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Synthesis, Applications and Challenges of Nanofluids – Review

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Abstract: *Nanofluids are stable suspensions of nanoparticles (1-100nm) in base fluids that show many interesting properties, and their distinctive features offer unprecedented potential for many applications. This review summarizes the development of nanofluids through various routes and presents the broad range of current and future applications in various fields including nuclear reactors, transportation, electrical energy, mechanical, magnetic, solar absorption, and biomedical fields. However, few barriers and challenges that have been identified due to size shape and temperature must be discussed carefully before it can be fully implemented in the industrial applications.*

Keywords: *Synthesis of nanofluids, Applications of nanofluids, Thermal conductivity, Challenges of nanofluids.*

I. INTRODUCTION

With the recent improvements in nanotechnology, the production of particles with sizes on the order of nanometers (nanoparticles) can be achieved with relative ease. As a consequence, the idea of suspending these nanoparticles in a base liquid for improving thermal conductivity has been proposed recently [1,2]. Such suspension of nanoparticles in a base fluid is called a nanofluid. Due to their small size, nanoparticles fluidize easily inside the base fluid, and as a consequence, clogging of channels and erosion in channel walls are no longer a problem. It is even possible to use nanofluids in microchannels [3,4]. When it comes to the stability of the suspension, it was shown that sedimentation of particles can be prevented by utilizing proper dispersants.

Particle Material and Base Fluid: Many different particle materials are used for nanofluid preparation. Al_2O_3, CuO, TiO_2, SiC, TiC, Ag, Au, Cu, and Fe nanoparticles are frequently used in nanofluid research. Carbon nanotubes are also utilized due to their extremely high thermal conductivity in the longitudinal (axial) direction. Base fluids mostly used in the preparation of nanofluids are the common working fluids of heat transfer applications; such as, water, ethylene glycol and engine oil. In order to improve the stability of nanoparticles inside the base fluid, some additives are added to the mixture in small amounts.

1.2 Particle Size: Nanoparticles used in nanofluid preparation usually have diameters below 100 nm. Particles as small as 10 nm have been used in nanofluid research [5]. When particles are not spherical but rod or tube-shaped, the diameter is still below 100 nm, but the length of the particles may be on the order of micrometers. It should also be noted that due to the clustering phenomenon, particles may form clusters with sizes on the order of micrometers.

1.3 Particle Shape**:** Spherical particles are mostly used in nanofluids. However, rod-shaped, tube-shaped and disk-shaped nanoparticles are also used. On the other hand, the clusters formed by nanoparticles may have fractal-like shapes.

II. PRODUCTION OF NANOPARTICLES

Production of nanoparticles can be divided into two main categories, namely, physical synthesis and chemical synthesis. Yu et al. [6] listed the common production techniques of nanofluids as follows.

***Physical Synthesis*:** Mechanical grinding, inert-gas-condensation technique.

***Chemical Synthesis*:** Chemical precipitation, chemical vapor deposition,micro-emulsions, spray pyrolysis, thermal spraying.

2.1 Production of Nanofluids

There are mainly two methods of nanofluid production, namely, two-step technique and one-step technique.

In the *two-step technique*, the first step is the production of nanoparticles and the second step is the dispersion of the nanoparticles in a base fluid. Two-step technique is advantageous when mass 4 production of nanofluids is considered, because at present, nanoparticles can be produced in large quantities by utilizing the technique of inert gas condensation [7]. The main disadvantage of the two-step technique is that the nanoparticles form clusters during the preparation of the nanofluid which prevents the proper dispersion of nanoparticles inside the base fluid [6].

In *one-step technique*, combines the production of nanoparticles and dispersion of nanoparticles in the base fluid into a single step. There are some variations of this technique. In one of the common methods, named direct evaporation one-step method, the nanofluid is produced by the solidification of the nanoparticles, which are initially gas phase, inside the base fluid [5]. The dispersion characteristics of nanofluids produced with one-step techniques are better than those produced with two-step technique [6]. The main drawback of one-step techniques is that they are not proper for mass production, which limits their commercialization [6].

