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Effects of Some Parameters on Thermal Conductivity of Nanofluids and Mechanisms of Heat Transfer Improvement.

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ABSTRACT

The present paper discusses the various effects of parameters like particle volume fraction, particle material, particle size, particle shape, particle material and base fluid, temperature, effect of acidity(PH) on thermal conductivity of nanofluids. And also discusses the different mechanisms of heat transfer enhancement like improvement in the thermal conductivity, effect of Brownian motion, thermophoresis, intensification of turbulence, clustering of nano particles. In order to put the nanofluid heat transfer technologies into reality, fundamental studies are greatly needed to understand the physical mechanisms.

***Keywords* –** heat transfer, nanofluids, nano particles, thermal conductivity,

I. INTRODUCTION

The main disadvantage of the Conventional heat transfer fluids like water, ethylene glycol, engine oil etc. is the lower thermal conductivity. To improve the heat transfer for these fluids, metals like Cu, Al, Fe, Ag, and metal oxides like CuO, Al_2O_3, TiO_2, Fe_2O_3, are dispersed in the base fluid in the nano meter size ie < 100nm. Nanofluids possesses immense potential of application to improve heat transfer and energy efficiency in several areas include electronics cooling, vehicular cooling, power generation, nuclear, defense, microelectronics and biomedical applications [1].

However, it is important to note that miniaturized devices are not alone in looking for innovative cooling technology. Large devices (such as transportation trucks) and new energy technology (such as fuel cells) also require more efficient cooling systems with greater cooling capacities and decreased sizes. Despite numerous experimental and theoretical studies, there is an ongoing debate on the mechanisms of thermal conductivity enhancements and whether such enhancements can be reconciled with the classical effective medium theories [2].

Many reports on the thermal conductivity of nanofluids are conflicting due to the complex issues involved in the surface chemistry of nanofluids and possible inaccuracies of the measurement techniques. Therefore, systematic studies are required for deriving a better understanding of the thermo-physical properties of nanofluids with a particular focus on the in-liquid particle configuration that may play an important role in the tunability of nanofluid properties. Alongside there is also an urgent need to explore new or non-traditional techniques such as neutron scattering for assessing the nanofluid in-liquid structure [3].

II. PREPARATION OF NANOFLUIDS

The CuO nano particles powder having an average size of 50 nm and density of 6.3 gm/cm^3 is procured from RESINTE, India and is used for investigation in the present experimental work. The distribution of CuO nano particles at nano scale can be observed under a Transmission electron microscope (TEM). The TEM images of Cu nanofluids, CuO nanoparticles, and alkanethiol terminated AuPd colloidal particles are shown in Fig.1. Preparation of nanofluids is an important stage and nanofluids are prepared in a systematic and careful manner. A stable nanofluid with uniform particle dispersion is required and the same is used for measuring the thermo physical properties of nanofluids.

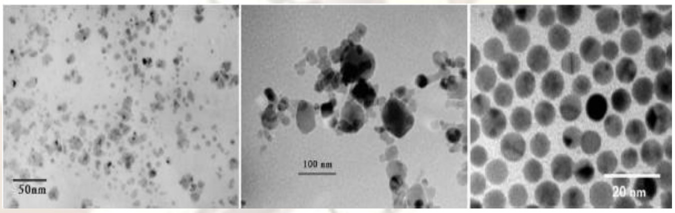

Fig 1. Transmission electron micrographs showing (left) Cu nanofluids, (middle) CuO nanoparticles, and (right) alkanethiol terminated AuPd colloidal particles.

In the present work, water-Ethylene glycol mixture (70:30 by volume) is taken as the base fluid for preparation CuO nanofluids.

1.1 By adding surfactants to the base fluid

In this method a small amount of suitable surfactant, generally one tenth of mass of nanoparticles, is added to the base fluid and stirred continuously for few hours. Nanofluids prepared using surfactants will give a stable suspension with uniform particle dispersion in the host liquid. The nanoparticles remain in suspension state for a long time without settling down at the bottom of the container.

