Effect of Nanoparticles on Thermophysical Properties of Nanofluid- A Review

Abhay Kumar Singh[1]
[1]Assistant Professor, Department of Mechanical Engineering
Bakhtiyarpur College of Engineering, Bakhtiyarpur, Bihar, India
Email id-kumarabhay347@gmail.com

Abstract-

The thermophysical characteristics of nanofluids are now a topic of discussion in this work. Nanofluids' viscosity, thermal conductivity, and heat transfer are taken into account. We provide experimental and molecular dynamics results. It is shown that conventional models are often unable to account for the viscosity and thermal conductivity of nanofluids. The size, substance, and volume concentration of the particles, as well as their concentration in the fluid, all affect the transport coefficients of nanofluids. While heat conductivity rises with increasing particle size, viscosity decreases as particle size increases. We talk about the causes of this behaviour. The nanofluid flow mode (laminar or turbulent) dictates the heat transfer coefficient. The magnitude of the heat transfer coefficient is considerably impacted by the usage of nanofluids as a coolant. The heat transfer coefficient of nanofluids in laminar flow is always substantially higher than that of a base fluid. It has been demonstrated that a 2% nanofluid increases heat exchange intensity more than twice as much as water. The outcome of employing nanofluids in turbulent mode depends on both the viscosity and thermal conductivity of the fluid.

Keywords— *Effect of Nanoparticles, Thermophysical, Properties of Nanofluid, Thermal Conductivity, Heat Transfer.*

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INTRODUCTION

A base fluid and nanoparticles make up the two phases of a nanofluid. Water, organic liquids (ethylene glycol, oil, biological liquids, etc.), and polymer solutions are examples of typical carrier fluids. Typically, nanoparticles of chemically stable metals and their oxides make up the scattered solid phase. The research of nanofluids was started over 20 years ago.First, due to their numerous existing and potential applications (in various chemical processes, biotechnologies, cooling of various devices, development of new systems for thermal energy production and transportation, new pharmaceutical, medicinal and cosmetic products, systems for detection of impurities of various types and air and water purification, new lubricants, paints and varnishes, etc.), nanofluids have an ever-increasing amount of interest. Because the flows of nanofluids are tied to all of their applications, the transport processes are essential activities. Hundreds of publications have been published and dozens of research organisations from across the world have explored these processes. However, these research' findings were incredibly controversial. The viscosity and thermal conductivity of nanofluids have been discovered to be incommensurable with classical theories (Einstein, Maxwell, etc.). In order to build a coherent theory of the transport mechanisms of condensed matter, it is crucial to examine nanofluids. In many engineering fields, including power generation, electronic applications, air conditioning, chemical production, heating and cooling processes, nuclear system cooling, space and defence, transportation, and microelectronics, conventional thermal fluids like water, oil, and ethylene/propylene glycol play a significant role. Compared to solids, these fluids have low thermal characteristics. The use of expanded surfaces (fins and microchannels), surface vibration, fluid suction/injection, and the employment of electrical and magnetic fields have all come to a halt in the quest to increase heat transmission. Therefore, there has been a lot of study into novel technologies that have the potential to improve the thermo-physical characteristics of traditional fluids. Superior thermal conductivities may be seen in the solid particles. Numerous research examined the thermal characteristics of these solid particles suspended in conventional fluids. When these dispersed particles of millimetre or micrometre size are added to the base fluid, the thermophysical characteristics of the base fluid are changed, which eventually improves heat transmission. However, these millimetre- or micrometer-sized particles have issues with channel clogging, poor suspension, and poor stability. New materials with better performance and qualities than conventional materials have emerged as a result of recent technological advancements. Over the past 10 years, several research organisations from the fields of material science, electronics, mechanical engineering, and healthcare have been interested in nanomaterials. Nanomaterials are now the most in-demand materials due to their incredible optical, mechanical, electrical, and thermal capabilities. The discovery of nanomaterials has made it possible to create a new class of fluids known as nanofluids. Different synthesis techniques are used to create nanomaterials, which are typically smaller than 100 nm. The thermophysical characteristics of the generated nanofluids are next examined by suspending these nanoparticles in the conventional fluids. Choi used the phrase "nanofluid" for the first time in 1995 at the American Argonne National Laboratory. In comparison to millimetre- or micrometer-sized particles, these nanofluids (Figure. 1) exhibit greater long-term stability, low pressure loss, and maybe improved thermal conductivity. A variety of materials, including oxide ceramics, metal carbides, nitrides, metals (Al, Cu, Au), nonmetals, single or multiwall carbon nanotubes (MWCNT), and functionalized nanoparticles to generate nano-fluids, have been employed by researchers to synthesise nanoparticles.

