NANOFLUIDS: A PROMISING FUTURE

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ABSTRACT

Processing and producing materials with average size in the range of 100 nm is being made possible by the modern nanotechnology. Nanometer-sized particles suspended in fluids forming colloidal solutions are called nanofluids. Nanofluids have novel properties that are making them next generation heat transfer fluids because they are opening new possibilities to enhance heat transfer performance compared to pure fluids Nanofluids are typically made of metals, oxides, carbides or carbon nanotubes in a base fluid like water, oil and ethylene glycol. Straight heat transfer enhancement is an important factor in many industries, nuclear reactors, engine cooling systems of automotives, refrigeration, space technology, defense, microelectronics, fuel cells etc. Nanofluids are acting as smart fluids in situations where heat transfer has to be reduced or enhanced as desired i.e., acting like a heat valve. Nanofluids, emphasizing their improved heat transfer properties that are controllable and the specific characteristics that these nanofluids possess make them suitable for such applications.

KEY WORDS: Nanofluids; Nanodrug delivery; Nuclear reactors, Cancer therapeutics.

INTRODUCTION

Dilute liquid suspensions of nanoparticles with at least one of their principal dimensions smaller than 100 nm are known as Nanofluids. These are prepared by dispersing and stably suspending nanometer sized solid particles in conventional heat transfer fluids. Past researches have shown that a very small amount of suspending nano particles have the potential to enhance the thermo physical, transport and radiative properties of the base fluid. Due to improved properties, better heat transfer performance is obtained in many energy and heat transfer devices as compared to traditional fluids which open the door for a new field of scientific research and innovative applications.

Nanomaterials can be classified as: Carbon based nanomaterials (eg: Carbon nanotubes), Metal based nanomaterials (metal oxides such as aluminium oxides), Dendrimers (nanosized polymers) and composites (nanosized clays). When these nanoparticles are suspended in conventional fluids (water, oil, ethylene glycol) called “nanofluids”. Nanofluids clearly exhibit improved thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficient. The property change of nanofluids depends on the volumetric fraction of nanoparticles, shape and size of the nanomaterials.

There is a growth in the use of nanofluids in biomedical industry for sensing and imaging purposes. This is directly related to the ability to design novel materials at the nanoscale level alongside recent innovations in analytical and imaging technologies for measuring and manipulating nanomaterials. This has led to the fast development of commercial applications which use a wide variety of manufactured nanoparticles. The production, use and disposal of manufactured nanoparticles will lead to discharges to air, soils and water systems. Negative effects are likely and quantification and minimization of these effects on environmental health is necessary. True knowledge of concentration and physicochemical properties of manufactured nanoparticles under realistic conditions is important to predicting their fate, behavior and toxicity in the natural aquatic environment.

HEAT TRANSFER APPLICATIONS OF NANOFLUIDS

Nanofluids can be used in broad range of engineering applications due to their improved heat transfer and energy efficiency in a variety of thermal systems. The following section gives a brief idea of different areas of nanofluid applications based on available literatures.

Industrial Cooling Applications: Routbort et al., (2009) employed nanofluids for industrial cooling and showed great energy savings and resulting emission reductions. They showed that replacement of cooling and heating water with nanofluids has the potential to conserve about 300 million kWh of energy for industries. For the electric power industry using nanofluids could save about 3000-9000 million kWh of energy per year which is equivalent to the annual energy consumption of about 50,000-150,000 households.

The associated emission reductions would be approximately 5600 million kg of carbon dioxide, 8.6 million kg of nitrogen oxides and 21 million kg of sulfur dioxide.

In the Defense Advanced Projects cooling enhancement by ~ 8-30% was reported using nanofluids in compact heat exchangers. The nanofluids were found to precipitate nano fins on the heater surface and there augment the heat flux. The nanoparticles used in this study were ex-foliated graphite and multi-walled carbon nanotubes (MWCNT). It was observed that the nanofluids specific heat capacity was enhanced by 50%. Hence, it was concluded that nanofluids have better efficacy in thermal energy storage applications compared to cooling applications.

Han et al., (2008) have used phase change materials as nanoparticles in nanofluids to simultaneously enhance the effective thermal conductivity and specific heat of the fluids. As an example, a suspension of indium nanoparticles (melting temperature, 157◦C) in poly alpha olefin has been synthesized using a one-step, nano emulsification method. The fluid's thermo physical properties, that is, thermal conductivity, viscosity, and specific heat, and their temperature dependence were measured experimentally. The observed melting-freezing phase transition of the indium nanoparticles significantly augmented the fluid's effective specific heat. This work is one of the few to address thermal diffusivity; similar studies allow industrial cooling applications to continue without thorough understanding of all the heat transfer mechanisms in nanofluids.

