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Study on Thermophysical Properties of Nanofluids and its Applications

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A B S T R A C T

This seminar summarizes the important results regarding the improvement in the thermo-physical properties of Nano fluids. The influence of important parameters like particle's (loading, material, size, and shape), base fluid type, temperature, additives and pH value has been considered. Also, properties including thermal conductivity, density, specific heat, effect of particle volume concentration, effects of additives, acidity, Nano particle interfacial layer, Brownian motion and particle clustering are also discussed. The different Nano particles discussed in this seminar includes Al70Cu30, Al2Cu, AG2Al, Al2O3, CuO, etc... And also compared them with thermal conductivities of various liquids and solids.

Further literature review of the applications of Nano fluids with a particular focus on the advantages of using Nano fluids in solar collectors and as coolants in automotive heat exchangers. This seminar can help in the translation of Nano fluid technology from the lab scale research to industrial applications in solar collectors and automotive sector. The pros and cons associated to the applications of Nano fluids in heat transfer devices are presented in details to determine the future direction of research in this arena.

Keywords: *Nano fluids, Brownian motion, Nanoparticle interfacial layer, Applications, Thermal conductivity.*

1. Introduction

Nanotechnology has been widely used in various engineering applications as a promising alternative for saving energy and reducing the cost of manufacturing engineering devices. The word "nano" is described as 1 billionth of a meter or 10-9 m. These nanoparticles are mixed in the base heat transfer fluid to form a colloidal solution in a stable capsule, and its addition to base fluids with low thermal conductivity is likely to increase the heat transfer characteristics of the base fluids. This creative fluid is known as nanofluid, which has a new heat transfer characteristic as one of the latest results of nanotechnology.

The main focus was on the nanotechnology revolution and its unique properties compared to the great extent of its originality. This dramatic growth stemmed from multifaceted applications in various areas of life: medicine, agriculture, engineering and industry. Nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes, while base fluids include water, ethylene glycol, and oil. Nanofluids have novel properties that make them potentially useful in many heat transfer applications, including microelectronics, fuel cells, pharmaceutical processes and hybrid engines, engine cooling/vehicle thermal management, domestic refrigerators, chillers and heat exchangers, and in grinding, machining and reduction flue gas temperature in the boiler. Nanotechnology as a scientific field studies the properties of materials at the nanoscale. This, of course, saves energy exactly like reducing the volume of heat transfer equipment.

Compared to conventional coolants such as water, kerosene, ethylene glycol and micro fluids, nanofluids have been shown to exhibit higher thermal conductivity. Furthermore, nanofluids do not block the flow channels and cause only a very small pressure drop during flow, which is advantageous for heat transfer applications. Traditionally, this field falls into the field of colloid science and thus a wealth of knowledge about the preparation; characterization and there is stabilization of nanofluids. Energetic Brownian motion of suspended nanoparticles inside base fluids make nanofluids more stable compared to micro fluids, which is one of the attractiveness of nanofluids for heat transfer applications. Three properties that make nanofluids promising coolants are increased thermal conductivity, increased heat transfer and increased critical heat flux.

1.1 Nanofluids

The word "nano" is described as 1 billionth of a meter or 10-9 m. These nanoparticles are mixed in the base heat transfer fluid to form a colloidal solution in a stable capsule, and its addition to base fluids with low thermal conductivity is likely to increase the heat transfer characteristics of the base fluids. This creative fluid is known as nanofluid, which has a new heat transfer characteristic as one of the latest results of nanotechnology. Conventional heat transfer fluids have inherently poor thermal conductivity compared to solids. Nanofluids are primarily used for their enhanced thermal properties as coolants in heat transfer equipment such as heat exchangers, electronic cooling system (such as flat plate) and radiators.

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Nanofluids have novel properties that make them potentially useful in many heat transfer applications, including microelectronics, fuel cells, pharmaceutical processes and hybrid engines, vehicle engine cooling/thermal management, domestic refrigerators, chillers, heat exchangers, during grinding, machining and when reducing the temperature of the boiler flue gases. They exhibit increased thermal conductivity and convection heat transfer coefficient compared to the base fluid. Knowledge of the rheological behavior of nanofluids is considered critical in deciding their suitability for convective heat transfer applications. Nanofluids also have special acoustic properties and in ultrasonic fields exhibit further conversion of the shear wave to the incident pressure wave; the effect becomes more pronounced with increasing concentration.

