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Review Article

AN OVERVIEW OF RECENT NANOFLUID RESEARCH

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ABSTRACT
Nanofluids consist of nanoparticles suspended in a liquid medium and the particle size is smaller than 100 nm. Nanofluids have great thermo-physical properties such as thermal conductivity, thermal diffusivity, viscosity and heat transfer coefficient as compared to their base fluids. The key feature of nanofluid is its superior thermal conductivity. They have exciting applications in various fields of science and technology. The production of efficient nanofluids with controllable micro structures has been possible because of the chemical solution method. This enables us to design micro structures that could helps to control chemical reactions which take place at a rapid pace and involve a high degree of precision. The industrial production of nanofluids would only be made possible with the help of future research. Nanofluids offer us greener solutions for our current technological problems. The nanofluid technology can only grow if the production costs are optimized and better stability is achieved for nanofluids. The pharmaceutical sector would gain a lot from the future research in the field of nanofluid technology because it would make the targeted delivery of drug possible.
Keywords: Nanoparticles, Thermal conductivity, base fluids.

INTRODUCTION

Nanofluid is the next exciting frontier in technology. The excitement can be attributed to the sheer brilliance of the idea and the applications of the technology[1]. The properties of nanofluids need a lot of fine tuning, many seemingly contradicting studies need clarity and validation. Nanofluids have potential applications in microelectronics, fuel cells and pharmaceutical industry, if we mention a few of the potential applications. The applications of nanofluids are largely because of the enhanced thermal conductivity. Let us explore the history of the nanofluid technology a bit and move on to other things. The history of nanotechnology can probably be traced back to ninth century AD in Mesopotamia for its use in pottery. Various other applications can be seen in the history. The famous paper of Michael Faraday marks the beginning of nanotechnology in the modern day world. Faraday talks about the optical properties of nanometer scale metals. The conceptual birth of nanotechnology can be found in the more recent lecture of the legendary scientist Richard P Feynman. Feynman delivered his famous lecture 'There is plenty of room at the bottom' at the American physical society meeting at Caltech on December 29, 1969. Feynman made his famous waver challenging young scientists to make a working motor no more than 1/64 of an inch on all sides. Most of the work in the field of nanotechnology came about without the knowledge of this lecture, but it marked the conceptual origin of modern nanotechnology. The invention of scanning tunneling microscope triggered the growth of nanotechnology in the 1980's. The word nanotechnology was probably used for the first time by the Japanese scientist Norio Taniguchi in 1974. K. Eric. Drexler is credited with initial theoretical work in the field of nanotechnology. The term nanotechnology was used by Drexler in 1986 book "engines of creation: The coming era of nanotechnology". Drexlers idea of nanotechnology is referred to as molecular nanotechnology[2]. Nanofluids were a result of the experiments intended to increase the thermal conductivity of liquids. The birth of nanofluids is attributed to the revolutionary idea of adding solid particles into HTF's to increase the thermal conductivity. This innovative idea was put forth by Maxwell in 1873. Solid particles of micrometer, millimeter magnitudes were added initially to the base fluids to achieve increase in the thermal conductivity but posed a range of serious issues like clogging, increase in the pressure drop and the erosion of pipes. These methods couldn't bring about any considerable improvement in the practical applications of heat transfer fluids. S. U. S. Choi and J. Eastman brought about radical changes by introducing nanoscale metallic particles and carbon nanotubes[3]. They worked with a variety of fluids and the result was great. But uncertainty did linger on the practical utility and nature of these 'nanofluids'. The nanofluid technology is still in its early phase and various scientists are working now to help use nanofluids as a tool to solve the technological riddles of the modern society. We shall look at them later. Nanofluids are prepared by dispersing nano meter sized particles in HTF (Heat transfer fluid). They have distinctive properties like large surface area to volume ratio, properties that depend on dimension, lower kinetic energy and greater stability. Nanofluids are more stable than micro-fluids, milli fluids. Base fluids behave more or less like pure fluids in the presence of nanoparticles thereby incurring very little pressure drop and eliminate the need for surfactants. The most curious property of nanofluid is that they show remarkable enhancement in thermal conductivity even by the addition of very small amounts of nanometer sized particles[4]. The thermal conductivities of various solids and liquids are given in the Table 1.

