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Review

A Review on Nano Applications: Fluids and Heat Transfer

Yong-Han Yoon
· Yeungnam University.
· han12blue@ynu.ac.kr

JaeSool Shim
· Yeungnam University.
· jshim@ynu.ac.kr

1. Introduction

The term “nano” originates from the Greek word “nanos” meaning “dwarf”. There are two methods to manufacture nanostructures – a top-down method and a bottom-up method. The top-down method is a process that sculpts a mass to make it small, and the bottom-up method is a process that builds up a structure by stacking on the atomic scale. The earliest systematic discussion of nanotechnology is considered to be a speech given by Richard Feynman (Fig. 1, American physicist, 1918-1988) who received the Novel Prize in physics in 1965. In a speech given for in American Physical Society in 1959, he stated "There's plenty of room at the bottom." In this speech, Feynman emphasized the importance of “manipulating and controlling things on a small scale” and “how they could tell us much of great interest about the strange phenomena that occur in complex situations.” He discussed how physical phenomena change their manifestation depending on scale, and posed two challenges: the creation of a nanaomotor, and the scaling down of letters to a size that would allow the whole Encyclopedia Britannica to fit on the head of a pin. A prediction of Dr. Feynman was realized by observing and manipulating atomic structure after the development of the scanning tunneling microscope at an IBM laboratory in Switzerland in 1981. Since then, the concepts of nanotechnology have been widely known after publication of “Engines of Creation” by Eric Drexler in 1986. Significant progress was made by IBM in 1990 when a team of physicists spelled out the letters "IBM" using 35 individual atoms of xenon on a nickel metal panel. Research in nanotechnology has increased with improvement of the performance of devices such as the scanning tunneling microscope, which is required to measure and control a nanostructure. Nanotechnology has been applied to biotechnology since the 1990s. It also used in fields including physics, chemistry, materials, electronic engineering, and biotechnology.[1,2]

There are various fields within nanotechnology, including nanofluids. The nanofluid field was started by Dr. Choi`s team[3] at Argonne National Laboratory in America. He suggested the idea that a normal fluid can have new properties.

Fig. 1 Richard Feynman.

by adding nanoparticles made through nanotechnology. He reported theoretical results in 1995. Dr. Choi's team presented the world`s first nanofluid and measured the conductivity of the nanofluid. Dr. Choi defined a nanofluid as a fluid in which nanoparticles are dispersed or suspended in a normal fluid. The experimental results of Dr. Choi`s team have been confirmed by other researchers. After that, many studies have been carried out recently on the next generation of cooling fluids.[4]

2. Heat and Fluids in Nanotechnology

There are many fields of nanotechnology. In this study, we focused on the nanofluids and heat transfer field, and reviewed heat transfer and electronic, automotive, biomedical, and energy applications.

2.1 Heat Transfer Applications

Nanofluids have received attention as potential heat transfer fluids with enhanced thermal properties and heat transfer performance. Because of these characteristics, there are strong possibilities for improving the efficiency of existing heat transfer processes. These processes can be applied industrial cooling, smart fluids, the heating of buildings, the extraction of geothermal power and other energy sources, heat exchangers, nuclear reactors, and space and defense. We reviewed industrial cooling, heat exchangers, and carbon nanotube (CNT) nanofluids.

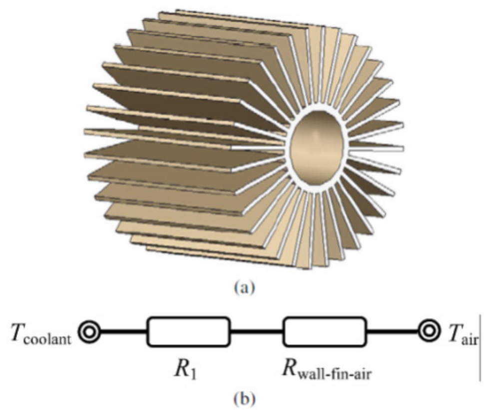


Fig. 2 Heat transfer using flowing liquid running inside a tube radiator. (a) Cylindrical tube radiator with fin structure. (b) Thermal resistance between coolant and ambient air.

