamic viscosity is presented. The results show that when the mass concentration percentage is increasing, the viscosity is also increasing.

Keywords: Nanofluid, Heat Transfer, Viscosity, Heat Exchanger, mass concentration percentage, Temperature,

Nomenclature

m	Mass flow rate	(kg/s)
Q	Heat transfer rate	(W)
L	Length of the test section	(m)
F	Friction factor	Dimensionless
u	Mean velocity of the fluid	(m/s)
U_i	Overall heat transfer coefficient based on inner surface area	(W/m^2.K)
D_i	Internal diameter of the pipe	(m)
A_i	Inner surface area of test section	(m^2)
T_1	Inlet temperature of hot fluid	(K)
T_2	Outlet temperature of hot fluid	(K)
T_3	Inlet temperature of cold fluid	(K)
T_4	Outlet temperatures of cold fluid	(K)
ΔT_{lm}	Logarithmic Mean Temperature Difference	(K)
C_p	Specific heat of the fluid	J/Kg. K
μ	Dynamic Viscosity	Pa.s
ρ	Density	kg/m^3
R_e	Reynolds Number	Dimensionless
F	Friction factor	Dimensionless

ϕ	Volume fraction of nanoparticles	Dimensionless
ϕ_v	Volume fraction percentage	Dimensionless
ϕ_m	Mass concentration percentage	Dimensionless
μ_w	Dynamic viscosity of water	

Subscripts

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

1. Introduction

Any type of nanoparticles mixed with bases fluid is called nanofluid. Nanofluid sometimes called an emulsion. Nanofluids are having several advantages. Due to nano size particles, pressure losses during flow will be less. Higher thermal conductivity of nano particles will increase the heat transfer rate. Successful employment of nanofluid will lead to lighter and smaller heat exchanger. There will be a drastic change in the properties of the base fluid after introducing suspending nanofluids. Heat transfer rate increases due to large surface area of the nano particles in the base fluid. Nanofluids are most suitable for rapid heating and cooling systems.

2. Research Background

Yimin Xuan and Qiang Li [1] presented a procedure for preparing a nanofuid which is a suspension consisting of nanophase powders and a base liquid. Kirubadurai *et.al* [2] showed varying factors affecting the thermal conductivity of nanofluids at different conditions. Thermal conductivity is affected by the parameters like shape, size, clustering, collision, porous layer, melting point of nanoparticle. They mentioned that the controlling of this type of parameters will increase the thermal conductivity of nanofluid

Viscosity of nanofluids is less investigated than thermal conductivity of nanofluids. However, the rheological properties of liquid suspensions had been studied long ego. Pak et al. [3] first time measured the viscosity of Al_2O_3-water nanofluids as a function of shear rate and concentration. The Al_2O_3 nanoparticles have an average diameter of 13 nm and the concentration is up to 10% by volume. It is observed that nanofluids show Newtonian behavior. This means, the viscosity is independent of the shear rate and the maximum viscosity of nanofluids is up to 300 times higher than that of the base fluid.

Wang et al. [4] observed 90% increase in the viscosity of Al_2O_3 nanoparticles mixed with water of similar concentrations and particle dimensions. Though they measured the viscosity of Al_2O_3 nanofluids, they did not find any non-Newtonian effect. Many nanofluid systems show non-Newtonian behavior, unlike the corresponding base fluids.

Das et al. [5] measured the viscosity of water based nanofluids containing Al_2O_3 nanoparticles and they observed slightly change in viscosity as the shear rate increased and exhibited Newtonian behavior.

They also investigated the temperature dependence of the viscosity and found similar to that of base fluids. The maximum viscosity of nanofluids was found at highest particle percentage and lower temperatures.

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Experiments are undertaken by Azmi *et.al.* [6] 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. The investigations are undertaken in the Reynolds number range of 8000 to 30,000 for flow in tubes and with tapes of different twist ratios. A significant enhancement of 23.2% in the heat transfer coefficients is observed at 1.0% concentration. Experimental determination of heat transfer coefficients of SiO_2/water and TiO_2/water nanofluid up to 3% volume concentration flowing in a circular tube is undertaken by Azmi *et.al.*[7]. Investigations are conducted in the Reynolds number range of 5000 to 25000 at a bulk temperature of 30^oC. The experiments are undertaken for flow in a circular tube with twisted tapes of different twist ratios in the range of $5 \leq H/D \leq 93$.

