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AL_2O_3 Nanofluids as Heat Transfer Liquids in Automotives.

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Abstract— The thermal conductivity of heating or cooling fluids is a very important property in the development of energy efficient heat transfer systems, which is one of the important needs of many industries. However, low thermal conductivity is a primary limitation in developing energy-efficient heat transfer fluids that are required for cooling purposes. Nanofluids are nanotechnology-based heat transfer fluids that are engineered by stably dispersing nanometer-sized (below 100nm) solid particles (such as ceramics, metals, alloys, semiconductors, nanotubes, and composite particles) in conventional heat transfer fluids (such as water, oil, diesel, ethylene glycol and mixtures) at relatively low particle volume concentrations. These suspended nanoparticles can change the transport and thermal properties of the base fluid. Adding to ethylene glycol, it has been observed that an enhancement of nearly 36 % with al2o3 nanoparticles and 40% enhancement with copper nanoparticles in the thermal conductivity. This paper focuses on some of the automotive applications such as coolant for automobiles, showcases a few of them that are believed to have the highest probability of success in this highly competitive industry and to raise the awareness on the promise of nanotechnology, its potential impact on the future of the automotive industry.

Keywords- *Nanofluids, Nanoparticles, Heat transfer, Thermal conductivity.*

I. INTRODUCTION

In the dimensional scale a nanometer is a billionth of a meter. Nanoscale science and engineering has revolutionized the scientific and technological developments in nanoparticles, nonstructured materials, nanodevices and systems. National Science Foundation defines nanotechnology as the creation and utilization of functional materials, devices, and systems with novel properties and functions that are achieved through the control of matter, atom-by-atom, and molecule by molecule or at the macro molecular level. A unique challenge exists in restructuring teaching at all levels to include nanoscale science and engineering concepts and nurturing the scientific and technical workforce of the future.

There is a great need for more efficient heat transfer fluids in many industries, from transportation to energy supply to electronics and photonics. The coolants, lubricants, oils, and other heat transfer fluids used in today's thermal management systems have inherently poor heat transfer properties. And conventional working fluids that contain millimeter- or micrometer-sized particles are not applicable to the newly emerging "miniaturized" technologies because they can clog micro channels.

Nanofluids are a new, innovative class of heat transfer fluids created by dispersing solid particles smaller than 40 nm in diameter (less than one-thousandth the diameter of a human hair) in traditional heat transfer fluids such as water, engine oil, and ethylene glycol. Solid particles are added because they conduct heat much better than liquid.

Nanofluids are nanotechnology-based heat transfer fluids that are engineered by stably dispersing nanometer-sized solid particles (such as ceramics, metals, alloys, semiconductors, nanotubes, and composite particles) in conventional heat transfer fluids (such as water, ethylene glycol, oil, and mixtures) at relatively low particle volume concentrations. Nanofluids have been considered for applications as advanced heat transfer fluids for almost two decades, since they have better suspension stability compared to micron-sized solid particles, can flow smoothly without clogging the system, and provide enhanced thermal and physical properties.

Conventional fluids, such as water, engine oil, and ethylene glycol are normally used as heat transfer fluids. Although various techniques are applied to enhance the heat transfer, the low heat transfer performance of these conventional fluids obstructs the performance enhancement and the compactness of heat exchangers. The use of solid particles as an additive suspended into the base fluid is technique for the heat transfer enhancement. Improving the thermal conductivity is the key idea to improve the heat transfer characteristics of conventional fluids. Since a solid metal has a larger thermal conductivity than a base fluid, suspending metallic solid fine particles into the base fluid is expected to improve the thermal conductivity of that fluid. The enhancement of thermal conductivity of conventional fluids by the suspension of solid particles, such as millimeter- or micrometer- sized particles has been well-known for many years. However, they have not been of interest for practical applications due to problems such as sedimentation leading to increased pressure drop in the flow channel. The recent advance in material technology has made it possible to produce innovative heat transfer fluids by suspending nanometer-sized particles in base fluids which can change the transport and thermal properties of the base fluid. Nanofluids are solid-liquid composite materials consisting of solid nanoparticles or nanofibers with sizes typically of 1 to 100 nm suspended in liquid. The nanofluid is not a simple liquid-solid mixture the most important criterion of nanofluid is agglomerate-free stable suspension for long durations without causing any chemical changes in the base fluid. This can be achieved by minimizing the density between solids and liquids or by increasing the viscosity of the liquid by using nanometer- sized particles and by preventing particles from agglomeration, the settling of particles can be avoided. Nanofluids have attracted great interest recently because of reports of enhanced thermal properties. Extensive research has been carried out on alumina-water- and CuO-water-based systems besides few reports in Cu-water, carbon nanotubes water systems.