Table 1: Thermal conductivities of various solids and liquids

Material	Form	Thermal conductivity (W/Mk)
Carbon	Nanotubes Carbon Diamond Graphite Fullerene film	1800-6600 2300 110-190 0.4
Metallic solids	Silver Copper Nickel	429 401 237
Non-metallic solids	Aluminums Sodium at 644k	40 72.3
Others[5]	Water Others[5] Ethylene glycol Engine oil	0.613 0.253 0.145

Features

The features of nanofluids can be understood better by having a good look at Newton's law of cooling.

$$Q = h * A * t$$

Q -> Rate of heat transfer, h -> Coefficient of convective heat transfer, A -> Surface area, t -> Temperature difference across which the transfer of thermal energy place

Nanofluids can help maximize 'Q' by increasing the value of 'h' for constant values of 'A' and 't'. Nanofluids have greater thermal conductivities and this goes a long way in increasing the rate of heat transfer. The features of nanofluid are directly related to this property. Nanofluids have greater thermal conductivity in comparison with pure fluids. Eddy current and the intensification of turbulence are responsible for this. The dependence of thermal conductivity on concentration is also a property that has greater applications. Agglomerates are not formed as the result of addition of the nanoparticles. The chemical composition of the base fluids do not change with the addition of nanoparticles. The conductivity of nanofluids also can be controlled by varying the particle size. The conductivity increases with the reduction of particle size[6]. The percentage of thermal conductivity enhancement with the volume concentration of some of the compounds can be seen in Figure 1.

Preparation

There are two methods for the preparation of nanofluid[7].

1. **Two step method**

The most common method used for the preparation of nanofluid is two step method. Nanomaterials are made into a dry powder using physical or chemical means. The next step involves the dispersion of nano sized powder into a base fluid using magnetic force agitation, ultrasonic agitation, high shear mixing, homogenizing and ball milling. This is the most economic method for the preparation of nanofluids because industrial production is already underway. Nanoparticles have the tendency to agglomerate owing to the large surface area and surface activity. Surfactants are used to prevent this and the behavior of the surfactants at high temperature also comes into play. It is quite difficult to prepare stable nanofluid using the two step method and this is where one step method come in[8]. The diagrammatical representation of two step method is shown in the Figure 2.

2. **One step method**

One step method was developed by Eastman. *et al* to reduce aggregation of nanoparticles. The one step method consists of making and dispersing the nanoparticles in the base fluid at the same time. Many steps like drying, storage, transportation and dispersion of nanoparticles are done away within this process; this reduces the agglomeration considerably and increases the stability of the nanofluid. One step method is highly successful in dispersing the nanoparticles uniformly and provides greater stability. One step method has not been successful in preparing nanofluid on a big scale and the production costs are also high as of now. Novel methods are being conceived now to make one step method industrially feasible and phase transfer method is one of them. Graphene oxide colloids with high stability and homogeneity can be prepared through the phase transfer method. The diagrammatical representation of one step method is shown in the Figure 3.

Applications

Nano drug delivery

Controlled targeting of cells and their monitoring is one of the innovative applications of nanofluid. Klein streuer *et.al* introduced the nano drug delivery system into the pharmaceutical industry[9]. Nano drug delivery system has been instrumental in increasing the residence time of drug via the controlled release of drug over a long period of time.

Cancer therapeutics

Cancer imaging and drug delivery can be made highly efficient by using nanofluids. Radiation can be administered to the cancer patients using iron based nanoparticles. Nanofluids which have magnetic properties can be used as biomarkers and can help in the targeted delivery of anticancer drugs without causing damage to the healthy cells nearby. Magnetic nanoparticles stick to tumor cells easily and not to healthy cells, this helps in the selective targeting of tumor cells.

Smart fluids

Nanofluids enable as to handle our energy resources efficiently and thus can act as smart fluids. It has been recently shown that nanofluids can be used as a smart heat valve to control the flow of heat. Nanofluid can be configured into a 'low' state, where it conducts heat poorly, can also be configured into a 'high' state, where it conducts heat efficiently. This enables the use of nanofluid as smart fluid in cooling.