2.1.1 Industrial Cooling

The main application of nanofluids is with heat transfer fluids in closed-loop liquid cooling systems. These systems are utilized in many applications including chemical/rubber processing, the semiconductor industry, petroleum refineries, electrical systems, computing, power generation, power electronics, production machinery, and combustion engines.[5]

Ma et al.[6] suggested for the first time the concept of a nano liquid-metal fluid, aiming to establish an engineering route to make a highest conductive coolant. Using several widely accepted theoretical models for characterizing a nanofluid, the thermal conductivity enhancement of a liquid metal fluid due to addition of more conductive nano-particles was predicted by Ma et al. Figure 2 shows a tube radiator and its thermal resistance.

Duangthongsuket et al.[7] examined experimentally the heat transfer coefficient and friction factor of TiO2-water nanofluids flowing in a horizontal double tube counter-flow heat exchanger under turbulent flow conditions. Their results show that the heat transfer coefficient of a nanofluid is higher than that of the base liquid, and increased with increasing Reynolds number and particle concentration.

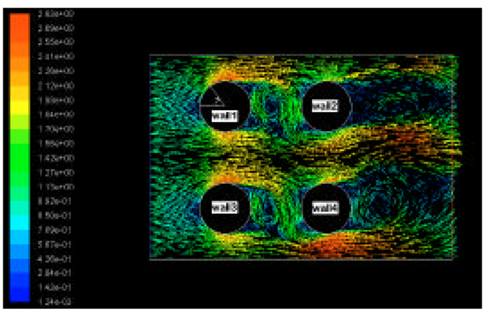


Fig. 3 Velocity contours of nanofluid in a heat exchanger with a rectangular arrangement.

Sajadiet et al.[8] studied experimentally the turbulent heat transfer and pressure drop behavior of Al2O3/water nanofluid in a circular pipe. Their results indicate that the heat transfer coefficient will increase with an increase in particle concentration–this increase was about 12% for a 2% particle concentration.

2.1.2 Heat Exchangers

Heat exchangers are widely utilized in engineering applications including the chemical industry, power production, food industry, environmental engineering, waste heat recovery, air conditioning, and refrigeration.[9]

Chun et al.[10] studied the convective heat transfer coefficient of nanofluids made of several types of alumina nanoparticles and transformer oil flowing through a double pipe heat exchanger system in the laminar flow regime. The nanofluids exhibited a considerable increase in their heat transfer coefficient. Although the thermal conductivity of alumina is not high, it is much higher than that of the base fluids.

Khoddamrezaee et al.[11] investigated the characteristics of (EG+Al2O3) nanofluid and (EG) fluid crossing a rectangular arrangement of tubes in a shell-and-tube heat exchanger. Figure 3 shows velocity contours of a nanofluid. Results show that by using a nanofluid, the stagnation and separation points of the flow were postponed, and the heat transfer coefficient and shear stress increased.

Tiwariet et al.[12] studied experimentally the heat transfer performances of various nanofluids. The heat transfer performance of a plate heat exchanger was investigated using different nanofluids (CeO2, Al2O3, TiO2, and SiO2) for various volume flow rates and a wide range of concentrations. Performance is discussed in terms of the overall heat transfer coefficient ratio, heat transfer coefficient ratio, pressure drop ratio, pumping power ratio, effectiveness ratio, and performance index ratio.

2.1.3 CNT Nanofluids

The field of nanofluids was highly developed along with development of nanotechnology. Also, carbon nanotubes came to the fore because of their outstanding thermal properties. Many studies are underway in the field of CNT nanofluids.

Hwang et al.[13] produced four kinds of nanofluids: multiwalled carbon nanotubes

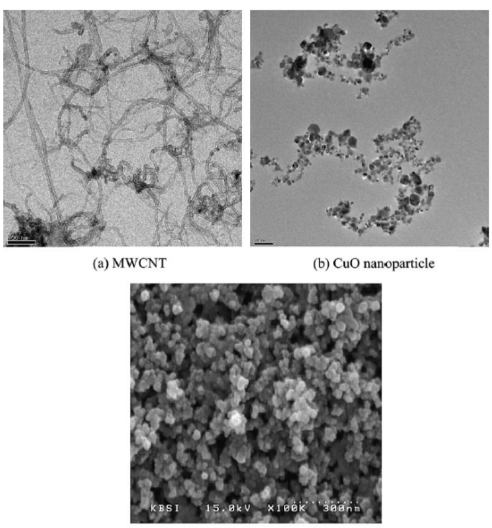
(MWCNTs) in water, CuO in water, SiO2 in water, and CuO in ethylene glycol. Their thermal conductivities were measured using the transient hot wire method. The results show that the thermal conductivity enhancement of nanofluids depends on the thermal conductivities of the particles and the base fluid. Figure 4 shows photographs of test particles.