Smart Fluids: In a recent paper published in the March 2009 issue of Physical Review Letters, Donzelli et al. (2009) showed that a particular class of nanofluids can be used as a smart material working as a heat valve to control the flow of heat. The nanofluid can be readily configured either in a "low" state, where it conducts heat poorly, or in a "high" state, where the dissipation is more efficient. To leap the chasm to heating and cooling technologies, the researchers will have to show more evidence of a stable operating system that responds to a larger range of heat flux inputs.

Nuclear Reactors: Possible applications include pressurized water reactor (PWR) primary coolant, standby safety systems, accelerator targets, plasma divertors, and so forth. In a pressurized water reactor (PWR) nuclear power plant system, the limiting process in the generation of steam is critical heat flux (CHF) between the fuels rods and the water—when vapor bubbles that end up covering the surface of the fuel rods conduct very little heat as opposed to liquid water. Using nanofluids instead of water, the fuel rods become coated with nanoparticles such as alumina, which actually push newly formed bubbles away, preventing the formation of a layer of vapor around the rod and subsequently increasing the CHF significantly. After testing in MIT's Nuclear Research Reactor, preliminary experiments have shown promising success where it is seen that PWR is significantly more productive. The use of nanofluids as a coolant could also be used in emergency cooling systems, where they could cool down overheat surfaces more quickly leading to an improvement in power plant safety. Some issues regarding the use of nanofluids in a power plant system include the unpredictability of the amount of nanoparticles that are carried away by the boiling vapor. One other concern is what extra safety measures that have to be taken in the disposal of the nanofluid.

Extraction of Geothermal Power and other Energy Sources: The world's total geothermal energy resources were calculated to be over 13000 ZJ in a report from MIT (2007). Currently only 200 ZJ would be extractable, however, with technological improvements, over 2,000 ZJ could be extracted and supply the world's energy needs for several millennia. When extracting energy from the earth's crust that varies in length between 5 to 10 km and temperature between $500^{o}C$ and $1000^{o}C$, nanofluids can be employed to cool the pipes exposed to such high temperatures. When drilling, nanofluids can serve in cooling the machinery and equipment working in high friction and high temperature environment. As a "fluid superconductor," nanofluids could be used as a working fluid to extract energy from the earth core and processed in a PWR power plant system producing large amounts of work energy.

In the sub-area of drilling technology, so fundamental to geothermal power, improved sensors and electronics cooled by nanofluids capable of operating at higher temperature in downhole tools, and revolutionary improvements utilizing new methods of rock penetration cooled and lubricated by nanofluids will lower production costs. Such improvements will enable access to deeper, hotter regions in high grade formations or to economically acceptable temperatures in lower-grade formations.

Tran et al., (2007), funded by the United States Department of Energy (USDOE), performed research targeted at developing a new class of highly specialized drilling fluids that may have superior performance in high temperature drilling. This research is applicable to high pressure high temperature drilling, which may be pivotal in opening up large quantities of previously unrecoverable domestic fuel resources. Commercialization would be the bottleneck of progress in this sub-area of Energy (USDOE), performed research targeted at developing a new class of highly specialized drilling fluids that may have superior performance in high temperature drilling. This research is applicable to high pressure high temperature drilling, which may be pivotal in opening up large quantities of previously unrecoverable domestic fuel resources. Commercialization would be the bottleneck of progress in this sub-area.

APPLICATION OF NANOFLUIDS IN SOLAR DEVICES

Direct absorption solar collectors have been proposed for a variety of applications such as water heating; however the efficiency of these collectors is limited by the absorption properties of the working fluid. Efficiency improvements of up to 5% in solar thermal collectors by utilizing nanofluids as the absorption mechanism have been observed. The experimental and numerical results demonstrate an initial rapid increase in efficiency with volume fraction, followed by a leveling off in efficiency as volume fraction continues to increase. For domestic hot water system, the nanofluid based solar collector has a slightly longer payback period but at the end of its useful life has the same economic savings as a conventional solar collector. The nanofluid based solar collector has a lower embodied energy ~9% and approximately 3% higher levels of pollution offsets than a conventional collector.

APPLICATIONS IN AUTOMOTIVE

In automobile arena, nanofluids have potential application as engine coolant, automatic transmission fluid, brake fluid, gear lubrication, transmission fluid, engine oil and greases. The first application in cooling automatic power transmission system done by Senthilraja et al., (2010) shows that CuO nanofluids have the lowest temperature distribution and accordingly the best heat transfer performance.

Nanofluid as coolant: The use of nanofluids as coolants would allow for smaller size and better positioning of the radiators. There would be less fluid due to the higher efficiency, coolant pump could be shrunk and truck engines could be operated at higher temperatures allowing for more horsepower. In a study done by Saidur et al., (2011) have shown that the use of nanofluids in radiators can lead to a reduction in the frontal area of the radiator by up to 10%. This reduction in aerodynamic drag can lead to a fuel saving of up to 5%.