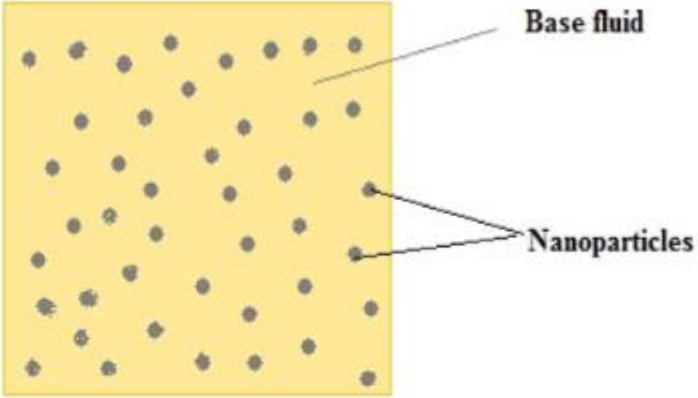

Figure 1- Nanoparticles dispersed in base fluid

LITERATURE REVIEW

Zhu et al. examined the effect of pH values variation on the thermal conductivity of Al 2O 3–H 2O nanofluid. They observed that the stability and enhancements of thermal conductivity of Al 2O3–H 2O nanofluids are extremely dependent on pH values and different SDBS dispersant concentration of nano-suspensions. The thermal conductivity improved by adding optimized SDBS dispersant. The combined treatment with both the pH and chemical dispersant was recom- mended to improve the thermal conductivity. The result of thermal conductivity showed a maximum enhancement of 10.1% at the 0.15 wt % suspension of nanoparticles.

Teng et al. studied the effect of particle (loading and size), the temperature on the thermal conductivity ratio of alumina ($Al\ 2O\ _3$) /water nanofluids. The results showed that the thermal conductivity improved with small nanoparticles size, high temperature and high weight fraction.

Chandrasekar et al. also performed similar experiments.. They prepared $Al2\ O_3$ nanoparticles using microwave assisted chemical precipitation method and dispersed them in distilled water using a sonicator. The thermal conductivity of nanofluids was measured at room temperature for different particle loadings (0.33–5%). It was concluded that the thermal conductivity increases with the nanoparticles volume concentration. The results show that the thermal conductivity enhancement of 9.7% was observed for a volume concentration of 3%.

Suresh et al. used the hydrogen reduction technique for preparing the Al2O 3–Cu/water hybrid nanofluids from the powder mixture of Al 2O 3 and CuO in the ratio of 90:10 weight proportions. The experimental result of thermal conductivity showed a highest improvement of 12.11% for a volume concentration of 2%. The hybrid nanoparticles showed better augmentation in thermal conductivity than Al 2O 3 nanoparticles.

Li et al. used Cu-H2O nanofluids at different weight fraction and observed that the thermal conductivity was extremely dependent on pH and sodium dodecyl benzene sulfonate (SDBS) surfactant. A thermal conductivity enhancement of 10.7% was observed at a weight fraction of the 0.001 (0.1 wt%) of Cu nanoparticles with optimum SDBS concentration and with optimum pH value.

Nasiri et al. investigated the thermal conductivity of carbon nanotube (CNT) structures in water-based nanofluid, and the effect of temperature and time variation. Five different structures, namely SWNT (single wall CNT), DWNT (double wall CNT), FWNT (few wall CNT) and two different multiwall were used in this study. The results from the zeta size distribution and thermal conductivity indicated that the thermal conductivity decrease with an increase in the number of nanotube wall.