Exhaustive review of the suspended nanoparticles in conventional fluids, called nanofluids, has been studied by several researchers. These studies have been compiled by Sarit Kumar Das et.al.[8]. This article presents an exhaustive review of these studies and suggests a direction for future developments. Ji-Hwan Lee *et.al.* [9] showed that the viscosity of the Al2O3–water nanofluids significantly decreases with increasing temperature. Furthermore, the measured viscosities of the Al_2O_3–water nanofluids show a nonlinear relation with the concentration even in the low volume concentration (0.01%–0.3%) range, while the Einstein viscosity model clearly predicts a linear relation, and exceed the Einstein model predictions.

3. Nanofluids preparation

Nanoparticles are defined as particulate dispersions or solid particles with a size in the range of 10-100 nm. These materials begin to exhibit distinct properties that affect biological, chemical, and physical behavior. Large variety of combinations of nanoparticles and heat transfer fluids can be used to synthesize stable nanofluids with improved thermal transport properties. Nanoparticles made from metals, oxides, carbides and carbon nanotubes can be dispersed into heat transfer fluids, such as water, ethylene glycol, hydrocarbons and fluorocarbons with or without the presence of stabilizing agents

For research purpose, alumina (alpha-Al_2O_3), Fe_2O_3 and CuO nanoparticles are used for preparation of nanofluids. Pure water is used as base fluid. Work is done on four mass fractions of all types of nanoparticles such as 0.5%, 1%, 1.5% and 2%.

The physical characteristics of alumina **(Al_2O_3)** are APS: 15±5 nm, with Purity: 99.99%, SSA: 17.8m^2/gm with Alpha-Phase Crystal Structure. Iron oxide (Fe_2O_3) physical and thermal characteristics are: APS: 30-50 nm, Purity: 99%, SSA: 20-60m^2/gm with spherical (alpha phase Fe_2o_3) Crystal Structure. The Density of these Particles are 5.25 gm/cm^2 and Specific heat of Nano Particles is 780 J/kg.k

Copper oxide (CuO) commonly referred to black crystalline powder that is found as balls or lumps of various mesh sizes, possesses strong ionic inter-atomic bonding giving rise to its desirable material characteristics. Copper Oxide is most cost effective and one of the most versatile of refractory ceramic oxides. The physical characteristics of Copper oxide nanoparticles used in the present study are APS: 30-50 nm, Purity: 99 %, Color: Black with Spherical Crystal Structure.

Surfactants are the substances that increase the solubility of nanoparticles into a base fluid by decreasing the surface tension of base fluid. These are also called as dispersants since they get attached to the solute particles (cohesion) and thereby increase the repulsion force between the nanoparticles. This repulsion prevents the nanoparticles from clustering and hence produces a homogenous and stable solution called nanofluid.

A suitable surfactant must be selected upon the type of base fluid and nanoparticles. For the present study, three surfactants are taken to select the best suitability for bulk preparation of nanofluid which are shown in figure 1. These are C-Tab, Twin-80, and Span-80.

After selecting the surfactant, required quantity of nanoparticles are added to the base fluid (pure water).The jar is kept on the magnetic stirrer for uniform solutions. Thermophysical properties of nanofluids are evaluated after nanofluid preparation.

Figure 1: Photograph of Samples of Surfactants

For all the three types of nanoparticles, samples have been prepared and tested with the help of Magnetic Stirrer. Pictorial view of magnetic stirrer is shown in figure 2.

Figure 2: Photograph of Magnetic Stirrer

4. *Thermophysical Properties of Nanofluids*

Thermal and other properties of nanofluids are different from base fluid. It will change with concentration percentage of nanoparticles. Scientist and engineers have done several experiments and presented the mathematical formulations. Most of the equations are taken from the reference [10] and the reference [11].

Specific heat of nanofluids at different mass concentrations is estimated by using the equation [10].

