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Review Article

Nanofluids: An Introduction to New Generation Heat Transfer Fluids

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Abstract

A nanofluid is the mixture of nanoparticles suspended in the base fluid. It is an advanced heat transfer fluid that possesses superior heat transfer properties. Recent developments in nanotechnology bring out fluids that possess better thermal properties than conventional fluids. The inherent properties like the larger relative surface area of nanoparticles and superior thermal conductivity makes them a choice for thermal engineers over conventional fluid. A suspended nanoparticle significantly improves heat transfer capabilities and stability of the suspension. Nanofluids possess wide range of possibilities as it can enhance heat transfer performance in comparison to that of pure liquids and hence can be considered as next generation heat transfer fluids. The most recent popular nanoparticles which are used to produce nanofluids are aluminum oxide (Al2O3), copper oxide (CuO), copper (Cu). While the most common base fluids which are being employed for producing nanofluids are water, oil, decene, acetone and ethylene glycol. The present review gives out a brief introduction, characteristics and application of nanofluids.

Keywords: Nanofluids; Thermal Conductivity; Heat Transfer; Nanoparticles

Introduction

Heat transfer is a pivotal area of research and study in thermal engineering and processing. Selection of heat transfer fluid is important for design and development of a heat exchanger for the desired thermal process. Heat transfer fluid (HTF) is one of the deciding factors as it affects the size and cost of heat exchanger systems. Generally, water and oils are mostly used heat transfer fluids as they satisfy most of the properties and are easily available at low cost. But conventional HTF like water and oils have limited heat transfer potentialities. Hence researchers are always trying to find out to develop a new group of HTFs which could reduce cost and meet the burgeoning demand of industry and commerce. The advances in thermal engineering made it possible to achieve higher efficiency and cost saving in heat transfer processes. Scientists have developed nanoparticle-based HTF which can boost the heat transfer potentials of conventional fluids. Recently nanoparticles are gaining importance in the area of applications in the heat transfer. Any host liquid, either organic or inorganic, which contains nanoparticles in a suspended state, is known as nanofluids [1]. NFs are the suspension of solid nanoparticles (1-100nm) in conventional fluids.

Nanofluid (NF), a name conceived by choi, in Argonne National Laboratory, to describe a fluid consisting of solid nanoparticles with size less than 100 nm suspended on it with solid volume fractions typically less than 4% [2]. Micro-sized particles help to improve thermal conductivity and convective heat transfer of liquids when mixed with base fluids [3].

Nanofluids can be used in engine cooling, cooling of electronics and transformer oil, solar water heating, domestic refrigerator-freezers, cooling of the heat exchanging devices, improving diesel generator efficiency, improving heat transfer efficiency of chillers, cooling in machining, in a nuclear reactor and defense and space etc.

Properties of Nanofluids

The Properties of NFs are Density, Viscosity, Specific Heat, Thermal Conductivity and Stability. These properties play a very important role in the preparation of NFs. The Properties are discussed below:

Physical properties

Density (ρ).

The density is a factor that affects the heat transfer properties. Density is an important thermophysical property and in order to evaluate the heat transfer performances of NFs, the density plays an important role. It directly affects the Reynolds number, friction factor, pressure loss, and Nusselt number. However, reports on the effect of density are found to be scarce. Since the nanoparticle's density is higher than liquids', it led to believe that an increase in the volume concentration of the nanoparticles would lead to increased density values of the nanofluid. Most researchers obtain the theoretical density values from the mixing equation introduced by Pak and Cho [4].

$$\rho_{nf} = \varphi\rho s + (1-\varphi)\rho_f$$

Where, ρ is the density, Φ is the volume concentration, and "nf" and "f" subscripts are the nanofluid and base fluid, respectively

Viscosity (μ)

Viscosity is the key parameter in determining the convective heat transfer coefficient. Understanding of viscosity mechanisms of NFs is troublesome due to lack of a general mathematical model that predicts the behavior of viscosity in nanofluids. Several mathematical models were developed to predict the viscosity of NFs. The first model which was developed in 1906, is an Einstein's model of effective viscosity for suspended rigid spherical solids in liquids as a function of volume. The model was derived from linear hydrodynamic equations. It only predicts the viscosity behavior for spherical rigid particles and for a low particle concentration. Nowadays viscometers are mostly used to measure the viscosity of nanofluids [5].