Nuclear reactors

The use of nanofluid as a coolant in nuclear reactors is a very promising application because nanofluids can be highly effective in cooling over heated surfaces in an emergency situation. There are a few concerns regarding the loss of nanoparticles through the boiling vapor and regarding the safety measures for the disposal of nanofluid. Despite the concerns that we have, application of nanofluids in nuclear reactors is a promising future application.

Automotive applications
There are a lot of fluids used in automotive engines. Nanofluids can go a long way in improving the efficiency of the heat transfer of these fluids. We could have superior engine oils, automatic transmission fluids, coolant, lubricants and other heat transfer fluids.

Electronic applications
Nanofluids can be greatly effective in the cooling of microchips. The high thermal conductivity of nanofluid enables them to cool microchips very quickly. Nanofluid can be used to control micro fluidic systems. Nanofluid can be engineered to control the wettability of a surface and its surface tension. Droplets of nanofluid have contact angles which can be varied and this can be applied to the moving of liquids in micro systems. The variability of the contact angle of nanofluids could provide us with novel methods for focusing lenses in small cameras and for cooling micro computer chips.

Nanofluid detergent
Nanofluids are very different from normal fluids and they do not behave in accordance with the classical concept of surface tension and adhesion. This property provides as with the possibility of exploring the chance of using nanofluids as detergents and as a lubricant.

Advantages

- **Great heat conduction**

Nanofluid has better thermal conductivity as compared to base fluids[10]. This increase in the surface area of nanofluids helps increase the rate of heat transfer between solid particles and base fluid. The mobility of nanoparticles is great owing to the fact that they are small in size and this increases the micro convection of fluids greatly leading to better heat transfer. The thermal conductivity of nanofluids can also be greatly increased by using nanoparticles having higher thermal conductivity. Thermal conductivity of nanofluid can also be increased by using the temperature because the increase in temperature in turn increases brownian motion.

- **Increased stability of nanofluid**

Nanofluids can stay in the liquid phase for months or years together because of the small size. The stability can be increased by brownian motion.

- **Prevention of clogging**

Many atoms combine together to form nanoparticles. They are about 1-1000 nm in diameter and are spread nicely in the base fluids. Nanofluids do not cause any clogging problems and this helps in the use of nanofluid in micro channels.

- **Reduction of erosion**

Nanofluids containing nanoparticles have lesser momentum and kinetic energy compared to micro and macro particles. They don't cause erosion of components like pipeline, pumps and heat exchangers. Nanoparticles dispersed in liquids reduce friction and wear.

- The properties of nanofluid can be varied with change in their concentration. This property has the great advantage that this enables the use of nanofluids as smart fluids.

- Nanofluids can be optically selective; they show high absorption in the solar range and low emittance in the infrared range.

Limitations
Nanofluids have a few physical and chemical limitations[11]. The long term stability of nanofluids is a very important issue. Nanofluids may not be physically or chemically stable for a long period of time. The homogeneity of nanofluids is greatly limited by the agglomeration of nanoparticles. The agglomeration is caused by the strong vanderwaals forces of attraction between nanoparticles. Physical or chemical stability of nanofluids can be increased by adding surfactants, but it can lead to further complications[12]. The boiling characteristics of nanofluids are poor. When the concentration of nanoparticles increases, the boiling performance gets degraded causing an increase in the surface temperature of the nanofluids. This imposes a severe limitation on the design of cooling system with nanofluids and can cause overheating.