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

Volume concentration of nanoparticles is calculated from the specified mass concentration by the following equation.

$$\phi_v = \frac{1}{\left(\frac{100}{\phi_m}\right)\left(\frac{\rho_{np}}{\rho_{bf}}\right)+1} \times 100(\%) \quad (2)$$

Density of the dispersed nanofluid can be determined from relation [10] as:

$$\rho_{nf} = (1-\phi_v)\rho_{bf} + \phi\rho_{np} \quad (3)$$

Viscosity of the nanofluid can be calculated by using Einstein's classical equation [12] as shown below:

$$\mu_{nf} = (1+2.5\,\phi_v)\mu_w \quad (4)$$

Friction factor *F* for nanofluids can be calculated by using the relation:

$$F = 0.961\, R_e^{-0.375}\phi_v^{0.052} \quad (5)$$

For nanofluid, friction factor (*f*) can be calculated using the Correlation [11] as:

$$f = 0.961\, R_e^{-0.375}\,\varphi_v^{0.052} \quad (6)$$

Absolute Viscosity (Dynamic) of the nanofluid can be calculated by using Einstein's classical equation [16] as shown below:

$$\mu_{nf} = (1+2.5\,\varphi)\mu_w \quad (7)$$

Reynolds Number (Re) for any flowing fluid can be calculated by using standard formula as:

$$Re = \frac{uD\rho_{nf}}{\mu_{nf}} \quad (8)$$

Average velocity (u) can be calculated by the relation:

$$u = \frac{m}{\rho A_i}(\text{For inner pipe}) \quad (9)$$

5. Experimentation

The heat exchanger fluid is ready to do the experimentation when the nanofluids of all four concentrations for all the three varieties of nanoparticles, i.e. 0.5%, 1%, 1.5% and 2%. by weight is ready. The heat exchanger is first run with distilled water as cold fluid and water as hot fluid to study various parameters of heat exchanger for water as base fluid. After completion of experimentation with distilled water, different concentrations of nanofluids of all the three nanoparticles are used to study the same parameters.

Counter flow heat exchanger is used to measure the heat transfer coefficient. It consists of concentric tube Heat Exchanger, Instant Water Heater and Water cooler, submerged pump, Thermocouples, Rotameters, Pressure gauges, Regulating valves. A photograph of experimental set up of counter flow heat exchanger is shown in Fig.3. Control valves are used to 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.

First the Instant Water cooler storage tank is filled with distilled water and fixed the flow rate of the water with the help of Rotameters. The water supply for Instant Water Heater is opened and Instant Water Heater is switched on to its maximum temperature level. This hot water is circulated through a hose pipe enters the heat exchanger. Hot and cold water are noncontact in a counter flow pattern in a counter flow heat exchanger. After attaining steady state condition, the temperature indicated by all the 4 temperature sensors, pressure drop across the test section and the flow rates are measured. The volume flow rate of cold fluid was varied from 50 LPH to 100 LPH and the corresponding values are noted down.

Distilled water is replaced by the Al_2O_3 nanofluid, Fe_2O_3 nanofluid and CuO nanofluid of four different concentrations and their respective readings were noted. This procedure is repeated for different mass flow rates of cold fluid.

Figure 3: A view of experimental setup

6. *Results and Discussion*

Experiments have been carried out in counter flow heat exchanger with pure water and also with different nanoparticles mass concentration called nanofluids. We have investigated how the dynamic viscosity is varying with temperature for all the nanoparticles. The viscosity generally plays a major role in estimating the pumping power sometimes called pressure drop. Most of the heat exchange equipment works above the room temperatures, particularly heat carrying fluids.

Influence of nanofluid temperature on dynamic viscosity is presented in the figures 4 to figures 7. When the mass concentration percentage is increasing, the viscosity is also increasing. Highest viscosity is observed for Fe_2O_3 lowest is for CuO. Aluminum is intermediary. This is due to the concentration difference. Also it is observed that as the temperature is increasing, the dynamic viscosity is decreasing. The change in viscosity is neither linear nor parabolic. It is intermediary. Mathematical correlations are sometimes possible. The variation pattern is more or less same for all the types of nanofluids.