The viscosity of NFs depends on various factors viz. volume concentration, particle size, shear rate, temperature and morphology [6-9], which can affect the viscosity.

Stability

The NF is not a simple liquid-solid mixture. The most important criterion while developing the NF is an agglomerate-free long-term stable suspension. Stability of the NFs is important for its potential application as a heat transfer fluid. Stability of NF is associated with its thermal conductivity and viscosity, which are critical parameters in the evaluation of any NF. The behavior of nanoparticles inside the base fluid is highly unpredictable and the stability of these particles within base fluid determines the stability of NFs. Different forces acting on the nanoparticles may cause them to agglomerate and precipitate out of the base fluid and such unstable NFs would not perform consistently. Longer the nanoparticles remain in suspension in the base fluid; better thermal properties are expected of NFs. Thus, the primary concern in the application of any NF for commercial heat transfer application would be to prepare stable NFs. Further, agglomerated fluid can cause operational problems like clogging of channels due to sedimentation. An agglomerated NF would possess properties that are different from their stable counterparts [10].

Thermal Properties

Specific Heat Capacity (Cp)

Specific heat capacity measures the ability of a material to store energy in the form of heat and exchange it if a temperature difference exists [11-13]. It is important to acquire accurate values of the specific heat as specific heat is used to calculate important properties, which include thermal conductivity, thermal diffusivity, and flow's spatial temperature. Researchers mostly use deferential scanning calorimeter (DSC) and double hot wire to measure Cp of nanofluids. Several models predict the specific heat values of nanofluids at different conditions. One model was based on a mixture of liquid and particle and was introduced by Pak and Cho [4].

$$C_{nf} = (1-\varphi_v)C_{bf} + \varphi_v C_p$$

Where "Cp" is for the specifc heat, "nf" is the nanofluid, ΦV is the volume fraction of the nanoparticle, and "bf" and "p" represent the base fluid and nanoparticle, respectively.

Thermal Conductivity (k)

Thermal conductivity "k" is the rate at which a material passes heat. It is a major factor in increasing nanofluid efficiency in heat transfer and researchers have extensively studied it. The rate of heat transfer through solids is much higher than that through liquids and gases; it is for this reason that nanofluids have higher "k" values compared to their base fluids.

The four possible mechanisms described by Saidu., *et al.* [14] and Eastman., *et al.* [15] to explain the abnormal rise of thermal conductivity in NFs includes motion of the nanoparticles due to

Brownian movement, molecular-level layering of the liquid at the liquid/particle interface, the type of heat transport in the nanoparticles, and the effects of clustering of nanoparticle.

Several factors affected thermal conductivity; includes nanoparticle type, volumetric concentration, different base fluids, temperature, particle size, pH, effect of sonication, the addition of a surfactant and much more. There are several methods to measure the thermal conductivity of a material like transient hot wire method, thermal constants analyzer, steady state parallel plate, and 3ω method. Among all these techniques, the thermal constants analyzer has been used mostly for analyzing thermal conductivity of NFs [13].

Thermal Conductivity of some materials, Base Fluids and NFs		
	Materials	Thermal Conductivity (W/mK)
Carbon	Nanotubes Diamond Graphite Fullerenes film	1800-6600 2300 110-190 0.4
Metallic solids (pure)	Copper Aluminum	401 237
Nonmetallic solids	Silicon Alumina (Al2O3	148 40
Metallic liquids	Sodium (644 K)	72.3
Nonmetallic liquids	Water Ethylene glycol (EG) Engine oil (EO)	0.613 0.253 0.145

Table 1

Preparation of Nanofluids

Preparation of NFs is the primary and most essential step for conducting experimental studies of NFs. Various types of nanofluids have been prepared by various researchers are basically metals such as copper (Cu), nickel (Ni), alumina (Al), Silver (Ag) metal oxides such as: titanium oxide (TiO_2), zirconium dioxide (ZrO_2), barium titanate ($BaTiO_2$), barium titanate ($BaTiO_2O_3$), copper oxide (CuO), iron oxide (Fe_3O_4), silicon dioxide (SiO_3), zinc oxide (ZnO) and some other compounds such as, silicon carbide (SiC), carbon nanotube (CNT), aluminium oxide (Al_2O_3), copper oxide (CuO), iron oxide (Fe_3O_4), Silicon dioxide, zinc oxide and some other compounds such as silicon carbide (SiC), carbon nanotube CNT, aluminium nitride (AIN), graphene, calcium carbonate ($CaCO_3$) etc.