Nanofluid in Fuel: It was shown that the combustion of diesel fuel mixed with aqueous aluminum nanofluid increased the total combustion heat while decreasing the concentration of smoke and nitrous oxide in the exhaust emission from the diesel engine. It is due to the high oxidation activity of pure Al which allows for increased decomposition of hydrogen from water during the combustion process.

Nanofluid in Brake Fluids: During the process of braking, the produced heat causes the brake fluid to reach its boiling point, a vapour lock is created that retards the hydraulic system from dispersing the heat caused from braking. It will create a brake malfunction and poses a safety hazard in vehicles. Nanofluids with enhanced characteristics maximize performance in heat transfer as well as remove any safety concerns.

ELECTRONIC APPLICATIONS

Nanofluids are used for cooling of microchips in computers and elsewhere. They are also used in other electronic applications which use micro fluidic applications.

Cooling of Microchips: A principal limitation on developing smaller microchips is the rapid heat dissipation. However, nanofluids can be used for liquid cooling of computer processors due to their high thermal conductivity. It is predicted that the next generation of computer chips will produce localized heat flux over 10MW/m2, with the total power exceeding 300W. In combination with thin film evaporation, the nanofluid oscillating heat pipe (OHP) cooling system will be able to remove heat fluxes over 10MW/m2 and serve as the next generation cooling device that will be able to handle the heat dissipation coming from new technology.

Microscale Fluidic Applications: The manipulation of small volumes of liquid is necessary in fluidic digital display devices, optical devices, and micro electromechanical systems (MEMS) such as lab-on-chip analysis systems. This can be done by electro wetting, or reducing the contact angle by an applied voltage, the small volumes of liquid. Electro wetting on dielectric (EWOD) actuation is one very useful method of micro scale liquid manipulation. Vafaei et al., (2006) discovered that nanofluids are effective in engineering the wettability of the surface and possibly of surface tension. Using a goniometer, it was observed that even the addition of a very low concentration of bismuth telluride nanofluid dramatically changed the wetting characteristics of the surface.

BIOMEDICAL APPLICATIONS

Nanodrug Delivery: An objective of the advanced endeavors in developing integrated micro- or nano-drug delivery systems is the interest in easily monitoring and controlling target-cell responses to pharmaceutical stimuli, to understand biological cell activities, or to enable drug development processes.

While conventional drug delivery is characterized by the "high-and-low" phenomenon, micro devices facilitate precise drug delivery by both implanted and transdermal techniques. This means that when a drug is dispensed conventionally, drug concentration in the blood will increase, peak and then drop as the drug is metabolized, and the cycle is repeated for each drug dose. Employing nanodrug delivery (ND) systems, controlled drug release takes place over an extended period of time. Thus, the desired drug concentration will be sustained within the therapeutic window as required.

Cancer Therapeutics: There is a new initiative which takes advantage of several properties of certain nanofluids to use in cancer imaging and drug delivery. This initiative involves the use of iron-based nanoparticles as delivery vehicles for drugs or radiation in cancer patients. Magnetic nanofluids are to be used to guide the particles up the bloodstream to a tumor with magnets. It will allow doctors to deliver high local doses of drugs or radiation without damaging nearby healthy tissue, which is a significant side effect of traditional cancer treatment methods. In addition, magnetic nanoparticles are more adhesive to tumor cells than non-malignant cells and they absorb much more power than micro particles in alternating current magnetic fields tolerable in humans; they make excellent candidates for cancer therapy. Magnetic nanoparticles are used because as compared to other metal-type nanoparticles, these provide a characteristic for handling and manipulation of the nanofluid by magnetic force.

CONCLUSION

The use of nanofluids seems attractive in a broad range of applications as reported in the previous section. But the development in the area of nanofluid application is hindered by many factors in which long term stability of nanofluid in suspension is major reason An ideal heat transfer fluid should possess higher value of specific heat so the fluid can exchange more heat. Previous studies show that nanofluids exhibit lower specific heat than base fluid. It limits the use of nanofluid application. Nanofluids are prepared by either one step or two step methods. Both methods require advanced and sophisticated equipments. This leads to higher production cost of nanofluids.

Nanofluids employed in experimental research have to be well characterized with respect to particle size, size distribution, shape and clustering so as to render the results most widely applicable. Once the science and engineering of nanofluids are fully understood and their full potential researched, they can be reproduced on a large scale and used in many applications. Colloids which are also nanofluids will see an increase in use in biomedical engineering and the biosciences. Further research still has to be done on the synthesis and applications of nanofluids so that they may be applied as predicted. Nevertheless, there have been many discoveries and improvements identified about the characteristics of nanofluids in the surveyed applications and we are a step closer to developing systems that are more efficient and smaller, thus rendering the environment cleaner and healthier.

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