THE GOAL AND APPLICATIONS OF NANO FLUIDS

The most important goal in nanofluid research is to create and develop a nanofluid with stability and ultra-high thermal conductivity for industrial applications. The use of these nanofluids can have a lot of benefits which are: the improvement of heat transfer, reduction in pumping power and lower operating costs, miniaturizing of smaller and lighter heat exchangers, reduction of emissions, suitable for small flow passages like microchannels and reduction in heat transfer fluid inventory.

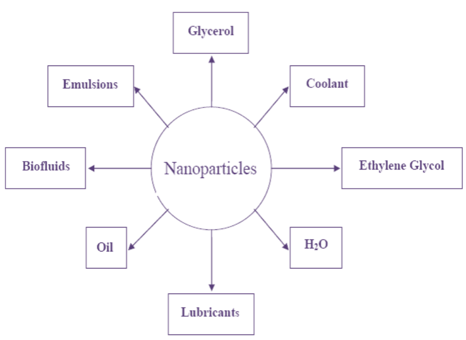

Fig: 1 A number of liquids (heat transfer fluids) that can host nanoparticles for the production of nanofluids.

The size of nanoparticles defines the surface-to-volume ratio and for the same volume concentrations suspensions of smaller particles have a higher area of the solid/liquid interface.Therefore the contribution of interfacial effects is stronger in such a suspension. Interactions between the nanoparticles and the fluid are manifested through the interfacial thermal resistance.

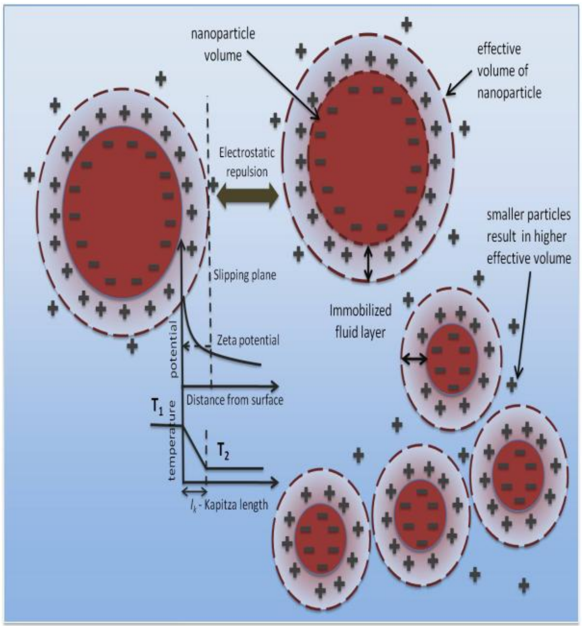

Fig: 2 Interfacial effects in nanoparticle suspensions

THE MOST PROMISING AUTOMOTIVE APPLICATIONS OF NANOTECHNOLOGY

- Improved materials with CNTs, graphene and other nanoparticles/structures
- Improved mechanical, thermal, and appearance properties for plastics
- Coatings & encapsulants for wear and corrosion resistance, permeation barriers, and appearance
- Cooling fluids with improved thermal performance
- Displays with lower cost and higher performance
- Automotive sensors with nano-sensing elements, nanostructures and nano-machines
- Self-assembly using fluid carriers
- Electrical switching including CNT transistors, quantum transistors, electronemission amplification, and more efficient solar cells

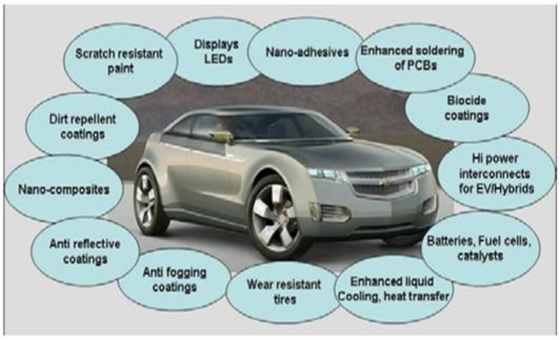

Fig: 3 automotive applications

EFFICIENT NANO FLUID BY DESIGN

In light of all the mentioned nanofluid property trends, development of a heat transfer nanofluid requires a complex approach that accounts for changes in all important thermophysical properties caused by introduction of nanomaterials to the fluid. Understanding the correlations between nanofluid composition and thermo-physical properties is the key for engineering nanofluids with desired properties.