Han et al.[14] used phase change materials as nanoparticles in nanofluids to simultaneously enhance the effective thermal conductivity and specific heat of the fluids.

Lee et al.[15] arranged experimental data on the thermal conductivity and viscosity of a water-based CNT nanofluid, and a methodology for the evaluation of the heating performance of a nanofluid in the laminar region. Also, the heating performance of the CNT nanofluid was evaluated by using experimental data and evaluation standard.

2.2 Electronic Applications

Recently developed electronic devices can produce enormous amounts of heat, which disturbs the normal performance of the devices, and reduces reliability and expected life. Therefore, an efficient cooling system is one of the most important considerations in designing electronic components. There are various approaches to removing high heat flux effectively, including air cooling, liquid cooling, and two-phase cooling. Nanofluids have been utilized as a coolant for electronic devices such as cameras, computer displays, microchips, microdevices, chillers, and domestic refrigerators. We focused on applications for the cooling of microchips.[16]



(a) MWCNT (b) CuO nanoparticle

(c) SiO_2 nanoparticle

Fig. 4 Photographs of test particles.

2.2.1 Cooling of microchips

Nanofluids are used for the cooling of microchips in computers. The enhanced characteristics of nanofluids can increase the efficiency of microchips and facilitate their development.

Ma et al.[17] developed an ultrahigh-performance cooling device called the "nanofluid oscillating heat pipe" by combining nanofluids with thermally excited oscillating motion in an oscillating heat pipe (OHP). Experimental results show that when the OHP is charged with nanofluid, the heat transport capability significantly increases. Figure 5 shows a nanofluid OHP.

Naphonet et al.[18] described the enhancement of heat pipe thermal efficiency using nanofluids. Nanoparticles were shown to have a significant effect on the enhancement of the thermal efficiency of heat pipes. The thermal efficiency of a heat pipe with nanofluids was compared with that of the base fluid.

Shafahiet et al.[19] investigated the thermal performance of rectangular and disk-shaped heat pipes using nanofluids by utilizing analytical models. The liquid pressure, liquid velocity profile, temperature distribution of the heat pipe wall, temperature gradient along the heat pipe, thermal resistance, and maximum heat load were obtained for flat-shaped heat pipes utilizing a nanofluid as the working fluid. The flat-shaped heat pipe's thermal performance using nanofluid was substantially enhanced compared to the use of a regular fluid.

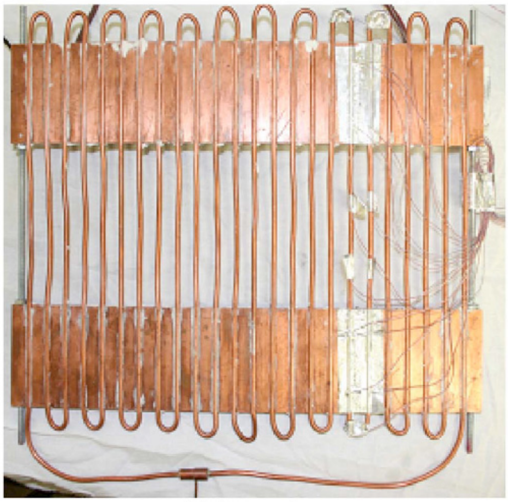


Fig. 5 Nanofluid oscillating heat pipe.

