Nanofluids: An efficient coolant

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Abstract: This paper presents an overview of nanofluids which are suspensions containing nanoparticles. Variousmethods of synthesizing nanofluids are discussed. Theenhanced thermal conductivity of nanofluid synthesized using traditional liquids containing different nanoparticles are discussed. The nanofluids finds various technological and industrial applications.

1. Introduction

Cooling has become one of the top technical challenges faced by hi-tech industries such as microelectronics, transportation, manufacturing and metrology. Technological developments such as microelectronic devices with smaller (sub-100 nm) features and faster (multi-gigahertz) operating speeds, higher-power engines, and brighter optical devices are driving increased thermal loads, requiring advances in cooling. Conventional heat transfer fluids have inherently poor heat transfer properties compared to most solids. As thermal conductivities of solids are orders of magnitude larger than those of traditional heat transfer fluids, dispersing solid particles in liquids is an innovative way to develop better quality heat transfer fluids. To make the suspension stable only the solid phases with densities very close to the base fluids could be used but the intrinsic thermal conductivity of those solids are always very low. If a solid with high thermal conductivity, e.g., metal or some metal oxide is dispersed into a fluid, the stability of the suspension is very poor because of the great difference of density between the solid and the fluid.

In recent years, nanomaterials have drawn considerable interest of both academics and industrialists due to the functionalities unavailable to micron structured materials. It is found that once the materials are prepared in the ultrafine particulate forms, significant changes could occur to their physical, chemical and electrical properties. As the technology to grow nanosized particles has rapidly developed, researchers have focused on a new class of heat transfer fluids "Nanofluids". *Nanofluids* is the term coined by Choi, are suspensions of nanometer-sized solid particles (with size < 100 nm) in traditional liquids. *Nanofluid technology*, a new interdisciplinary field of great importance where nanoscience, nanotechnology, and thermal engineering meet, has developed largely over the past decade. researchers in Argonne National Laboratory, USA noticed the unusual large thermal conductivity of fluid with nanometric alumina (Al_2O_3) particles.

Nanosized particles in fluids provide advantages such as better dispersion behavior, less clogging and abrasion, and larger total surface area, nanofluids have great potential to improve the efficiency of heat transfer behavior of the conventional heat-transfer fluids. The stability of suspension is one of the crucial factors required for improving the thermal conductivity of the fluid and its applications as an efficient coolant. The exact mechanism of thermal conductivity enhancement is under study yet but different factors affecting the thermal conductivity of nanofluids are particle size, particle volume fraction, temperature, effect of surfactants, shape of dispersed particles, thermal property of particles.

2. Synthesis

The performance of nanofluid for applications in thermal management depends mainly on size and distribution of dispersoids and their stability to remain suspended and chemically un-reacted in the fluid. The main challenge in the synthesis of nanofluid is to synthesize monodispersed nanoparticles in base fluid that forms stable dispersion. The mostly studied systems involve metals, oxides, nitrides and carbon related compounds in various fluids depending on requirements of a particular application. Nanofluids have been produced by two techniques: a two-step technique and one-step technique. The two-step process involves synthesis of nanoparticles by either physical or chemical processes, and then dispersing the nanoparticles in required base fluids[1]. The one step process involves simultaneous synthesis and dispersing of nanoparticles in base fluids[2].

Several studies related to nanofluids have been carried out using two-step process. The extensive use of two step process is due to commercial availability of nanopowders. First step is to synthesize nanoparticles in dry powder form using chemical and physical processes. The second step is to disperse the powder in fluid using ultrasonication for certain interval of time or addition of surfactants.Eastman et al[3], Xie et al[4], used this method to synthesize Al_2O_3 nanofluids.Chopkar et al[5] prepared Al-Cu alloy dispersion in Ethylene Glycol (EG) using the two step method. Al-Cu alloy was first prepared using mechanical alloying and were then dispersed in EG. The solid particles were de-agglomerated using ultra sonication and homogenized by addition of oleic acid.Stability of Zinc Oxide- water nanofluid prepared using this process has also been investigated by Leonard et al[6]. ZnO powders used in the study were commercially available products. The powders were dispersed water using ultrasonication and ball milling.Kulkarni et al[7] employed the two step process in synthesizing CuO-water dispersions. The dispersoids used in this case were obtained commercially.TiO2- water nanofluid[8], multi-walled carbon nanotubes dispersion[9] in different fluids have also been synthesized using this process.