III. APPLICATIONS OF NANOFLUIDS

Nanofluids can be used to improve heat transfer and energy efficiency in a variety of thermal systems. Much of the work in the field of nanofluids is being done in national laboratories and academia and is at a stage beyond discovery research. Recently, the number of companies that see the potential of nanofluid technology and are in active development work for specific industrial applications is increasing. In the transportation industry, GM and Ford, among others, have ongoing nanofluid research projects.

3.1 Transportation:

An ethylene glycol and water mixture, the nearly universally used automotive coolant, is a relatively poor heat transfer fluid compared to water alone. Engine oils perform even worse as a heat transfer medium. The addition of nanoparticles to the standard engine coolant has the potential to improve automotive and heavy-duty engine cooling rates. Such improvement can be used to remove engine heat with a reduced-size coolant system. Smaller coolant systems result in smaller and lighter radiators, which in turn benefit almost every aspect of car and truck performance and lead to increased fuel economy.

Alternatively, improved cooling rates for automotive and truck engines can be used to remove more heat from higher horsepower engines with the same size of coolant system. A promising nanofluid engine coolant is pure ethylene glycol with nanoparticles. Pure ethylene glycol is a poor heat transfer fluid compared to a 50/50 mixture of ethylene glycol and water, but the addition of nanoparticles will improve the situation. If the resulting heat transfer rate can approach the 50/50 mixture rate, there are important advantages. Perhaps one of the most prominent is the low pressure operation of an ethylene-glycol-based nanofluid compared with a 50/50 mixture of ethylene glycol and water. An atmospheric-pressure coolant system has lower potential capital cost. This nanofluid also has a high boiling point, which is desirable for maintaining single-phase coolant flow. In addition, a higher boiling point coolant can be used to increase the normal coolant operating temperature and then reject more heat through the existing coolant system.

More heat rejection allows a variety of design enhancements including engines with higher horsepower. Tzeng et al. (2005) dispersed CuO and Al2O3 nanoparticles into engine transmission oil. The experimental platform was the transmission of a four-wheel-drive vehicle. The transmission has an advanced rotary blade coupling, where high local temperatures occur at high rotating speeds. Recent results from a research project involving industry and university points to the use of nanoparticles in lubricants to enhance tribological properties such as load-carrying capacity, wear resistance, and friction reduction between moving mechanical components. Such results are encouraging for improving heat transfer rates in automotive systems through the use of nanofluids.

3.2 Electronic applications:

Due to higher density of chips, design of electronic components with more compact makes heat dissipation more difficult. Advanced electronic devices face thermal management challenges from the high level of heat generation and the reduction of available surface area for heat removal. So, the reliable thermal management system is vital for the smooth operation of the advanced electronic devices. In general, there are two approaches to improve the heat removal for electronic equipment. One is to find an optimum geometry of cooling devices; another is to increase the heat transfer capacity. Nanofluids with higher thermal conductivities are predicated convective heat transfer coefficients compared to those of base fluids. Recent researches illustrated that nanofluids could increase the heat transfer coefficient by increasing the thermal conductivity of a coolant. Jang *et al.* designed a new cooler, combined microchannel heat sink with nanofluids [8]. Higher cooling performance was obtained when compared to the device using pure water as working medium. Nanofluids reduced both the thermal resistance and the temperature difference between the heated microchannel wall and the coolant. A combined microchannel heat sink with nanofluids had the potential as the next generation cooling devices for removing ultra-high heat flux. Nguyen *et al.* designed a closed liquid-circuit to investigate the heat transfer enhancement of a liquid cooling system, by replacing the base fluid (distilled water) with a nanofluid composed of distilled water and Al2O3 nanoparticles at various concentrations [9]. Measured data have clearly shown that the inclusion of nanoparticles within the distilled water has produced a considerable enhancement in convective heat transfer coefficient of the cooling block. With particle loading 4.5 vol%, the enhancement is up to 23% with respect to that 15 of the base fluid. It has also been observed that an augmentation of particle concentration has produced a clear decrease of the junction temperature between the heated component and the cooling block.