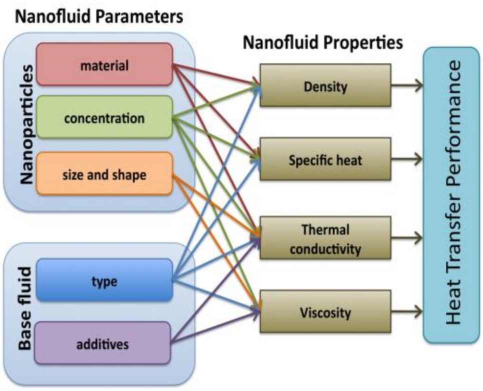

Fig: 4 Complexity and multi-variability of nanoparticle suspensions

PREPARATION OF NANO FLUIDS

Synthesis and Preparation of Nanofluids:

Preparation of nanofluids is the first key step in experimental studies with nanofluids. Nanofluids are not just dispersion of solid particles in a fluid. The essential requirements that a nanofluid must fulfill are even and stable suspension, adequate durability, negligible agglomeration of particles, no chemical change of the particles or fluid, etc. Nanofluids are produced by dispersing nanometerscale solid particles into base liquids such as water, ethylene glycol, oil, etc. In the synthesis of nanofluids, agglomeration is a major problem. There are mainly two techniques used to produce nanofluids the single-step and the two-step method.

THE SINGLE-STEP PROCESS

Various investigators have produced Al2O3 and CuO nanopowder by direct evaporation condensation method that produced 2–200 nm-sized particles.Even though this method has limitations of low vapor-pressure fluids and oxidation of pure metals; it provides excellent control over particle size and produces particles for stable nanofluids without surfactant or electrostatic stabilizers. The single-step direct evaporation approach was developed by Akoh et al.and is called the Vacuum Evaporation onto a Running Oil Substrate technique. The original idea of this method was to produce nanoparticles, but it was difficult to subsequently separate the particles from the fluids to produce dry nanoparticles. Eastman et al. developed amodified vacuum evaporation onto oil technique, in which Cu vapor is directly condensed into nanoparticles by contact with a flowing low-vapor-pressure liquid ethylene glycol. Zhu et al. presented a novel one-step chemical method for preparing copper nanofluids by reducing CuSO4・5H2O with NaH2PO2・H2O in ethylene glycol under microwave irradiation. Results showed that addition of NaH2PO2・H2O and the adoption of microwave irradiation are two significant factors which affect the reaction rate and properties of Cu nanofluids. Lo et al. developed a vacuum-based submerged arc nanoparticle synthesis system to prepare CuO, Cu2O, and Cu based nanofluids with different dielectric liquids. The morphologies of nanoparticles depended on the thermal conductivity of the dielectric liquids. An advantage of the onestep technique is that nanoparticle agglomeration is minimized, while the disadvantage is that only low vapor pressure fluids are compatible with such a process.