The two-step process works well for oxide particles, while it is less successful in case of metallic particles. Making nanofluids using this two-step process is very challenging because the individual particles in dry form are already agglomerated before complete dispersion. This agglomeration due to weak van der Waals' force causes the particles to settle down in the liquid. Well dispersed suspensions are produced by separating the nanoparticles agglomerates into individual particles in the host fluid. The complete separation of the agglomerates is not possible even by ultrasonication. Thus the key step towards success in synthesizing stable nanofluids could not be achieved. Also, to form stable dispersion using two step process many other factors are also to be considered – the use of appropriate surfactants, control of pH of solution, the volume fraction of the dispersoids. Thus the nanofluids synthesized using this process have relatively lower thermal conductivity due to the poor dispersion quality.

To overcome the problem of agglomeration and poor stability of nanofluids single-step nanofluid processing methods have also been developed. Akoh et al.[10] developed a new technique of condensing nanophase powders from its vapour directly into flowing liquid of low vapour pressure. The process is called Vacuum Evaporation onto a Running Oil Substrate technique and is a useful technique for producing non agglomerated nanoparticles but the process is only compatible with low vapour pressure liquids.

There are also other techniques for producing nanofluids using single step process. Zhu et al.[11] developed a one-step chemical method for producing stable Cu-ethylene glycol nanofluids by reducing ($CuSO_4 \cdot 5H_2O$) with ($NaH_2PO_2 \cdot H_2O$) in ethylene glycol under microwave irradiation.

Wang et al[12] presented a novel chemical precipitation technique for producing CuO dispersion in water. NaOH was added to $CuSO_4$ solution to precipitate $Cu(OH)_2$ which was further added to water containing ammonium citrate as dispersant. CuO water nanofluid was obtained by ultrasonicating the solution and irradiating using microwave.

Park et al[13] used the single step technique to produce graphene nanosheets-in-water nanofluids by reducing Graphite oxide in water using $NaBH_4$/ $N_2H_4.H_2O$ and then dispersing using ultrasonication.

3. Experimental studies on thermal conductivity

Eastman et al[2] studied the thermal conductivity of Cu-EG nanofluids synthesized, by one-step method, using THW method. The average size of the synthesized Cu nanoparticles was 10 nm. The thermal conductivity enhancement was upto 40% for particle loadings below one volume per cent. Nanofluids containing small amount of thioglyolic acid as stabilizer showed a better result compared to those without stabilizer. The nanofluids prepared afresh showed a comparably higher thermal conductivity than the old nanofluids (prepared two months before).

The Cu-EG nanofluids thus prepared by one-step method showed higher thermal conductivity compared to reported values of oxide nanofluids which holds significant potential for revolutionizing industries.

Assael et al[16] investigated the thermal behavior of multiwalled carbon nanotube(MWNT)-water nanofluids. The nanofluid was synthesized using two-step process, the dispersoids used were commercially available. The average diameter and length of MWNTs were 80 nm (outer), 25 nm (inner) and 50 µm. The stable dispersion of MWNT in water was obtained by adding SDS as dispersant followed by ultrasonication. The variation of thermal conductivity with different amount of dispersant and different time of ultrasonication was studied. The thermal-conductivity enhancement of 0.6 vol% suspension of C-MWNT in water with SDS as the dispersant was 38%.

Baby et al[17] applied two-step process to synthesize graphene-in-water nanofluid. Graphene was prepared by treating Graphite oxide in Argon atmosphere at $1050^{O}C$ and was dispersed in water and EG by acid treatment and ultrasonication. The variation of thermal conductivity with nanoparticles loading volume percent and temperature has been investigated. 14% enhancement in thermal conductivity was observed for a volume fraction of 0.056% for water based nanofluid at 25 °C and 64% enhancement for the same volume fraction at 50 °C.The results suggest that graphene based nanofluids can find potential applications as coolants and is also effective.

4. Conclusions

Owing to the enhanced thermal conductivity of nanofluids, they find application in automotive industries, computers, medical arena as well as power plant cooling systems. Nanofluids can be used to improve heat transfer and energy efficiency in many thermal control systems. Nanofluids used as coolant would allow smaller size and better positioning of radiators. The enhanced thermal conductivity optimizes heat transmission and lubrication. Nanofluids have the potential to provide the required cooling in such applications as well as in other military systems, including military vehicles, submarines, and high-power laser diodes. Nanofluids mixed with diesel fuel increase the total combustion heat and decrease the concentration of smoke. Nanofluids have many advantages: for example, higher cooling rates, smaller and lighter cooling systems, reduced inventory of heat transfer fluids, decreased pumping-power needs, reduced friction coefficient, and improved wear resistance. The increased thermal transport of transformer oils with addition nanoparticles translates into either a reduction in the size of new transformers at the same level of power transmitted or an increase in the performance of existing transformers.

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