After estimating the amount of nanoparticles required for preparation of CuO Nanofluid for a given volume concentration nanoparticles are mixed in the base fluid of water-ethyylene glycol mixture. In the present investigation, neither surfactants nor acid are added in the CuO nanofluids, because with the addition of surfactants the thermo physical properties of nanofluids are affected. Addition of acid may damage the tube material because corrosion takes place after a few days with the prolonged usage of such nanofluids in practical applications. Copper oxide nanofluids of five different volume concentrations in range of 0.025, 0.1, 0.4, 0.8, and 1.25 % are prepared for measuring the temperature dependent thermal conductivity and viscosity of all the nanofluids concentration considered in the present work. Normally agglomeration of nanoparticles takes place when nanoparticles are suspended in the base fluid. All the test samples of CuO nanofluids used subsequently for estimation of their properties were subjected to magnetic stirring process followed by ultrasonic vibration for about 5 hours. The photographic view of CuO nanofluid sonication process using Ultrasonic Cleaner is shown in Fig.1.

Fig 1. Ultrasonic sonicator

The CuO, Al_2O_3 nanofluids prepared are assumed to be an isentropic, Newtonian in behavior and their thermo physical properties are uniform and constant with time all through the fluid sample.

2.2 Measurement of thermal conductivity of liquids.

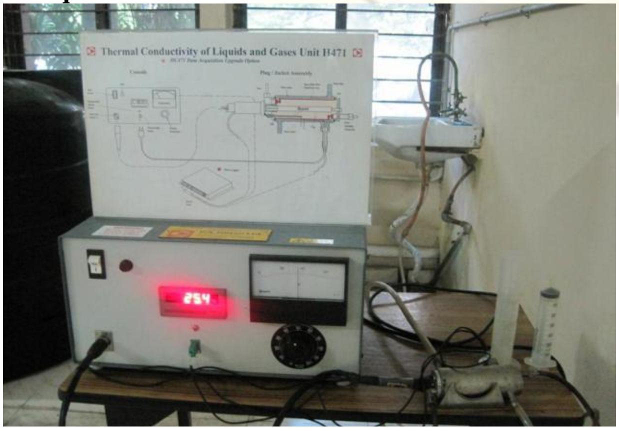

Fig. 2. Measurement of thermal conductivity of liquids.

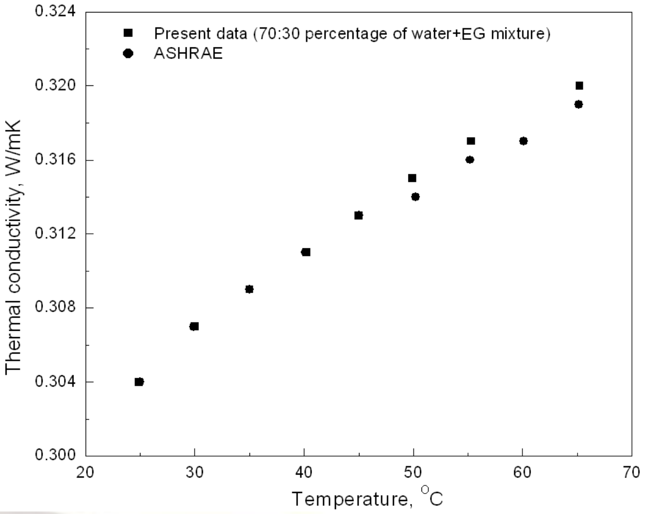

Fig.3. Comparision of the thermal conductivity of water + EG mixture (70: 30) with ASHRAE.

For calibrating the thermal conductivity of water, EG mixture (70:30) the results getting from the apparatus are compared with ASHRAE and the results matched satisfactorily. The comparison of both can be seen in Fig.3.

According to Maxwell model [5][6]

$$\frac{K_{eff}}{K_f} = \frac{K_p + 2K_f + 2\phi_p (K_p - K_f)}{K_p + 2K_f - 2\phi_p (K_p - K_f)} \qquad (1)$$

Where K_{eff} is the effective thermal conductivity of the nano fluid. K_f is the thermal conductivity of the base fluid.

K_f is the thermal conductivity of nano particle.

ϕ_p is the volume fraction.