The thermal requirements on the personal computer become much stricter with the increase in thermal dissipation of CPU. One of the solutions is the use of heat pipes. Nanofluids, employed as working medium for conventional heat pipe, have shown higher thermal performances, having the potential as a substitute for conventional water in heat pipe. At a same charge volume, there is a significant reduction in thermal resistance of heat pipe with nanofluid containing gold nanoparticles as compared with water [10]. The suspended nanoparticles tend to bombard the vapor bubble during the bubble formation. Therefore, it is expected that the nucleation size of vapor bubble is much smaller for fluid with suspended nanoparticles than that without them. This may be the major reason for reducing the thermal resistance of heat pipe. Chen *et al*. studied the effect of a nanofluid on flat heat pipe (FHP) thermal performance [11], using silver nanofluid as the working fluid. The temperature difference and the thermal resistance of the FHP with the silver nanoparticle solution were lower than those with pure water. The plausible reasons for enhancement of the thermal performance of the FHP using the nanofluid can be explained by the critical heat flux enhancement by higher wettability and the reduction of the boiling limit. The thermal performance investigation of heat pipe indicated that nanofluids containing silver or titanium nanoparticles could be used as an efficient cooling fluid for devices with high energy density. For a silver nanofluid, the temperature difference decreased 0.56-0.65℃ compared to water at an input power of 30-50 W [12]. For the heat pipe with titanium nanoparticles at a volume concentration of 0.10%, the thermal efficiency is 10.60% higher than that with the based working fluid [13]. These positive results are promoting the continued research and development of nanofluids for such applications.

3.3 Industrial cooling applications:

The application of nanofluids in industrial cooling will result in great energy savings and emissions reductions. Experiments were performed using a flow-loop apparatus to explore the performance of polyalphaolefin nanofluids containing exfoliated graphite nanoparticle fibers in cooling [14]. It was observed that the specific heat of nanofluids was found to be 50% higher for nanofluids compared with polyalphaolefin and it increased with temperature. The thermal diffusivity was found to be 4 times higher for nanofluids. The convective heat transfer was enhanced by ~10% using nanofluids compared with using polyalphaolefin. Ma *et al.* proposed the concept of nano liquid-metal fluid, aiming to establish an engineering route to make the highest conductive coolant with about several dozen times larger thermal conductivity than that of water [15]. The liquid metal with low melting point is expected to be an idealistic base fluid for making super conductive solution which may lead to the ultimate coolant in a wide variety of heat transfer enhancement area. The thermal conductivity of the liquid-metal fluid can be enhanced through the addition of more conductive nanoparticles.

3.4 Heating buildings and reducing pollution*:*

Nanofluids can be applied in the building heating systems. Kulkarni *et al.* evaluated how they perform heating buildings in cold regions [68]. In cold regions, it is a common practice to use ethylene or propylene glycol mixed with water in different proportions as a heat transfer fluid. So 60:40 ethylene glcol/water (by weight) was selected as the base fluid. The results showed that using nanofluids in heat exchangers could reduce volumetric and mass flow rates, resulting in an overall pumping power savings. Nanofluids necessitate smaller heating systems, which are capable of delivering the same amount of thermal energy as larger heating systems, but are less expensive. This lowers the initial equipment cost excluding nanofluid cost. This will also reduce environmental pollutants because smaller heating units use less power, and the heat transfer unit has less liquid and material waste to discard at the end of its life cycle.