1.2 Preparation of nanofluids

Nanofluids are prepared by dispersing nanoparticles in the base fluids. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. Several liquids including water, ethylene glycol, and oils have been used as base fluids.

There are two fundamental methods for preparing nanofluids, they are:

- One step method
- Two step method

1.3 Nanofluid properties

The thermophysical properties of solutions are profoundly modified by the addition of nanoparticles, and this modification is significantly influenced by a large number of factors, including the type of material, the size and shape of the nanoparticles used, as well as the volume concentration of suspended particles and conductivity of the base fluid. These new types of fluids were created with different thermophysical properties such as density, heat capacity, thermal conductivity, convective heat transfer, thermal diffusivity and viscosity

1.4 Thermal conductivity

Thermal conductivity is the ability of a material to conduct or transfer heat. It is the most important property for improving the thermal performance of the heat transfer fluid. Several theoretical and experimental studies have been carried out to estimate the thermal conductivity value of the nanofluid. This property depends on many parameters, such as the temperature of the medium, the conductivity of the base fluid, the thermophysical properties of the nanoparticles, the size and shape of the particles, Brownian motion, and the volume fraction of suspended particles.

There are four modes of energy transfer in nanofluids:

- Collision between base fluid molecules.
- Thermal diffusion in nanoparticle suspended in fluids.
- Collision between nanoparticles.
- Thermal interaction of dynamic nanoparticles with base fluid.

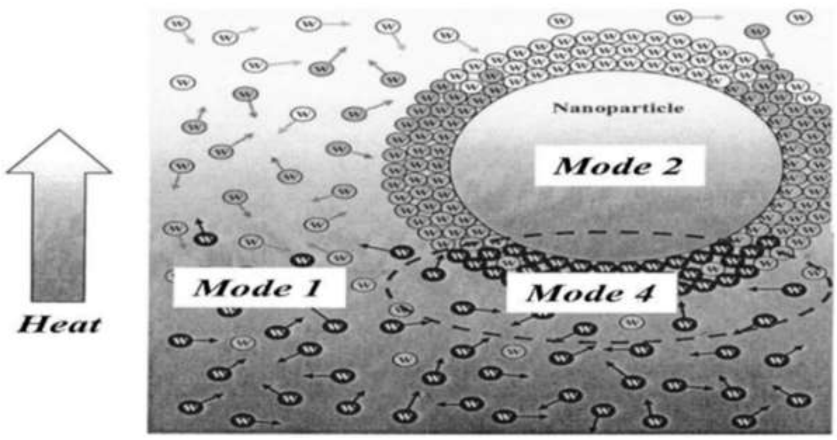

Fig. 1: Modes of energy transport

The main factors affecting the thermal conductivity are volumetric concentration, particle size, particle shape, fluid temperature and pH value of nanofluids. The volumetric loading of suspended nanoparticles affects the thermal conductivity. Increasing the concentration of particles increases thermal conductivity. Particle size plays an important role in improving the thermal conductivity of nanofluids. The thermal conductivity of nanofluids improves with decreasing particle size, and the stability of the suspension deteriorates with particle size. Another factor that affects the thermal conductivity is the temperature of the fluid, the thermal conductivity of all the nanofluids was improved by temperature, regardless of the synthesis methods, but the trends varied from case to case. The pH value of nanofluids is one of the key parameters affecting thermal conductivity and viscosity as well as particle clustering and stability of nanofluids. The best stability and improvement in thermal conductivity can be obtained at the optimal pH of the suspension.