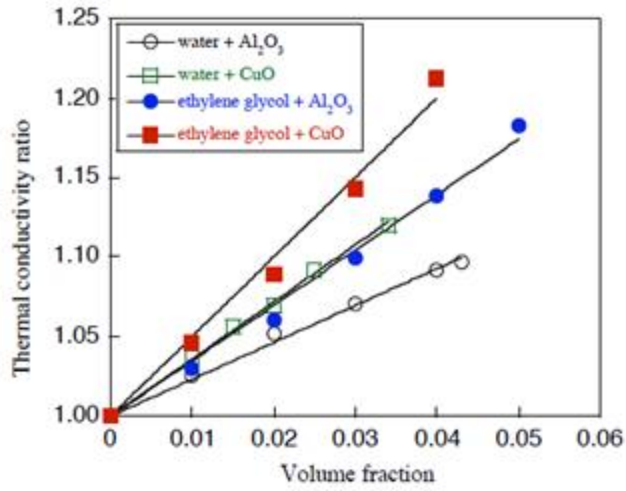

Fig.3 variation of thermal conductivity ratio with volume fraction with volume fraction for different nano fluids.

III. EFFECTS OF SOME PARAMETERS ON THERMAL CONDUCTIVITY OF NANOFLUIDS

Experimental studies show that thermal conductivity of nanofluids depends on many factors such as particle volume fraction, particle material, particle size, particle shape, base fluid material, and temperature. Amount and types of additives and the acidity of the nanofluid were also shown to be effective in the thermal conductivity enhancement.

3.1 Particle Volume Fraction

Particle volume fraction is a parameter that is investigated in almost all of the experimental studies and the results are usually in agreement qualitatively. Most of the researchers report increasing thermal conductivity with increasing particle volume fraction and the relation found is usually linear. However, there are also some studies which indicate nonlinear behaviour. According to the some authors, such a nonlinear relation is an indication of interactions between particles. It was concluded that despite the fact that particle volume fraction is very small, nanotubes interact with each other due to the very high particle concentration (1011 particles/cm^3).

3.2 Particle Material

Most of the studies show that particle material is an important parameter that affects the thermal conductivity of nanofluids. At first glance, it might be thought that the difference in the thermal conductivities of particle materials is the main reason of this effect. However, studies show that particle type may affect the thermal conductivity of nanofluids in other ways. For example the thermal conductivity of nanofluids with Al_2O_3 and CuO nano particles and they found that nanofluids with CuO nanoparticles showed better enhancement when compared to the nanofluids prepared using Al_2O_3 nanoparticles. It should be noted that Al_2O_3, as a material, has higher thermal conductivity than CuO. Therefore, thermal conductivity of particle material may not be the dominant parameter that determines the thermal conductivity of the nanofluid.

3.3 Particle Size

Particle size is another important parameter of thermal conductivity of nanofluids. It is possible to produce nanoparticles of various sizes, generally ranging between 5 and 100 nm. Mushed.[6] concluded that the size of the nanoparticles is an important factor that affects the thermal conductivity enhancement, which is contrary to the predictions of conventional models such as Hamilton and Crosser model, which does not take the effect of particle size on thermal conductivity into account. The general trend in the experimental data is that the thermal conductivity of nanofluids increases with decreasing particle size. This trend is theoretically supported by two mechanisms of thermal conductivity enhancement; Brownian motion of nanoparticles and liquid layering around nanoparticles. However, there is also a significant amount of contradictory data in the literature that indicate decreasing thermal conductivity with decreasing particle size. In fact, for the case of nanofluids with Al_2O_3nanoparticles, such results are more common than the results showing increasing thermal conductivity with decreasing particle size.