2.3 Automotive Applications

Automobile systems, including radiators, engines, heating systems, ventilation systems, and air conditioning (HVAC), have inherently poor heat transfer performance. These systems could benefit from the high thermal conductivity of nanofluids as a result of the addition of nanoparticles. Nanofluids can be applied in automobile applications–engine oils, automatic transmission fluids, coolants, lubricants, and other synthetic high temperature heat transfer fluids. We investigated one of these applications–nanofluid coolant.[20]

2.3.1 Nanofluid coolant

Nano-coolants are used to extract heat generated from cylinder heads, radiators, and automatic transmissions in automobiles. Generally, water and other synthetic liquids are used for this purpose. Nano-coolants, compared to water, have enhanced heat transfer properties. Also, less quantity and a lower flow rate are required, resulting in lower pumping power, lower initial cost of the equipment, and smaller size of the equipment.[21]

Leong[22] et al. studied the application of ethylene glycol-based copper nanofluids in an automotive cooling system. Relevant input data, nanofluid properties, and empirical correlations were obtained from the literature, and the heat transfer enhancement of an automotive car radiator operated with nanofluid-based coolants was investigated.

Bozorganet et al.[23] investigated the potential mass flowrate reduction in an exchanger with a given heat exchange capacity using nanofluids. The results show that the flowrate of nanofluid coolant decreased with an increase in the concentration of nanoparticles in the exchanger for a given heat exchange capacity.

Eftekharet et al.[24] used a nanofluid as an engine coolant with an optimized heat exchanger to reduce warmup time. Their results indicate that using a different percentage of nanofluid mixtures, such as Al2O3-Water/EG as the engine coolant enhances the heat transfer coefficient and reduces the warm-up timing. This, in turn, results in reduced emissions and fuel consumption. Figure 6 shows the finned-tube heat exchanger used in this study.

2.4 Biomedical Applications

In the biomedical industry, nanofluids and nanoparticles have wide applications including nanodrug delivery, cancer therapeutics, cryopreservation, nanocryosurgery, and sensing and imaging. We investigated nanodrug delivery.

2.4.1 Nanodrug Delivery

A drug delivery system using nanoparticles can be used to destroy cancerous cells by containing a carcinostatis substance in particles at the nanometer scale. Blood vessels, which supply nutrition, grow in a short time because cancerous cells grow faster than normal cells. Blood vessels located at cancerous cells are looser than those located at normal blood vessel. Therefore, the cancer will be able to be cured by the particles about 30㎚ which contain a carcinostatis substance.[25)]

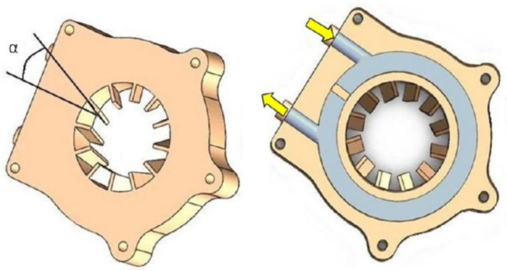


Fig. 6 Schematic of finned tube heat exchangers in two orientations.

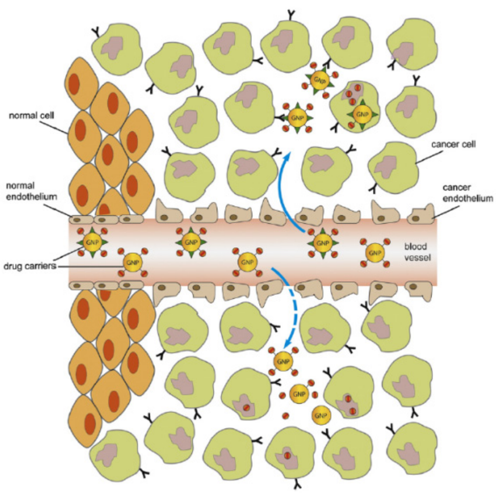


Fig. 7 Illustration of drug delivery via "active" and "passive" targeting (solid and dotted lines, respectively).

Ghoshet et al.[26)] reported that gold nanoparticles (AuNPs) provide non-toxic carriers for drug and gene delivery applications. With these systems, the gold core imparts stability to the assembly, while the monolayer allows tuning of surface properties such as charge and hydrophobicity. Figure 7 shows a schematic of a drug delivery system.

Yang et al.[27)] developed a dual targeting drug delivery and pH-sensitive controlled release system based on multifunctionalized graphene oxide (GO) in order to enhance the effect of targeted drug delivery and realize an intelligently controlled release. Their results show that this multi-functionalized GO has potential applications for targeted delivery and the controlled release of anticancer drugs.