3.5 Space and defense:

Due to the restriction of space, energy and weight in space station and aircraft, there is a strong demand for high efficient cooling system with smaller size. You *et al.* [16] and Vassalo *et al.* [17] have reported order of magnitude increases in the critical heat flux in pool boiling with nanofluids compared to the base fluid alone. Further research of nanofluids will lead to the development of next generation of cooling devices that incorporate nanofluids for ultrahigh-heat-flux electronic systems, presenting the possibility of raising chip power in electronic components or simplifying cooling requirements for space applications. A number of military devices and systems require high-heat flux cooling to the level of tens of MW/m2. At this level, the cooling of military devices and system is vital for the reliable operation. Nanofluids with high critical heat fluxes 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. Therefore, nanofluids have wide application in space and defense fields where power density is very high and the components should be smaller and weight less.

3.6 Mass transfer enhancement:

Several researches have studied the mass transfer enhancement of nanofluids. Kim *et al.* initially examined the effect of nanoparticles on the bubble type absorption for NH3/H2O absorption system [18]. The addition of nanoparticles enhances the absorption performance up to 3.21 times. Then they visualized the bubble behavior during the NH3/H2O absorption process and studied the effect of nanoparticles and surfactants on the absorption characteristics [19]. The results show that the addition of surfactants and nanoparticles improved the absorption performance up to 5.32 times. The addition of both surfactants and nanoparticles enhanced significantly the absorption performance during the ammonia bubble absorption process. The theoretical investigations of thermo diffusion and diffusion thermo on convective instabilities in binary nanofluids for absorption application were conducted. Mass diffusion is induced by thermal gradient.

So far the mechanism leading to mass transfer enhancement is still unclear. The existing research work on the mass transfer in nanofluids is not enough. Much experimental and simulation work should be carried out to clarify some important influencing factors.

3.7 Energy applications:

For energy applications of nanofluids, two remarkable properties of nanofluids are utilized, one is the higher thermal conductivities of nanofluids, enhancing the heat transfer, and another is the absorption properties of nanofluids.

3.7.1 Energy storage:

The temporal difference of energy source and energy needs made necessary the development of storage system. The storage of thermal energy in the form of sensible and latent heat has become an important aspect of energy management with the emphasis on efficient use and conservation of the waste heat and solar energy in industry and buildings [19]. Latent heat storage is one of the most efficient ways of storing thermal energy. Wu *et al*. evaluated the potential of Al2O3-H2O nanofluids as a new phase change material (PCM) for the thermal energy storage of cooling systems. The thermal response test showed the addition of Al2O3 nanoparticles remarkably decreased the super cooling degree of water, advanced the beginning freezing time and reduced the total freezing time. Only adding 0.2 wt% Al2O3 nanoparticles, the total freezing time of Al2O3-H2O nanofluids could be reduced by 20.5%. Liu *et al*. prepared a new sort of nanofluid phase change materials (PCMs) by suspending small amount of TiO2 nanoparticles in saturated BaCl2 aqueous solution [20]. The nanofluids PCMs possessed remarkably high thermal conductivities compared to the base material. Copper nanoparticles are efficient additives to improve the heating and cooling rates of PCMs [21]. For composites with 1 wt % copper nanoparticle, the heating and cooling times could be reduced by 30.3 and 28.2%, respectively. The latent heats and phase-change temperatures changed very little after 100 thermal cycles.

3.7.2 Solar absorption:

Solar energy is one of the best sources of renewable energy with minimal environmental impact. The conventional direct absorption solar collector is a well established technology, and it has 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, which is very poor for typical fluids used in solar collectors. Recently this technology has been combined with the emerging technologies of nanofluids and liquid-nanoparticle suspensions to create a new class of nanofluid-based solar collectors. Otanicar *et al*. reported the experimental results on solar collectors based on nanofluids made from a variety of nanoparticles (CNTs, graphite, and silver) [22]. The efficiency improvement was up to 5% in solar thermal collectors by utilizing nanofluids as the absorption media. In addition they compared the experimental data with a numerical model of a solar collector with direct absorption nanofluids. The experimental and numerical results demonstrated an initial rapid increase in efficiency with volume fraction, followed by a leveling off in efficiency as volume fraction continues to increase.