3.4 Particle Shape

There are mainly two particle shapes used in nanofluid research; spherical particles and cylindrical particles. Cylindrical particles usually have a large length-to-diameter ratio. Two types of nanoparticles were used for the preparation of nanofluids; spherical particles with 26 nm average diameter and cylindrical particles with 600 nm average diameter. It was found that 4.2 vol. % water-based nanofluids with spherical particles had a thermal conductivity enhancement of 15.8%, whereas 4 vol. % nanofluids with cylindrical particles had a thermal conductivity enhancement of 22.9%. In addition to these experimental results, the fact that nanofluids with carbon nanotubes (which are cylindrical in shape) generally show greater thermal conductivity enhancement than nanofluids with spherical particles should also be considered. As a result, one can conclude that cylindrical nanoparticles provide higher thermal conductivity enhancement than spherical particles. One of the possible reasons of this is the rapid heat transport along relatively larger distances in cylindrical particles since cylindrical particles usually have lengths on the order of micrometers. However, it should be noted that nanofluids with cylindrical particles usually have much larger viscosities than those with spherical nanoparticles. As a result, the associated increase in pumping power is large and this reduces the feasibility of usage of nanofluids with cylindrical particles.

3.5 Particle Material and Base Fluid

Many different particle materials are used for nanofluid preparation. Al_2O_3, CuO, TiO_2, SiC, TiC, Ag, Au, Cu and Fe nanoparticles are frequently used in nanofluid research. Carbon nanotubes are also utilized due to their extremely high thermal conductivity in the longitudinal (axial) direction. Base fluids mostly used in the preparation of nanofluids are the common working fluids of heat transfer applications; such as, water, ethylene glycol and engine oil. According to the conventional thermal conductivity models such as the Maxwell model, as the base fluid thermal conductivity of a mixture decreases, the thermal conductivity ratio (thermal conductivity of nanofluid (k_{nf}) divided by the thermal conductivity of base fluid (k_f)) increases.

It is seen that poor conductive fluid serve best then highly conductive ones. Hence water is generally is avoided. When it comes to nanofluids, the situation is more complicated due to the fact that the viscosity of the base fluid affects the Brownian motion of nanoparticles and that in turn affects the thermal conductivity of the nanofluid.

3.6 Temperature

In conventional suspensions of solid particles (with sizes on the order of millimeters or micrometers) in liquids, thermal conductivity of the mixture depends on temperature only due to the dependence of thermal conductivity of base liquid and solid particles on temperature. However, in case of nanofluids, change of temperature affects the Brownian motion of nanoparticles and clustering of nanoparticles, which results in dramatic changes of thermal conductivity of nanofluids with temperature.

3.7 Effect of Acidity (PH)

The number of studies regarding the pH value on the effect of fluid acidity on the thermal conductivity enhancement of nanofluids is limited when compared to the studies regarding the other parameters. A significant decrease in thermal conductivity ratio with increasing pH values as reported in literature. It was also observed that the rate of change of thermal conductivity with particle volume fraction was dependent on pH value. Thermal conductivity enhancement of 5 vol. % Al_2O_3/water nanofluid was 23% when pH is equal to 2.0 and it became 19% when pH is equal to 11.5. It is obtained optimum values of pH (approximately 8.0 for Al_2O_3/water and 9.5 for Cu/water nanofluids) for maximum thermal conductivity enhancement. At the optimum value of pH, surface charge of nanoparticles increases, which creates repulsive forces between nanoparticles. As a result of this effect, severe clustering of nanoparticles is prevented (excessive clustering may result in sedimentation, which decreases thermal conductivity enhancement)[7].

IV. Mechanisms of Heat Transfer Improvement

Apart from the basic reason of improvement in thermal conductivity in nano fluids, the suspension of nano particles alters the flow behaviour in general. Following section describes several of the proposed mechanisms.

4.1 **Enhancement of heat transfer by improvement in thermal conductivity.**

Liquid molecules close to a solid surface are known to form layered structures. The layered molecules are in an intermediate physical state between a solid and bulk liquid. With these solid like liquid layers, the nanofluid structure consists of solid nanoparticles, solid-like liquid layer, and a bulk liquid. The solid-like nanolayer acts as a thermal bridge between a solid nanoparticle and a bulk liquid and so is key to enhancing thermal conductivity[8]. Macroscopically, the forced convective heat transfer coefficient, h, is given by $h = K_f /\delta t$, with δt representing the local thickness of thermal boundary layer and K_f- the local effective thermal conductivity of nanofluids adjacent to the wall surface. This simple expression indicates that either an increase in K_f and a decrease in δt, or both, can result in an increase of the convective heat transfer coefficient. This, according to $h = K_f /\delta t$, can lead to three possible scenarios: (i) h is enhanced if the decrease in δt exceeds the decrease in K_f; (ii) h does not change if the decrease in δt is equal to the decrease in K_f; and (iii) h is reduced if the decrease in δt is lower than the decrease in K_f. This qualitatively explains the experimental results. However, quantitative explanation requires understanding of how nanoparticles behave under shear and how they interact with each other and with fluid in the boundary layer.