THE TWO STEP PROCESS

The two-step method is extensively used in the synthesis of nanofluids considering the available commercial nano-powders supplied by several companies. In this method, nanoparticles were first produced and then dispersed in the base fluids. Generally, ultrasonic equipment is used to intensively disperse the particles and reduce the agglomeration of particles. For example, Eastman et al.Lee et al, and Wang et al. used this method to produce Al2O3 nanofluids. Also, Murshed et al. prepared TiO2 suspension in water using the two-step method. Other nanoparticles reported in the literature are gold (Au), silver (Ag), silica and carbon nanotubes. As compared to the single-step method, the two-step technique works well for oxide nanoparticles, while it is less successful with metallic particles. Except for the use of ultrasonic equipment, some other techniques such as control of pH or addition of surface active agents are also used to attain stability of the suspension of the nanofluids against sedimentation. These methods change the surface properties of the suspended particles and thus suppress the tendency to form particle clusters. It should be noted that the selection of surfactants should depend mainly on the properties of the solutions and particles. For instance, salt and oleic acid as dispersant are known to enhance the stability of transformer oil– Cu and water–Cu nanofluids, respectively. Oleic acid and cetyltrimethylammoniumbromide (CTAB) surfactants were used by Murshed et al.to ensure better stability and proper dispersion of TiO_2–water nanofluids. Sodium dodecyl sulfate (SDS) was used by Hwang et al.during the preparation of water-based multi wall carbon nanotube dispersed nanofluids since the fibers are entangled in the aqueous suspension. In general, methods such as change of pH value, addition of dispersant and ultrasonic vibration aim at changing the surface properties of suspended particles and suppressing formation of particlescluster to obtain stable suspensions

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EXPERIMENTAL INVESTIGATIONS

Measurement of Thermal Conductivity

Since thermal conductivity is the most important parameter responsible for enhanced heat transfer, many experimental works have been reported on this aspect.Alumina (Al_2O_3) and copper oxide are the most common and inexpensive nanoparticles used by many researchers in their experimental investigations. All the experimental results have demonstrated the enhancement of the thermal conductivity by addition of nanoparticles. Eastman et al.measured the thermal conductivity of nanofluids containing Al_2O_3, CuO, and Cu nanoparticles with two different base fluids: water and HE-200 oil. A 60% improvement of the thermal conductivity was achieved as compared to the corresponding base fluids for only 5 vol% of nanoparticles. They also showed that the use of Cu nanoparticles (using the one-step method) results in greater improvements than that of CuO (using the two-step method). Lee et al. suspended CuO and Al_2O_3 (18.6 and 23.6 nm, 24.4 and 38.4 nm, respectively) in two different base fluids: water and ethylene glycol (EG) and obtained four combinations of nanofluids: CuO in water, CuO in EG, Al_2O_3 in water and Al_2O_3 in EG. Their experimental results showed that nanofluids have substantially higher thermal conductivities than the same liquids without nanoparticles. The CuO/EG mixture showed enhancement of more than 20% at 4 vol% of nanoparticles. In the low volume fraction range ($<0.05\%$ in test), the thermal conductivity ratios increase almost linearly with volume fraction. Results suggest that not only particle shape but size is considered to be dominant in enhancing the thermal conductivity of nanofluids. The base fluids (water, ethylene glycol (EG), vacuum pump oil and engine oil) contained suspended Al_2O_3 and CuO nanoparticles of 28 and 23 nm average diameters, respectively. Experimental results demonstrated that the thermal conductivities of all nanofluids were higher than those of their base fluids. Also, comparison with various data indicated that the thermal conductivity of nanofluids increases with decreasing particles size. Results demonstrated 12% improvement of the effective thermal conductivity at 3 vol% of nanoparticles as compared to 20% improvement reported by Masuda et al. and 8% reported by Lee et al. at the same volume fraction of particles. Xuan and Li enhanced the thermal conductivity of water using Cu particles of comparatively large size (100 nm) to the same extent as has been found using CuO particles of much smaller dimension (36 nm). An appropriate selection of dispersants may improve the stability of the suspension. They used oleic acid for transformer oil-Cu nanofluids and laurate salt for water-Cu suspension in their study and found that Cu particles in transformer oil had superior characteristics to the suspension of Cu particles in water. Xie et al. investigated the effects of the pH value of the suspension, the specific surface area (SSA) of the dispersed Al_2O_3 particles, the crystalline phase of the solid phase, and the thermal conductivity of the base fluid on the thermal conductivity of nanofluids. They found that the increase in the difference between the pH value and isoelectric point (the pH at which a molecule carries no net electrical charge) of Al_2O_3 resulted in enhancement of the effective thermal conductivity.Also, the thermal conductivity enhancements were highly dependent on the specific surface area (SSA) of the nanoparticles. The crystalline phase of the nanoparticles did not appear to have any obvious effect on the thermal conductivity of the suspensions. Eastman et al. used pure Cu nanoparticles of less than 10 nm size and achieved a 40% increase in thermal conductivity for only 0.3% volume fraction of the solid dispersed in ethylene glycol.