Formulating stable NFs, with controlled properties such as thermal conductivity, stability viscosity and wettability for heat transfer applications, still presents a challenge for the NF community. Wen., *et al.* [16] proposed that the most commonly used formulation methods are namely, the top-down method obtained through size reduction which is two-step method and the bottom-up approach (single-step method) which involves simultaneous production and dispersion of nanoparticles.

Single step preparation process

The single step preparation process indicates the synthesis of NFs in one-step and a wide range of single step methods are available for preparation of NF. Vacuum Evaporation onto a Running Oil Substrate (VEROS) was developed by Akoh., *et al.* [17] which is a single step direct evaporation method. But it was found that separation of nanoparticle from the base fluid is difficult. The VEROS technique was modified by Eastman., *et al* [18], in which condensation of Copper (Cu) vapour directly into nanoparticles is achieved by contact with flowing low vapor pressure ethylene glycol. Zhu., *et al.* [19] developed a single step chemical process using microwave irradiation for the preparation of Cu NFs by reduction of $CuSO_4.5H_2O$ with $NaH_2PO_2.H_2O$ in ethylene glycol which is proved to be a better way for production of mineral oil based silver NFs. A process was developed by Lo., *et al.* [20] for production of CuO, Cu_2O and Cu based NFs from different dielectric liquids by vacuum based submerged arc nanoparticle synthesis technique. An electric arc between 6000-12000°C operated by a suitable power source is used for melting and vaporizing the metal rod and the vaporized metal is allowed to condense followed by dispersion using deionized water to produce NFs. The nanoparticle agglomeration is minimized by single step synthesis method, but the compatibility of the process is only for low vapor pressure fluids.

Two-step preparation process

This method is widely preferred in the preparation of NFs. In this method, NF is prepared by mixing base fluids with commercially available Nano powders. These Nano powders are prepared from different mechanical, physical and chemical methods like milling, grinding, and sol-gel and vapor phase methods. The proper mixing of Nano powders with host fluids is achieved by higher shear mixing device or an ultrasonic vibrator and Murshed., *et al.* [21] prepared the nanosuspension of TiO_2-water by using the same method. Xuan and Li [22] used commercially available Cu nanoparticles to prepare NFs of both water and transformer oil. The two-step method was adopted by Kwak and Kim [23] for the preparation of CuO dispersed ethylene glycol NFs by Sonication and without stabilizers and this method can also be utilized for the production of carbon nanotube based NFs. The pyrolysis method was first used for production of single walled and multi walled carbon nanotubes and further it was suspended in base fluids with or without the use of surfactants [24]. Suggestions are made by different authors that two-step process is the ideal process for preparation of NFs containing oxide nanoparticles than those containing metallic nanoparticles [15]. Aggregation of powders due to strong Van der Walls attraction force between nanoparticles affects its stability, which is the major drawback of this operation. But still this process is popular and most economic for NFs production in spite of its disadvantages. The widely used two-step method is described in the following figure 1.

Figure 1: Two step preparation process of NFs.