3.8. Mechanical applications:

Why nanofluids have great friction reduction properties? Nanoparticles in nanofluids form a protective film with low hardness and elastic modulus on the worn surface can be considered as the main reason that some nanofluids exhibit excellent lubricating properties. Magnetic fluids are kinds of special nanofluids. Magnetic liquid rotary seals operate with no maintenance and extremely low leakage in a very wide range of applications, and it utilizing the property magnetic properties of the magnetic nanoparticles in liquid.

3.8.1 Friction reduction:

Advanced lubricants can improve productivity through energy saving and reliability of engineered systems. Tribological research heavily emphasizes reducing friction and wear. Nanoparticles have attracted much interest in recent years due to their excellent load-carrying capacity, good extreme pressure and friction reducing properties. Zhou *et al*. evaluated the tribological behavior of Cu nanoparticles in oil on a four-ball machine. The results showed that Cu nanoparticles as an oil additive had better friction-reduction and antiwear properties than zinc dithiophosphate, especially at high applied load. Meanwhile, the nanoparticles could also strikingly improve the load-carrying capacity of the base oil [23]. Dispersion of solid particles was found to play an important role, especially when a slurry layer was formed. Water-based Al2O3 and diamond nanofluids were applied in the minimum quantity lubrication (MQL) grinding process of cast iron.

3.8.2 Magnetic sealing:

Magnetic fluids (Ferromagnetic fluid) are kinds of special nanofluids. They are stable colloidal suspensions of small magnetic particles such as magnetite (Fe3O4). The properties of the magnetic nanoparticles, the magnetic component of magnetic nanofluids, may be tailored by varying their size and adapting their surface coating in order to meet the requirements of colloidal stability of magnetic nanofluids with non-polar and polar carrier liquids [24]. Comparing with the mechanical sealing, magnetic sealing offers a cost-effective solution to environmental and hazardous-gas sealing in a wide variety of industrial rotation equipment with high speed capability, low friction power losses and long life and high reliability [25]. Ferro-cobalt magnetic fluid was used for oil sealing, and the holding pressure is 25 times as high as that of a conventional magnetite sealing [26].

3.9 Biomedical application:

For some special kinds of nanoparticles, they have antibacterial activities or drug delivery properties, so the nanofluids containing these nanoparticles will exhibit some relevant properties.

3.9.1 Antibacterial activity:

Organic antibacterial materials are often less stable particularly at high temperatures or pressures. As a consequence, inorganic materials such as metal and metal oxides have attracted lots of attention over the past decade due to their ability to withstand harsh process conditions. The antibacterial behaviour of ZnO nanofluids shows that the ZnO nanofluids have bacteriostatic activity against [27]. Electrochemical measurements suggest some direct interaction between ZnO nanoparticles and the bacteria membrane at high ZnO concentrations. Further investigations have clearly demonstrated that ZnO nanoparticles have a wide range of antibacterial effects on a number of other microorganisms. The antibacterial activity of ZnO may be dependent on the size and the presence of normal visible light [28].

The antibacterial treatment of the textile fabrics was easily achieved by padding them with nano sized silver colloidal solution. The antibacterial efficacy of the fabrics was maintained after many times laundering. Silver colloid is an efficient antibacterial agent. The silver colloid prepared by a one-step synthesis showed high antimicrobial and bactericidal activity against Gram-positive and Gram-negative bacteria, including highly multiresistant strains such as methicillin-resistant staphylococcus aureus. The antibacterial activity of silver nanoparticles was found to be dependent on the size of silver particles.