Das et al. (2003c) examined the effect of temperature on thermal conductivity enhancement for nanofluids containing Al_2O_3 (38.4 nm) or CuO (28.6 nm) through an experimental investigation using the temperature oscillation method. They observed that a 2 to 4-fold increase in thermal conductivity can take place over the temperature range of 21oC to 52oC. The results suggest the application of nanofluids as cooling fluids for devices with high energy density where the cooling fluid is likely to work at a temperature higher than room temperature. They also mention that the inherently stochastic motion of nanoparticles could be a probable explanation for the thermal conductivity enhancement since smaller particles show greater enhancements of thermal conductivity with temperature than do larger particles. Li and Peterson conducted an experimental investigation to examine the effects of variations in the temperature and volume fraction on the effective thermal conductivity of CuO (29 nm) and Al_2O_3 (36 nm) water suspensions. Results demonstrated that nanoparticle material, diameter, volume fraction and bulk temperature have significant effects on the thermal conductivity of the nanofluids. For example, for Al2O3/water suspensions, increase in the mean temperature from 27 to 34.7oC results in an enhancement of nearly three times. They also derived two simple two-factor linear regressions for the discussed nanofluids (Al2O3/water)

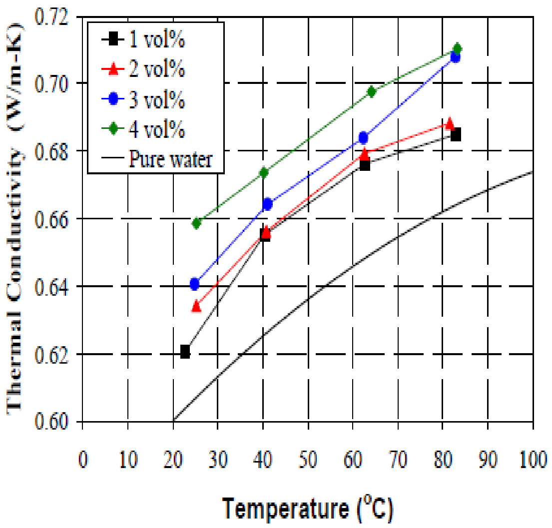
$$(k_{eff} - k_b)/k_b = 0.764\varphi + 0.0187(T - 273.15) - 0.462,$$

CuO/water

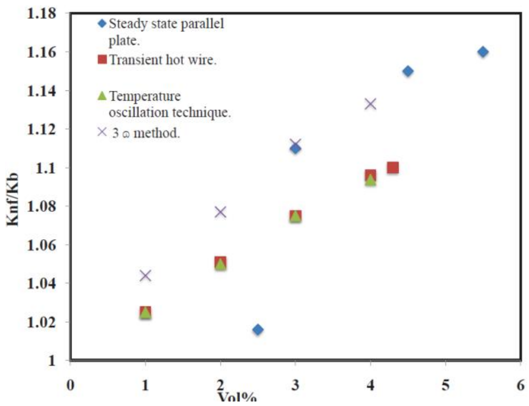
$$(k_{eff} - k_b)/k_b = 3.761\varphi + 0.0179(T - 273.15) - 0.307 .$$

EXPERIMENTAL RESULTS ON THERMAL CONDUCTIVITY OF AL2O3 BASED NANOFLUIDS

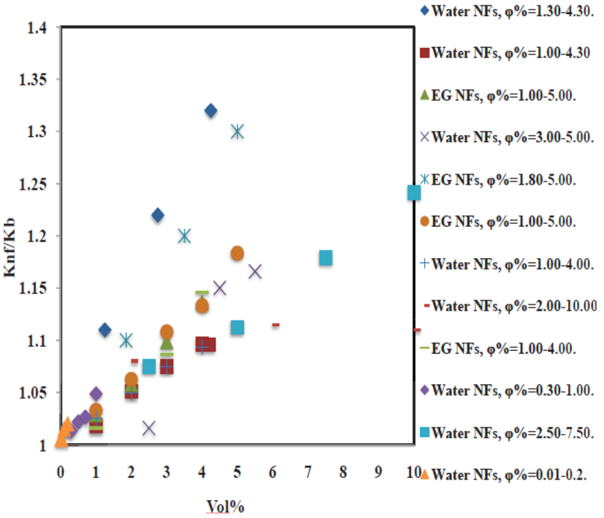
1. Effect of temperature on thermal conductivity of Al2O3- based nanofluids