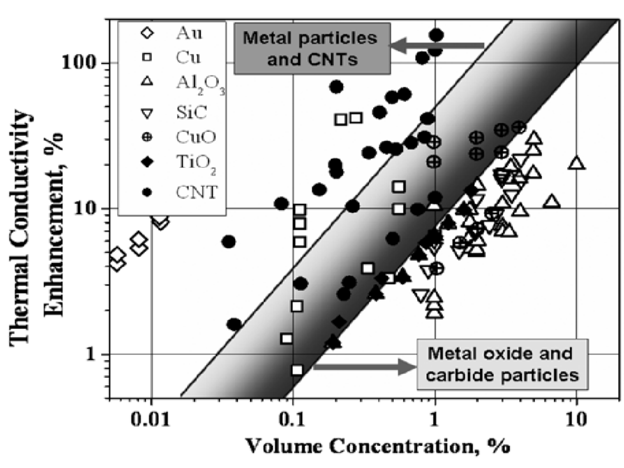

Figure 1: Thermal conductivity of nanofluids

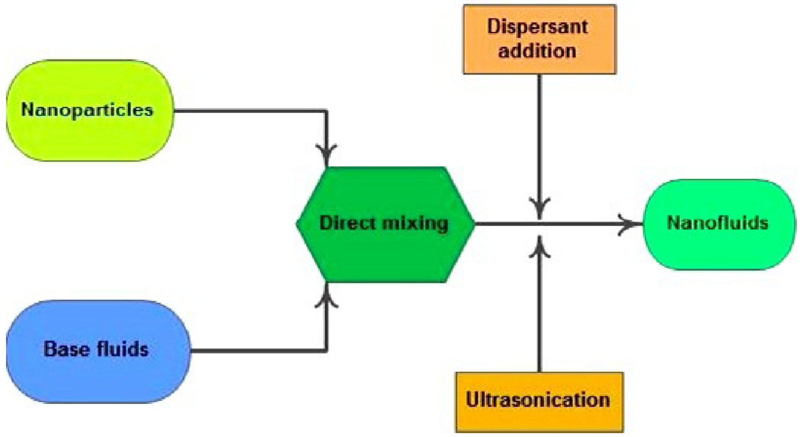

Figure 2: Two step preparation process of nanofluids

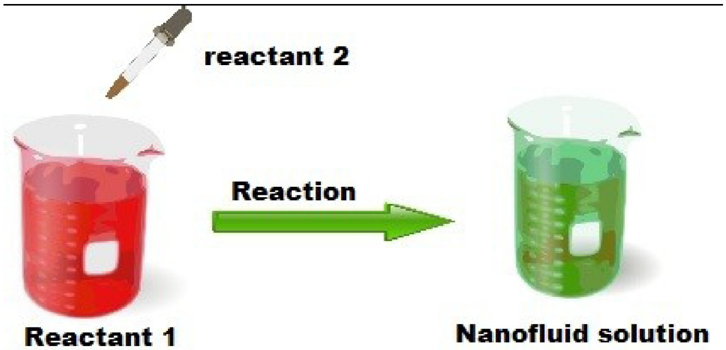

Figure 3: One step preparation process of nanofluids

Future aspects

Nanofluids have a variety of applications as of now and many more are expected in the future. The main area of research should probably be directed towards inventing efficient energy transport methods using nanofluids[13]. The rate of heat transfer is mainly depended on the thermal conductivity of nanofluid. The effect of particle shape, particle agglomeration on the thermal conductivity of nanoparticles should be thoroughly researched for inventing efficient energy transport mechanisms. There are concerns regarding the safety in the use and production of nanofluids currently and these are also areas of future research. Nanofluids present a novel method for extracting energy from the core of the earth. Nanofluid particles could also help in improving the efficiency of the cooling system employed by the nuclear reactors. Nanofluid particles could also aid in developing micro chips of smaller size. Smaller microchips could lead to better computers. Nanofluids could also help in targeted drug delivery, will help pharmaceutical industry to make big leaps and bounds. Improvement of thermal conductivity of nanofluids could also help to make better automobile engines. Nanofluid technology can only be harnessed by inventing non-toxic or biodegradable nanoparticles.

CONCLUSION

The increased thermal conductivity of nanofluids makes nanofluids as a very good prospect in the future technology. Nanofluids also can be used as smart fluids. There are various problems of nanoparticles like agglomeration, settling and erosion potential that need to be thoroughly researched. The science and technology of nanofluids are yet not fully understood and the full potential can be revealed only through further research. The synthesis and applications of nanofluids pose a variety of problems which are to be dealt away with for developing efficient and smaller systems which would go a long way towards creating a cleaner and healthier environment.

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