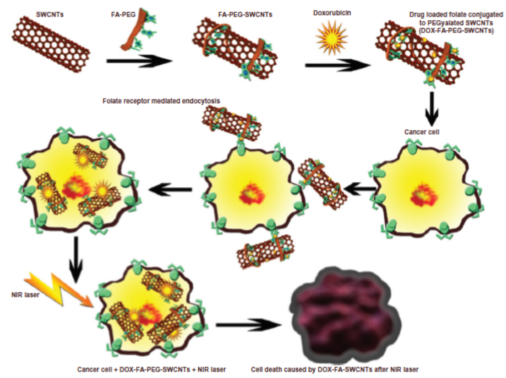


Fig. 8 Representation of a nanodrug delivery system.

Jeyamohanet et al.[28)] demonstrated the photothermal effect of single-walled carbon nanotubes (SWCNTs) in combination with the anticancer drug doxorubicin (DOX) for the targeting and accelerated destruction of breast cancer cells. A targeted drug delivery system was developed to selectively kill breast cancer cells. Figure 8 shows a diagram of the nanodrug delivery system used in their study. Results of *in vitro* experiments show that the laser was effective in destroying the cancer cells while sparing the normal cells.

2.5 Energy Applications

Nanofluids have two outstanding properties related to energy applications of nanofluids. One is the higher thermal conductivities of nanofluids that enhance their heat transfer, and the other is the absorption properties of nanofluids. Applications in the energy field include energy storage, solar absorption, fuel cells, and thermal absorption systems. We reviewed energy storage applications.[29)]

2.5.1 Energy Storage

Energy storage systems utilize the temporal difference between an energy source and energy needs. There is an increasing demand for the efficient use and conservation of the waste heat and solar energy in industry and buildings. Therefore, the storage of thermal energy in the form of sensible and latent heat has become an important aspect of energy management.[30)]

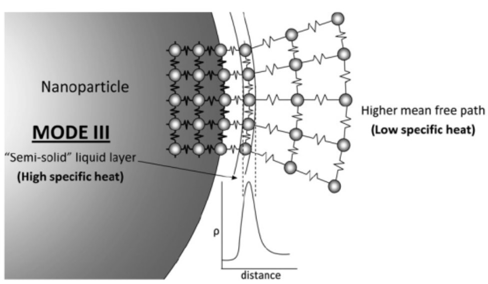


Fig. 9 Schematic showing mode III energy storage.

Khodadadiet et al.[31)] showed that nanoparticle-enhanced phase change materials (NEPCMs) exhibit enhanced thermal conductivity in comparison to the base material. Given a proper suspension of nanoparticles within conventional phase change materials such as water, it has been shown that NEPCMs have great potential for thermal energy storage applications.

Shin et al.[32)] presented the anomalous enhancement of the specific heat capacity of high temperature nanofluids. Dispersion behavior of the nanoparticles was confirmed by scanning electron microscopy (SEM). Three independent competing transport mechanisms are used to explain this anomalous behavior. Figure 9 shows a schematic of mode III of energy storage. Mode III means one of three independent competing transport mechanisms.

Cingarapuet et al.[33)] reported that novel high temperature heat transfer fluids (HTFs) with incorporated phase change nanomaterials were synthesized and tested for heat transfer and thermal energy storage. The advanced thermal properties were achieved by preparing a nanofluid.3

3. Conclusion

There are many applications of nanofluids such as cooling in electronics, cameras, microdevices, displays, heat exchangers, spacecraft, Military equipments, ships, medicine, nuclear reactors, sensors, and fuel cells. It has been found that the improved thermal conductivities of nanofluids are the one of the driving factors for improved performance in various applications; therefore, nanofluids can be considered to be potential candidates for many applications. However, there are still many challenges that need to be identified and overcome. These challenges include the long term stability of nanoparticle dispersions, increased pressure drop, pumping power requirements, nanofluid thermal performance in turbulent flow and in fully developed flow regions, higher viscosity, lower specific heat, thermal conductivity, high cost, and difficulties in production processes. Especially, nanofluid stability and production costs are obstacles for the commercialization of nanofluids. By solving these challenges, it is expected that there will be considerable developments in many applications. Finally, further research should be done on various applications related to heat and fluids.[34)]

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