3.9.2 Nano drug delivery:

Over the last few decades, colloidal drug delivery systems have been developed in order to improve the efficiency and the specificity of drug action [29]. The small size, customized surface, improved solubility, and multi-functionality of nanoparticles open many doors and create new biomedical applications. The novel properties of nanoparticles offer the ability to interact with complex cellular functions in new ways [30]. Gold nanoparticles provide non-toxic carriers for drug and gene delivery applications. Another attractive feature of gold nanoparticles is their interaction with thiols, providing an effective and selective means of controlled intracellular release [31]. Nakano *et al*. proposed the drug delivery system using nano-magnetic fluid [32], which targeted and concentrated drugs using a ferrofluid cluster composed of magnetic nanoparticles. CNT has emerged as a new alternative and efficient tool for transporting and translocating therapeutic molecules. In recent years, graphene based drug delivery systems have attracted more and more attention. In 2008, Sun *et al*. firstly reported the application of nano-graphene oxide (NGO) for cellular imaging and drug delivery [33]. They have developed functionalization chemistry in order to impart solubility and compatibility of NGO in biological environments. Simple physicosorption via π-stacking can be used for loading doxorubicin, a widely used cancer drug onto NGO functionalized with antibody for selective killing of cancer cells in vitro.

3.10 Other applications:

Cancer Theraupetics.
Nanocryosurgery.
Sensing and Imaging.
Cryopreservation
Nanofluid Detergent.
Intensify micro reactors,
Nanofluids as vehicular brake fluids,
Nanofluids based microbial fuel cell,
Nanofluids as optical filters.

IV. CHALLENGES OF NANOFLUIDS

Many interesting properties of nanofluids have been reported in the review. In the previous studies, thermal conductivity has received the maximum attention, but many researchers have recently initiated studies on other heat transfer properties as well. The use of nanofluids in a wide variety of applications appears promising. But the development of the field is hindered by (i) lack of agreement of results obtained by different researchers; (ii) poor characterization of suspensions: (iii) lack of theoretical understanding of the mechanisms responsible for changes in properties.

Therefore, this paper concludes several important issues that should receive greater attention in the near future. Experimental studies in the convective heat transfer of nanofluids are needed. Many issues, such as thermal conductivity, the Brownian motion of particles, particle migration, and thermo physical property change with temperature, must be carefully considered with convective heat transfer in nanofluids. Though, all the convective studies have been performed with oxide particles in high concentrations (for example Pakand Cho [41] used 10vol. % of Al2O3 which increased the viscosity and pumping power of the fluid, it is interesting to know the energy transport in low concentration (<1vol. %) nanofluids with metallic particles, since the thermal conductivity of pure metallic nanoparticles is more than100 times higher than that of the oxide nanoparticles. Future convective studies must be per-formed with metallic nanoparticles with different geometries and concentrations to consider heat transfer enhancement in laminar, transition and turbulent regions.

The use of nanofluids in heat pipes has shown enhancement in performance and considerable reduction in thermal resistance. However, recent studies indicate particle aggregation and deposition in micro-channel heat sinks. Further study is required in these areas to identify the reasons for and the effects of particle deposition. Finally, the reappears to be hardly any research in the use of nanofluids as refrigerants. Nanoparticle refrigerant dispersions in two-phase heat transfer applications can be studied to explore the possibility of improving the heat transfer characteristics of evaporators and condensers used in refrigeration and air-conditioning appliances. Applied research in nanofluids which will define their future in the field of heat transfer is expected to grow at a faster pace in the near future [41].

4.1 Long term stability of nanoparticles dispersion:

Preparation of homogeneous suspension remains a technical challenge since the nanoparticles always form aggregates due to very strong Vander Waals interactions. To get stable nanofluids, physical or chemical treatment have been conducted such as an addition of surfactant, surface modification of the suspended particles or applying strong force on the clusters of the suspended particles. Dispersing agents, surface-active agents, have been used to disperse fine particles of hydro phobic materials in aqueous solution [42]. On the other hand, if the heat exchanger operates under laminar conditions, the use of nanofluids seems advantageous, the only disadvantages so far being their high price and the potential instability of the suspension [43]. Generally, long term stability of nanoparticles dispersion is one of the basic requirements of nanofluids applications. Stability of nanofluids have good corresponding relationship with the enhancement of thermal conductivity where the better dispersion behavior, the higher thermal conductivity of nanofluids [44].