Other Novel Methods

A continuous-flow microfluidic micro reactor was developed by Wei and Wang [25] for the production of copper NFs and copper NFs can be continuously synthesized by this method. The parameters such as reactant concentration, flow rate, and additives can be adjusted for varying the microstructure and properties of NFs. Zhu., *et al.* [26] has developed Novel precursor transformation method utilizing ultrasonic and microwave irradiation for the synthesis of CuO NFs with high solid volume fraction (up to 10%) in which complete transformation of precursor $Cu(OH)_2$ in to CuO nanoparticle in water in presence of microwave irradiation. Addition of ammonium citrate can prevent the aggregation and growth of nanoparticles, which results in the synthesis of a stable CuO aqueous NF having a thermal conductivity higher than those prepared by other dispersing methods. Chen and Wang, [27] stated that Phase-transfer method is an ideal method for obtaining mono disperse noble metal colloids. In a water-cyclohexane two-phase system, conversion of aqueous formaldehyde into cyclohexane phase is achieved by reaction with dodecyl amine resulting in the production of reductive intermediates in cyclohexane. The intermediates produced has the capacity to reduce silver or gold ions in aqueous solution to produce dodecyl amine-protected silver and gold nanoparticles in cyclohexane solution at room temperature. Feng., *et al*. [28] described that preparation of gold, silver, and platinum nanoparticles by aqueous organic phase-transfer method relies on principle that the solubility of PVP's in water decreases with the rise in temperature and this method is applied for the production of stable kerosene-based Fe_3O_4 NFs. By chemisorption mode, Oleic acid is successfully adjoined onto the surface of Fe_3O_4 nanoparticles, which makes it to highly compatible with kerosene. The time dependence of the thermal conductivity characteristic is not been found in Fe_3O_4 NFs prepared by phase-transfer method. The preparation of NFs with controllable microstructure is one of the key issues. It is well known that the properties of NFs strongly depend on the structure and shape of nanomaterials.

Advantages of Nanofluids

NFs are suitable for various applications as follows:

1. Solar energy absorption can be maximized by changing the size, shape, material and volume fraction of the nanoparticles in suspension.

2. Increase in the surface area and the heat capacity of the fluid due to its smaller particle size.
3. Enhancement of the thermal conductivity results in an increase of efficiency of heat transfer systems.
4. Heating within the fluid volume, transfers heat to a small area of fluid and allowing the peak temperature to be located away from surfaces losing heat to the environ ment.
5. A nanofluid enhances the mixing efficiency and turbul ence in the fluid.
6. To make suitable for different applications, properties of fluid can be changed by varying concentration of nano particles.
7. NFs increase the temperature of solar thermal applications.

Higher viscosity

Increase of particle concentration in the suspension results in increase of viscosity of nanoparticle-water suspensions so that the particle mass fraction cannot be increased beyond a limit. Pantzali., *et al*. [29] conducted studies and concluded that replacement of conventional fluids by NFs in industrial heat exchangers seems unpromising since large volumes of NFs are necessary and turbulent flow is usually developed, the substitution.

Lower specific heat

Literatures have suggested that specific heat of NFs are normally found lower than base fluid. Namburu., *et al.* [30] has conducted study and found that NFs produced from CuO/ethylene glycol, SiO_2/ethylene glycol and Al_2O_3/ethylene glycol exhibit lower specific heat compared to base fluids. It is desirable to have higher value of specific heat for aan ideal coolant which enables the coolant to remove more heat.

High cost of NFs

The major drawback for application of NFs in industry is its high production cost. Nanoparticles themselves have high manufacturing cost due to the size of the particles. NFs production can be achieved either by single step or two steps methods, but success in both methods is achieved only by advanced and sophisticated equipment's which are important for production of NFs.

Applications of Nano fluids

NFs offers a huge range of possibilities in engineering applications as it has improved heat transfer and energy efficiency in thermal applications.

Heat Transfer Intensification

Since the origination of the NF concept about a decade ago, the potentials of NFs in heat transfer applications have attracted more and more attention. Up to now, there are some review papers which present overviews of various aspects of NFs [31], including preparation and characterization, techniques for the measurements of thermal conductivity, theory and model, thermo physical properties, and convective heat transfer.

Transportation

NFs finds broad range of application in automotive and heavy-duty engines as it possesses potential to improve the cooling rates by increasing the efficiency, weight reduction and by reducing the complexity of thermal management systems. The increased cooling rates achieved in automotive and truck engines by NFs can be used to remove the excess heat from higher horsepower engines having the same size of the cooling system. Use of NFs helps the engineers to design smaller and lighter radiators which helps to make the cooling system more compact which in turn improves the performance and fuel economy of cars and truck. Ethylene glycol-based NFs have attracted much attention in the application as engine coolant [32] due to the low-pressure operation compared with a 50:50 mixture of ethylene glycol and water, which is the nearly universally used automotive coolant.