4.2 Effect of Brownian Motion

It is a seemingly random movement of particles suspended in a liquid or gas and the motion is due to collisions with base fluid molecules, which makes the particles undergo random-walk motion. Thus, the Brownian motion intensifies with an increase in temperature as per the kinetic theory of particles. Some researchers have suggested that the potential mechanism for enhancement of thermal conductivity is the transfer of energy due to the collision of higher temperature particles with lower ones. The effectiveness of the Brownian motion decreases with an increase in the bulk viscosity [8].

4.3 Thermophoresis

Thermophoresis or the Soret effect is a phenomenon observed when a mixture of two or more types of motile particles (particles able to move) is subjected to the force of a temperature gradient. The phenomenon is most significant in a natural convection process, where the flow is driven by buoyancy and temperature. The particles travel in the direction of decreasing temperature and the process of heat transfer increases with a decrease in the bulk density[9].

4.4 Intensification of turbulence

Lee [4] proposed that the enhancement could also come from intensification of turbulence due to the presence of the nanoparticles. However, pressure drop measurements by Mushed[6] clearly show that turbulent friction factors in their nanofluids can be very well predicted by the traditional friction factor correlations for pure fluids, if the measured nanofluid viscosity is used. This suggests that, beyond the obvious viscosity effect, turbulence is not affected by the presence of the nanoparticles. This conclusion is corroborated by a comparison of the time and length scales for the nanoparticles and the turbulent eddies.

4.5 Clustering of nano particles

Nanoparticles are known to form clusters. These clusters can be handled by using fractal theory. Evans et al. proposed that clustering can result in fast transport of heat along relatively large distances since heat can be conducted much faster by solid particles when compared to liquid matrix. This phenomenon is illustrated schematically in below.

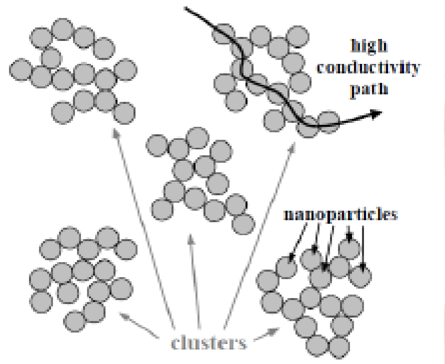

Fig. 3 Schematic illustration representing the clustering phenomenon. High conductivity path results in fast transport of heat along large distances.

It was shown that the effective thermal conductivity increased with increasing cluster size. However, as particle volume fraction increased, the nanofluid with clusters showed relatively smaller thermal conductivity enhancement. When it comes to interfacial resistance, it was found that interfacial resistance decreases the enhancement in thermal conductivity, but this decrease diminishes for nanofluids with large clusters[10].

4.6 Variation of thermal conductivity ratio with particle diameter:

As we will increase the particle diameter the thermal conductivity of the nano fluid will increase. Because as the particle size increase the Brownian motion will decrease and the Brownian motion [8] will decrease the randomness will decrease and as we know that decrease in randomness will increase the thermal conductivity.

4.7 Variation of thermal conductivity with particle volume fraction:

As we increase the particle volume fraction of the nano fluids the thermal conductivity will increases simultaneously. But from the figure we see that some authors have got different variation of the thermal conductivity with variation of the nano particle volume fraction.

V. CONCLUSION

1. we can conclude that nanofluids thermal conductivity increases with increment in particle volume fraction and temperature.
2. The chaotic movement of nano particles increases fluctuation and turbulence of the fluids, which increases the heat exchange process.
3. Convective heat transfer coefficient is enhanced by increasing the particle concentration and the Reynolds number.
4. Effects of nanofluids like clustering of nanoparticle, coagulation should be avoided.

VI. ACKNOWLEDGEMENT

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