The dispersion behavior of the nanoparticles could be influenced by period of time. So, thermal conductivity of nanofluids is eventually affected. *Eastman etal*. [45] revealed that, thermal conductivity of ethylene glycolbasednanofluidscontaining0.3%coppernanoparticles is decreased with time. In their study, the thermal conductivity of nanofluids was measured twice: first was within2days and second was two months after the preparation. It was found that fresh nanofluids exhibited slightly higher thermal conductivities than nanofluids that were stored up to two months. This might due to reduced dispersion stability of nanoparticles with respect to time. Nanoparticles may tend to agglomerate when kept for long period of time. *Lee and Mudawar* [46] compared theAl2O3 nanofluids stability visually over time span. It was found that nanofluids kept for 30days exhibit some settlement and concentration gradient compared to fresh nanofluids. It indicated long term degradation in thermal performance of nanofluids could be happened. Particles settling must be examined carefully since it may lead to clogging of coolant passages. Choi etal. [47] reported that the excess quantity of surfactant has a harmful effect on viscosity, thermal property, chemical stability, and thus it is strongly recommended to control the addition of the surfactant with great care. However, the addition of surfactant would make the particle surface coated, there by resulting in the screening effect on the heat transfer performance of nanoparticles. Authors also mentioned that the surfactant may cause physical and/or chemical instability problems.

4.2. Increased pressure drop and pumping power:

Pressure drop developed during the flow of coolant is one of the important parameter determining the efficiency of nanofluids application. Pressure drop and coolant pumping power are closely associated with each other. There are few properties which could influence the coolant pressure drop: density and viscosity. It is expected that coolants with higher density and viscosity experience higher pressure drop. This has contributed to the disadvantages of nanofluids application as coolant liquids. Leeetal. [48] and Yuetal. [49] Investigated viscosity of water based Al2O3 nanofluids and ethylene glycol based ZnO nanofluids. Results clearly show viscosity of nanofluids is higher than base fluid. Nam- buru etal. [50] in their numerical study reviewed that density of nanofluids is greater than base fluid. Both properties are found proportional with nanoparticles volume fraction. Several literatures have indicated that there is significant increase of nanofluids pressure drop compared to basefluid. Lee and Mudawar [46] revealed that single phase pressure drop of Al2O3 nanofluids in micro channel heat sink increases with nanoparticles concentration. Vasu et al. [47] studied the thermal design of compact heat exchanger using nanofluids. Pantzali et al. [48] reported there was substantial increase of nanofluids pressure drop and pumping power in plate heat exchanger. About 40% increase of pumping power was observed for nanofluids com- pared with water. Peng etal. [49] reported that the frictional pressure drop of refrigerant-based nanofluids flow boiling inside the horizontal smooth tube is larger than that of pure refrigerant, and increases with the increase of the mass fraction of nanoparticles. The maximum enhancement of frictional pressure drop can reach20.8% under the experimental conditions. An important parameter in the application of nanofluids in heat exchanging equipment is the pressure drop developed during the flow through the Plate Heat Exchanger (PHE). Pantzali etal. [48] Observed that the measured viscosity of the suspension (i.e. nanofluids) exhibits a two fold increase compared to water. This leads to a significant increase in the measured pressure drop and consequently in the necessary pumping power when the nanofluids are applied.

V. CONCLUSION

Nanofluids are important because they can be used in numerous applications involving heat transfer, enhancement of thermal conductivity and other applications. Nanofluids have also been demonstrated for use as smart fluids. 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, nanofluids further research still has to be done on the synthesis and applications of nanofluids so that they may be applied as predicted.

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