Sundar et al. used the Fe3O 4 nanofluids for investigation the thermal conductivity. They performed experiments were considering volume concentration range from 0.0% to 2.0% and the temperature range 20–60 °C. The results showed that the thermal conductivity was clearly dependent on the particle volume concentration and temperature. It increased with an increase in the particle volume concentration and showed a maximum enhancement of 48% with 2.0% volume concentration at 60 °C temperature related to the base fluid.

Cuenca et al. experimentally investigated the thermal conductivity of NH 3 and H 2O mixtures (ammonia mass fractions from 0.10 to 0.50) at temperatures between 293.15 K and 313.15 K. The result showed that the thermal conductivity of NH3 + H2 O mixtures increased with the increase in the temperature and decrease with the ammonia mass fraction.

Yeganeh et al. measured the thermal conductivity augmentation of nanodiamond particles (NDs) suspended in pure deionized (DI) with different loadings in the range of 0.8% to 3 vol%. In this investigation, the thermal conductivity improvement of 7.2% was obtained with 3 vol% of the nano-diamond nanoparticles at a temperature of 30 °C. At higher temperature, (50 °C) thermal conductivity
showed improvement up to 9.8%.

Gandhi et al. studied the thermal conductivity of promising nanoparticles graphene for different concentrations of 0.01–0.2 vol% at different temperatures. The thermal conductivity was found to improve with the increase in concentration of graphite and maximum enhancement of 27% was observed at 0.2% concentration.

Recently, Jiang et al. developed a model to predict the effective thermal conductivity of nanofluids by including the effect of the nano- shell formed by fluid molecules around the nanoparticles. The effective thermal conductivity predicted by the present model along with the ratio of the thermal conductivities of the particle and liquid and their relative volume fractions, also considers nanoparticles radius and the thermal conductivity and thickness of the interfacial nano-shell which are not considered in traditional models.

THERMOPHYSICAL PROPERTIES OF NANOFLUIDS

When nanoparticles are added to the base fluid, thermophysical parameters including thermal conductivity, viscosity, and specific heat change, which has an impact on convective heat transfer. Various nanomaterials alter their parameters to varying degrees. The main elements that substantially change the thermophysical characteristics of nanomaterials are their concentration, purity level, shape, and size. The most recent evaluation of the thermophysical characteristics of various base fluids and nanoparticules, as well as elements influencing thermal conductivity.

(i) Thermal conductivity- Numerous theoretical and experimental studies have been conducted to look into how the thermal conductivity of nanofluids changes over time. The thermal conductivity of a typical fluid is increased by the inclusion of nanoparticles. This is as a result of Brownian motion, a crucial process governing the thermal behaviour of nanoparticle-fluid suspensions (Figure 2). The interfacial layer (nanolayer), which is formed when liquid molecules are near to the surface of a solid particle (Figure 3), is the second explanation. These layered structures increase thermal conductivity by serving as a thermal link between nanoparticles and a bulk liquid. The thermal characteristics of solid/liquid suspensions and this nanolayer have very little in common. Between a bulk liquid and a solid particle, these stacked molecules exist in a physical state that is in between. Thermal conductivity is predicted to be increased more than in the bulk conventional fluid by the solid-like nanolayer of liquid molecules. According to studies, base fluids don't have nanofluids' great thermal conductivity. The transient hot-wire device and the hot disc thermal constants analyzer are two methods that may be used to measure the thermal conductivity of nanofluids. Different base fluids (ethylene glycol, propylene glycol, methanol, glycerol, gear oil, engine oil, paraffin, etc.) and various nanoparticles were used in the studies conducted by the researchers.