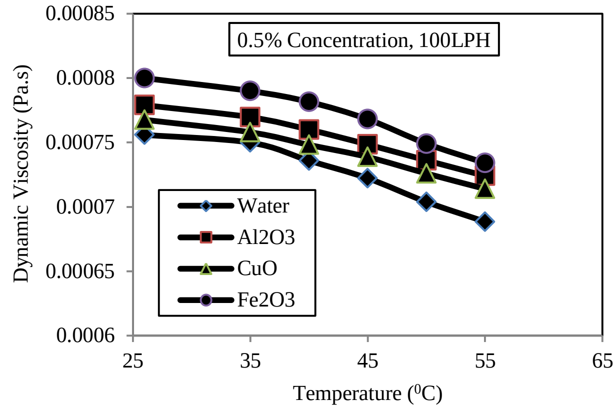

Figure.4: Influence of temperature on viscosity at fixed flow rate and 0.5% mass concentration

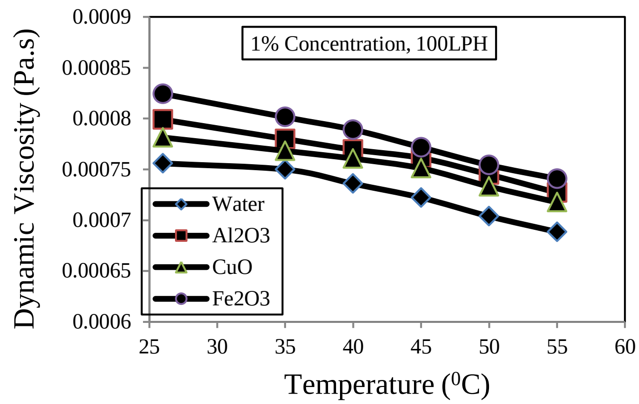

Figure.5: Influence of temperature on viscosity at fixed flow rate and 1% mass concentration

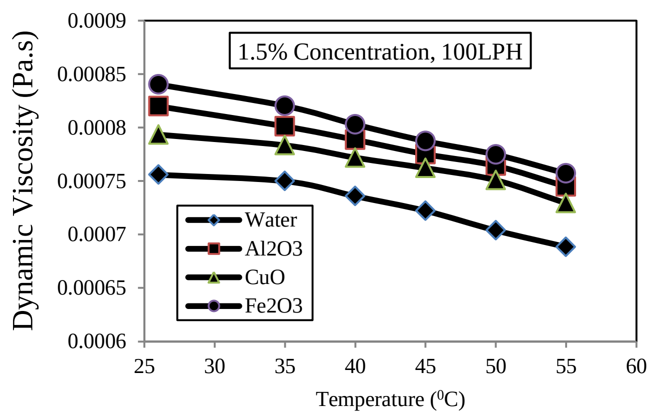

Figure.6: Influence of temperature on viscosity at fixed flow rate and 1.5% mass concentration

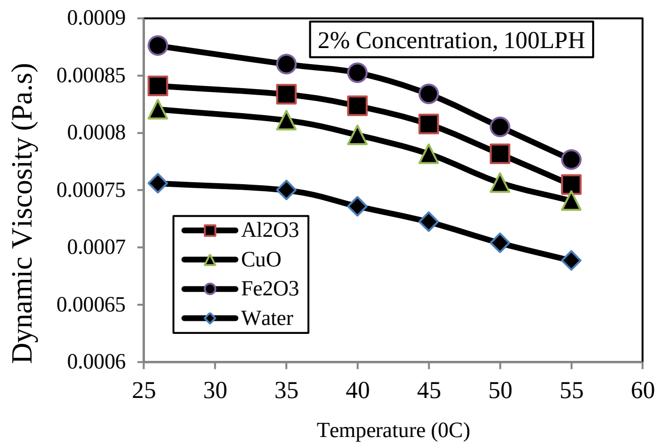

Figure.7: Influence of temperature on viscosity at fixed flow rate and 2% mass concentration

7. Conclusions

Nanofluids are prepared by dispersing the nanoparticles into base fluids. A custom built stirrer is used to disperse the particles 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 surfactant for CuO.

All the three variety of nanoparticles are used for preparing the nanofluids with distilled water as a base fluid. These are prepared with the help of surfactants with mass concentration percentage of 0.5 %, 1.0%, 1.5% and 2.0%.

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

Viscosity results are also in an increasing pattern. Nanofluids for all three varieties and for four concentrations have shown an increase in viscosity when compared with bas fluid. At 0.5% there is an approximate increment of 0.66%, and at 1.0%, an increment of 0.86% is observed. Similarly, at 1.5%, there is an increment of 1.62% and at 2.0% , an increment of 1.72 % is observed.

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