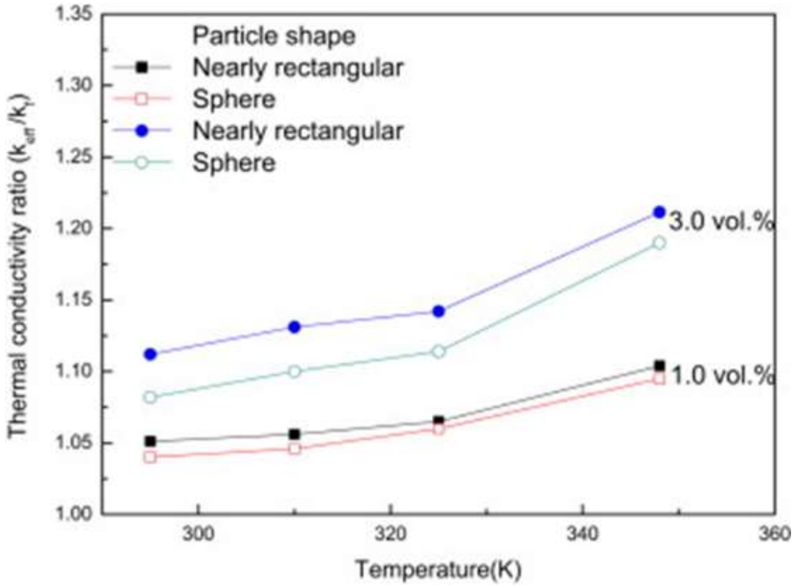

Fig 2: Particle shape effect on the thermal conductivity of ZnO nanofluids

From the graph above we can understand the difference in thermal conductivity of nanofluid related to the particle shape. For nearly rectangular shaped nanoparticles showed higher thermal conductivity compared to spherical shaped particles.

1.5 Thermal diffusivity

Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure. It measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy. High diffusivity means heat transfers rapidly.

The thermal diffusivity of a material is given by the following equation;

$$\alpha = \frac{heat\ conducted}{heat\ stored} = \frac{k}{\rho c_p}$$

where

k is the materials conductivity [$W.m^{-1}.K^{-1}$]

ρ is the density [$kg.m^{-3}$]

c_p is the specific heat capacity [$J.kg^{-1}.K^{-1}$]

From this relation it is clear that as the conductivity of the material increases the thermal diffusivity also increases. SO according to the thermal conductivity of the nanofluid prepared the thermal diffusivity also increases.

1.6 Specific heat

Specific heat is one of the essential properties and has an essential role in influencing the thermal transfer rate of nanofluids. Specific heat is the quantity of heat needed to raise the temperature of one gram of nanofluid by one degree centigrade. The specific heat capacity of the nanofluid depends mainly on the type of nanoparticle and the nanostructure. The preparation methods, the choice of base fluid, the temperature regime and the nanoparticle material all seem to play role, to varying degrees.

The specific heat of nanofluids has seen increasing and decreasing from the specific heat of the base fluids based on the above mentioned parameters. When nanoparticles such as SiO_2, Al_2O_2, TiO_2 are used with molten salt as base fluid the specific heat has been increased to a great extend as well as when

SiO_2, Al_2O_3, CuO are used with water as base fluid it is observed that the specific heat decreased to a great extent, so the specific heat can either increase or decrease according to the composition of the fluid and particles

1.7 Viscosity

Viscosity is an important factor for thermal applications involving liquids. In addition, convection heat transfer is affected by viscosity. As a result, viscosity requires the same attention as thermal conductivity because it has a very significant effect on heat transfer. The viscosity of nanofluids increases mainly by increasing the concentration of nanoparticles and decreases by increasing the temperature. The viscosity improves with increasing mass fraction and decreases with increasing temperature.

The viscosity of nanofluid depends on many parameters such as base fluids, particle volume fraction, particle size, particle shape, temperature, shear rate, pH value, surfactants, dispersion techniques, particle size distribution, and particle aggregation. The viscosity of nanofluid is measured through rheometers or viscometers. Viscosity of nanofluids is different for different sizes of the same nanoparticles. In general, an increase in nanofluids' viscosity has been reported with an increase in particle sizes. However, few studies reported the decrease in viscosity with the increase in particle size. The reason for the decrease in viscosity was ascribed to the increased resistance at the nanoparticle fluid interface due to the increased surface-to-volume ratio in smaller nanoparticles. The shape of the dispersed nanomaterial has shown a strong influence on the viscosity of nanofluids. Nanofluids with elongated particles have increased viscosity compared to nanofluids with spherical nanoparticles.

Temperature is reported as the most influential factor in the viscosity of nanofluids. The attractive force within the particles and with the fluid decreases with the increase in temperature; hence the viscosity decreases.

1.8 Density

The density/bulk mass density of a substance is its mass per unit volume. For a pure substance, the density has the same numerical value as its mass concentration and is relevant to buoyancy, cleanliness and packaging. Usually, the density of any material changes with temperature and pressure which is small for solids and liquids but larger for gases. Increasing the pressure on an object will decrease the volume object and thus increases its density. In most materials, heating the bottom of the fluid results in heat convection from the bottom up due to the decrease in density heated liquid. This causes it to rise relative to the denser unheated material.