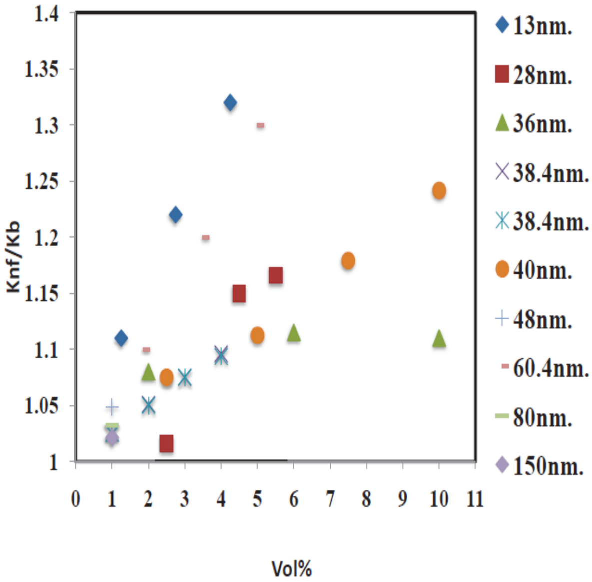
2. Thermal conductivity of Al2O3 nanofluids measured by different techniques



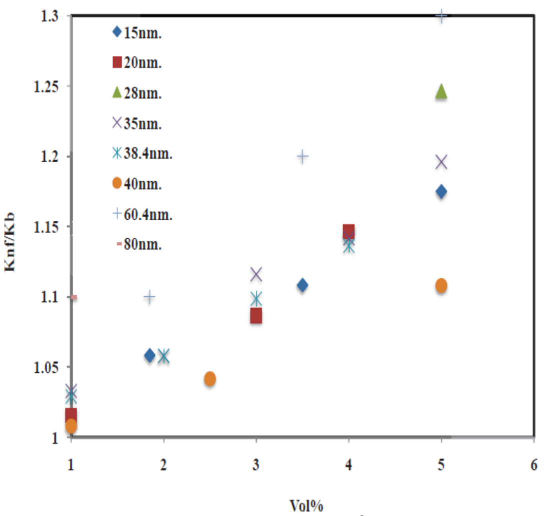
3. Effect of volume fraction of nanoparticles on thermal conductivity of Al2O3-based nanofluids



4. Effect of particle size on thermal conductivity of Al2O3 based nanofluids

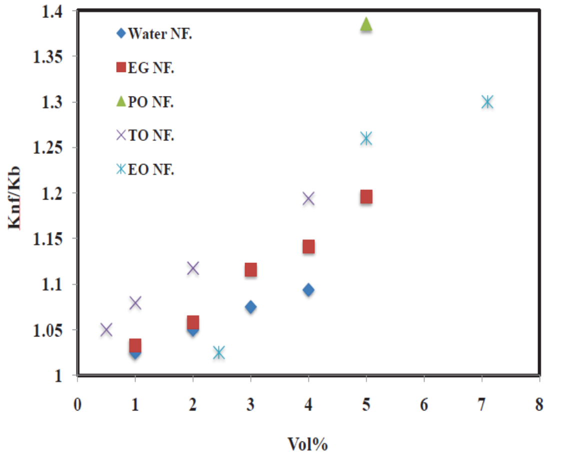


Water-based Al2O3 nanofluids

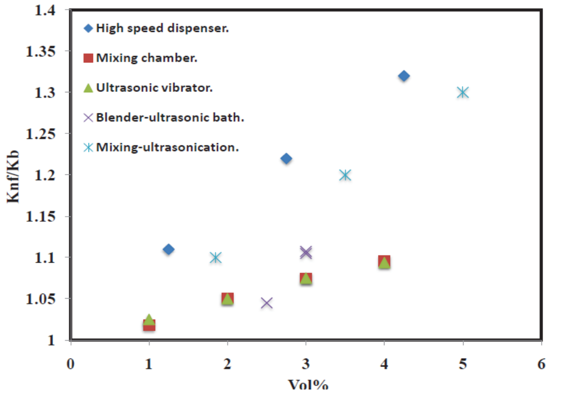


EG -based Al2O3 nanofluids.