(ii) Base fluids- Water, TiO_2 nanoparticles with a rod and spherical form were employed by Murshed et al. to create nanofluids by dispersing the nanoparticles in deionized water. The results of the experiment demonstrated that particle size and shape have an impact on thermal conductivity and that it improves as particle loadings (0.5–5 vol%) rise. According to the results, thermal conductivity for TiO_2 (15 nm)-water nanofluids increased by 29.70% with 5% particle volume fraction and by 32.80% with the same volume fraction. Nanoparticles with a rod form shown greater improvements than those with a spherical shape. When TiO_2 nanoparticles were disseminated in water at a concentration of 0.2-2 vol%, Duangthongsuk and Wong wises examined their thermal conductivity. With increasing particle loading and temperature (between 15 °C and 35 °C), nanofluids become more thermally conductive. In an International Nanofluid Property Benchmark Exercise (INPBE), Buongiorno et al. used experimental techniques such as the transient hot wire method, steady-state methods, and optical methods to measure the thermal conductivity of matched samples of colloidally stable nanofluids from thirty organisations across the globe.

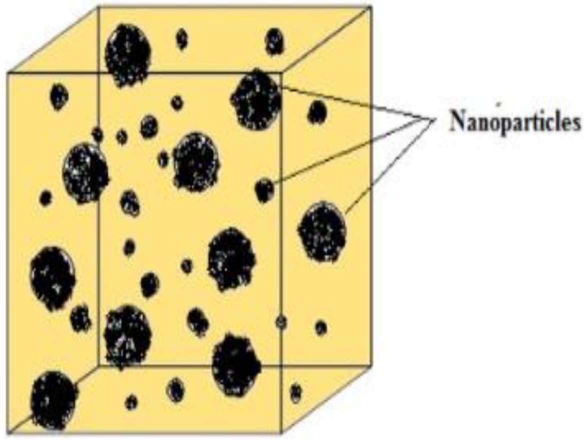

Figure 2- Brownian motion of nanoparticles

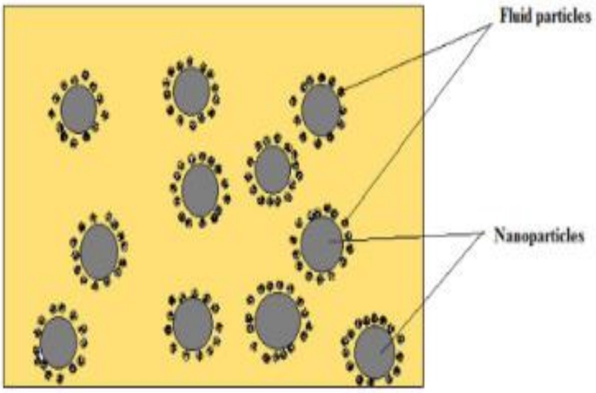

Figure 3- Nanofluid structure consisting of nanoparticles, bulk liquid, and nanolayers at the solid / liquid interface

(iii) Ethylene glycol- With an increase in volume concentration of the nanoparticles, Liu et al. investigated the improvement in thermal conductivity of multiwalled carbon nanotubes (MWNTs) based on ethylene glycol and synthetic motor oil. The enhancement value of heat conductivity for CNT-ethylene glycol at 1% volume concentration was up to 12.4%, while for CNT-synthetic motor oil suspension at 2% volume concentration, the enhancement value of thermal conductivity was up to 30%.

(iv) Other base fluids - Kole and Dey investigated the improvement of thermal conductivity of CuO-gear oil nanofluids and investigated the factors influencing thermal conductivity, such as temperature and nanofluid volume percentage. The temperature range between 5 and 80 °C was used to measure thermal conductivity. The results of the experimental study indicated that adding 0.025 volume percent of CuO nanoparticles to nanofluids boosts their thermal conductivity by 10.4% at ambient temperature and by 11.9% at 80 °C.

EFFECTS OF VARIOUS FACTORS ON THERMAL CONDUCTIVITY OF NANOFLUIDS

(i) Particle Size- The size of the particle is a significant parameter affecting the thermal conductivity of nanofluids. The nanoparticles can be synthesized of various sizes, ranging from 5 and 100 nm. Paul et al. discussed about the effect of the size of the nanoparticles on the base fluid. Teng et al. studied the effect of particle size on the thermal conductivity ratio of alumina (Al_2 O_3)/water nanofluids. The experiment results showed that the thermal conductivity of nanofluids increases with decrease particle size.