Density of the nanofluid depend on both base fluid and nanoparticle parameters, it increases with increase in concentration and decrease with increase in temperature. For water, ethylene glycol based and sodium based nanofluids it is observed that the density increases with increase in nanoparticle concentration.

2. Applications

Nanofluids as a combination of base fluid and a low concentration of nano-sized particles of metal or metal oxides are used in different fields of human activity, including engineering devices in power and chemical engineering, medicine, electronics, and others. The main reason for such huge variety of nanofluid applications is the possibility, from one side, to enhance the heat and mass transfer due to the low concentration of nano-sized particles and, from the other side, to control the transport processes that can be used. Nanofluids are widely employed in different cooling systems for effective heat removal from electronics.

2.1 Automobile industry

Engine oils, automatic transmission fluids, coolants, lubricants, and other synthetic high-temperature heat transfer fluids found in conventional truck thermal systems—radiators, engines, heating, ventilation, and air conditioning have inherently poor properties heat transfer. These could benefit from the high thermal conductivity offered by nanofluids resulting from the addition of nanoparticles.

The use of nanofluids as coolants would allow for smaller size and better positioning of the radiators. Owing to the fact that there would be less fluid due to the higher efficiency, coolant pumps could be shrunk and truck engines could be operated at higher temperatures allowing for more horsepower while still meeting stringent emission standards. Future engines that are designed using nanofluids’ cooling properties would be able to run at more optimal temperatures allowing for increased power output. With a nanofluids engine, components would be smaller and weigh less allowing for better gas mileage, saving consumers money and resulting in fewer emissions for a cleaner environment.

2.2 Solar collectors

Nanofluid-based direct solar collectors are solar thermal collectors where nanoparticles in a liquid medium can scatter and absorb solar radiation. They have recently received interest to efficiently distribute solar energy. Nanofluid-based solar collector have the potential to harness solar radiant energy more efficiently compared to conventional solar collectors. Solar thermal collectors can also be considered legendary based on the type of heat transfer fluid and their construction (water, antifreeze, and air or heat transfer fluid) and whether they are covered or uncovered. Flat solar collectors are used for water heating the efficiency of these systems is around 70%, which is very high compared to direct solar energy conversion systems with an efficiency of around 17%. These collectors are useful for household applications, space heating and industrial low-temperature applications. Currently, a large amount solar collectors based on Concentrated Solar Power systems are available on the market which use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam that is then used as a heat source for a conventional power plant. Extensive series of concentration technologies parabolic trough, concentrating linear Fresnel reflector, concentrating Sterling are developed dish and solar tower collectors. Recently connected solar thermal configuration system with the emerging technologies of nanofluids and various nanoparticle suspensions to develop an innovative approach of solar collectors based on nanofluids.

For energy applications, two remarkable properties of nanofluids are utilized, one is the thermo-physical properties of nanofluids, enhancing the heat transfer and another is the application of nanofluids in solar collectors. The conventional direct absorption solar collector is a well-established technology, and it has been proposed for a variety of applications. However, the efficiency of these collectors is limited by the absorption properties of the working fluid. This technology has been combined with the emerging nanofluids technologies prepared by liquid-nanoparticle suspensions

3.0. Conclusion

Nanofluids are important because they can be used in many applications involving heat transfer and other applications such as detergent. Colloids, which are also nanofluids, have been used in biomedicine for a long time and their use will continue to increase. Nanofluids have also been demonstrated for use as smart fluids. Nanoparticle agglomeration issues, settling and erosion potential all need to be explored in detail in applications. Nanofluids used in experimental research must be well characterized with respect to particle size, size distribution, shape and agglomeration in order to make the results as broad as possible. Once the science and engineering of nanofluids are fully understood and their full potential explored, they can be reproduced on a large scale and used in many applications. Colloids, which are also nanofluids, will see increased use in biomedical engineering and life sciences.

The thermophysical properties of nanofluids, such as thermal conductivity, viscosity, and specific heat, and the factors determining these properties were examined. Indeed, a summary on the recent achievements of the use of nanofluids in solar collectors, namely PTSC (parabolic trough solar collector), FPSC (flat plate solar collector), direct absorption solar collector (DASC), the impact of the method of preparation of nanofluid, the type of additive chosen and other factors influenced on the performance and efficiency of solar collectors. Finally, the major difficulties are still the high production cost, the stability, the agglomeration of the particles, the pumping power and the pressure drop.

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