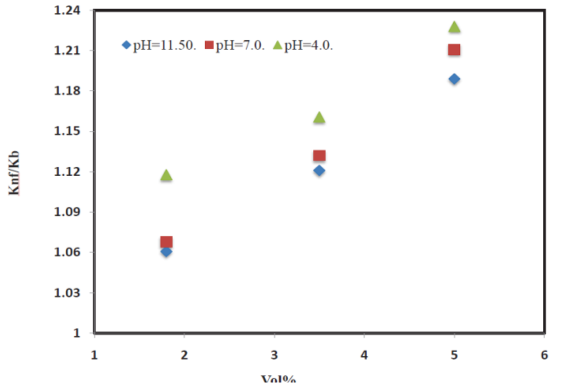
5. Effect of base fluids on thermal conductivity of Al2O3- based nanofluids



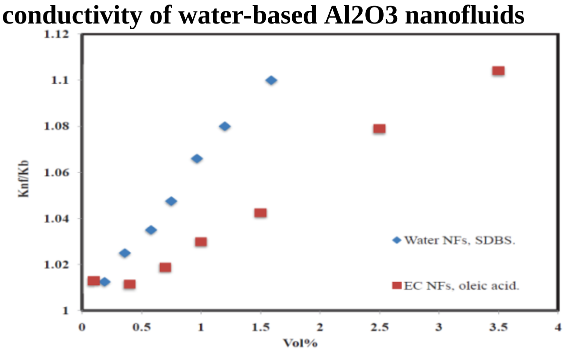
6. Effect of preparation method on thermal conductivity of Al2O3-based nanofluids



7. Effect pH on thermal conductivity of Al2O3 water-based nanofluids.



8. Effect of surface active agents on thermal conductivity of water-based Al2O3 nanofluids



EXPERIMENTAL RESULTS ON THERMAL CONDUCTIVITY OF CU-CONTAINING -EG

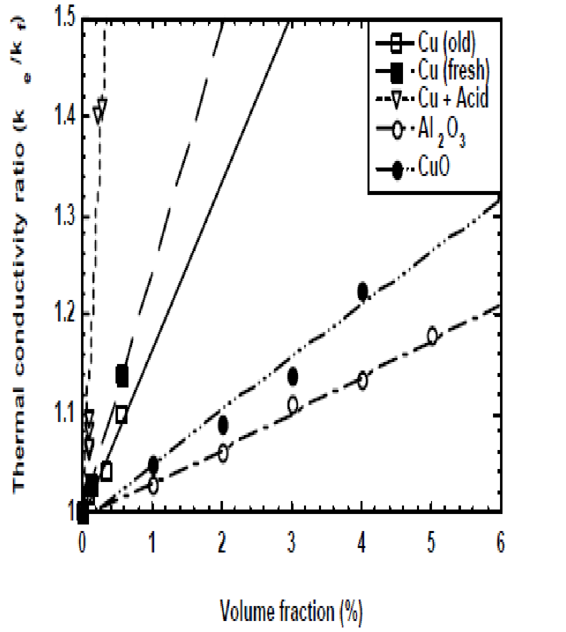


Fig 5: Thermal conductivity enhancement of copper, copper oxide, and alumina particles in ethylene glycol.

CONCLUSIONS

- Nano fluids containing copper nano particles enhance the thermal conductivity of base fluids dramatically For example; adding only 0.3 vol. % of 10-nm copper nanoparticles to ethylene glycol increased its thermal conductivity up to 40%. Further, nanotubes have yielded by far the highest thermal conductivity enhancement ever achieved in a liquid: a 150% increase in conductivity of oil at ~1 vol. % of 25-nm nanotubes.
- From the observed results, it is clearly seen that nanofluids have a greater potential for heat transfer enhancement and are suitable for application in practical heat transfer processes. The enhancement of thermal conductivity of base fluid will be a definite requirement in the future to improve the thermal efficiency of different systems.
- Researchers can concentrate on the effect of temperature and the hysteresis behavior for AL_2O_3 nanofluids and can try to increase the temperature withstanding capacity of the Al2O3 nanofluids.
- On the basis of the promising results to date, nanofluid research could lead to a major breakthrough in solid/liquid composites for numerous engineering applications, such as coolant for automobiles, air conditioning, and supercomputers.

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