(ii) Particle Shape- Normally two particle shapes are used in nanofluids research; cylindrical particles and spherical particles. The cylindrical shapes of nanoparticles have a large length-to-diameter ratio. Xie et al. was the first researchers who investigated the effects of the shape of the nanoparticles, including spherical or cylindrical, on the augmentation of thermal conductivity of SiC nanofluids. Murshed et al. also investigated the effect of spherical and cylindrical shape nanoparticles on the thermal conductivity of nanofluids.

(iii) Particle Material and Base Fluid- Oxide ceramics, Metal carbides, Nitrides, Metals, nonmetals are the various types of particle material which are used for nanofluids preparation. Carbon nanotubes (single or multiwall) are also used as particle material and it have a high thermal conductivity. Common working fluids such as, water, ethylene/propylene-glycols, bio-fluids and engine oil are used as base fluids for the preparation of nanofluids for heat transfer applications.

(iv) Temperature- The thermal conductivity of the nanofluids depends on the temperature of the thermal conductivity of base fluid and particles.

Brownian motion and clustering of nanoparticles are affected by the change in temperature and shows the changes in thermal conductivity of nanofluids. Yu et al. examined the thermal conductivity enhancement based on the effect of temperature for nanofluids containing ZnO nanoparticles. The thermal conductivity of nanofluids increased with increase in temperature. Duangthongsuk and Wongwises experimentally studied the thermal conductivity of nanofluids. In this study, TiO_2 nanoparticles dispersed in water with volume concentration of 0.2– 2 vol% is used. The results showed that the measured thermal conductivity of nanofluids increased with increasing nanofluids temperatures.

(v) Additives- Additives are used to keep the nanoparticles in suspension and prevent them from agglomeration. Thus, they are expected to cause thermal conductivity enhancement of nanofluids. Eastman et al. worked some tests on Cu in ethylene glycol with and without additives. The results showed that additives can strongly increase effective thermal conductivity of nanofluids. Kole and Dey prepared the Cu-gear oil nanofluids having 0.11–2% volume concentration of Cu nanoparticles with oleic acid surfactant. A 24% thermal conductivity enhancement was achieved by 2 vol% of the Cu nanoparticles at room temperature. Li et al. used sodium dodecyl benzene sulfonate as a surfactant and presented the effects on the thermal conductivity of Cu-H 2O nanofluids. The results indicated that the thermal conductivity enhancements of Cu-H2 O nanofluids were extremely dependent on the SDBS surfactant concentration of nano-suspensions.

CONCLUSION

Nanofluids are therefore not like typical suspensions. The conventional theories cannot explain their thermophysical characteristics. We can confidently state now that the viscosity of nanofluids is considerably higher than the viscosity of typical coarse dispersed fluids. Recent studies and simulations of molecular dynamics support this conclusion. When compared to coarsely dispersed fluid, the viscosity of nanofluids depends not only on the quantity of the particles but also on their size and composition. The motivations behind this behaviour are obvious. The nanofluid is significantly more ordered (in terms of short-range order) than the basic fluid, which is the fundamental cause of this reliance. The fluid becomes more organised as particle concentration and size decrease. A subtler characteristic is the dependence of the nanofluid viscosity on the particle material. This characteristic is quite simple to explain for nanofluids with extremely tiny particles. However, in studies, big particle nanofluid has also shown similar relationship. Therefore, more study is needed to solve this problem. However, currently almost every assigned nanofluid's viscosity can be confidently predicted. Like their viscosity, the thermal conductivity of nanofluids is not explained by classical theories, in particular, by the Maxwell's formula (or its generalisations). The size and composition of the nanoparticles affect the nanofluid's thermal conductivity. Typically, thermal conductivity is much higher than the value predicted by Maxwell's equations. It rises with increasing particle concentration, reaches a maximum, and then barely minimally fluctuates after that. Contrary to conventional wisdom, the thermal conductivity of nanofluids relies on the size of the particles and rises as their number grows.

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