Industrial Cooling Applications

NFs finds applications in industrial cooling will helps in improving energy efficiency and emission reductions. For US industry, the replacement of cooling and heating water with NFs has the potential to conserve 1 trillion Btu of energy [27]. For the US electric power industry, using NFs in closed loop cooling cycles could save about 10–30 trillion Btu per year (equivalent to the annual energy consumption of about 50,000–150,000 households). The associated emissions reductions would be approximately 5.6 million metric tons of carbon dioxide, 8,600 metric tons of nitrogen oxides, and 21,000 metric tons of sulfur dioxide [33]. Xie and Chen [34], conducted experiments on polyalphaolefin NFs containing exfoliated graphite nanoparticles using a flow-loop apparatus to study the performance of fibers in cooling and the results revealed that NFs are having specific heat which is 50% higher than those for NFs compared with polyalphaolefin. The specific shown a temperature dependence and it increased with rise in temperature. Studies also shown that thermal diffusivity was increased by 4 times and convective heat transfer by 10% on use of NFs in comparison with that of use polyalphaolefin.

Milk Cooling Applications

Ravi [35] investigated the NF based raw milk cooling with an objective to cool the raw milk from 37°C to below 10°C. Cooling module viz. cooling module-Stainless Steel, cooling module-Aluminum, cooling module- Stainless steel with extended surface were evaluated. $Al2o_3$, CuO and TiO_2 based NFs were prepared and evaluated for their milk cooling performance inside the cooling module.

Mechanical Applications

NFs has shown excellent lubricating properties as the nanoparticles present in it has the ability to form a protective film on the worn surface with low hardness and elastic modulus.

Magnetic Sealing

Magnetic fluids (ferromagnetic fluid) come under special category NFs which utilizes the magnetic properties of nanoparticles in liquid possessing magnetic properties. They are stable colloidal suspensions of small magnetic particles such as magnetite (Fe_3O_4). Magnetic fluids find broad range of applications in industry as the rotary seals can operate without much maintenance for a long time and extremely low leakage is detected. Vekas., *et al*. [36] reported that the magnetic properties can be varied by changing their size and adapting their surface coating so that the colloidal stability of magnetic NFs with nonpolar and polar carrier liquids can be maintained. 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 [37].

Biomedical Application

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

Antibacterial Activity

Organic antibacterial materials are relatively having less stability and are destroyed especially at high temperatures or pressures. Inorganic materials such as metal and metal oxides can withstand harsh process conditions in comparison to organic materials and is gaining huge popularity. The antibacterial behavior of ZnO NFs indicates that ZnO NFs have bacteriostatic activity against bacteria [38]. Interaction effects has been studied using electrochemical measurements and found that at higher ZnO concentrations, there occurs some direct interaction between ZnO nanoparticles and the bacteria membrane. Jalal., *et al.* [39] prepared ZnO nanoparticles via a green method and evaluated the antibacterial activity of suspensions of ZnO nanoparticles against Escherichia coli (*E. coli*) which is obtained by estimation of ratio of reduction of the bacteria treated with ZnO. Survival ratio of bacteria decreases with increasing the concentrations of ZnO NFs and time.

Challenges of Nano fluids

In addition to the studies on thermal conductivity of NFs, currently researchers have moved on to on other heat transfer properties of nano fluids as well. NFs are found to be a promising technology in a wide variety of applications, but the major factors that obstructs the development in this field are (i) variations in results and poor agreement of results obtained by different researchers; (ii) Difficulty in characterization of the developed suspensions (iii) Improper theoretical knowledge about the mechanisms which are reasonable for changes in properties [14]. There is a lack of experimental studies of NFs on convective heat transfer properties and during its studies considerations must be given on properties such as thermal conductivity, Brownian motion of particles, migration of particles, and variation of thermophysical properties change with temperature. Almost all the studies on convective heat transfer has been conducted with oxide particles in high concentrations. Pak and Cho [4] used 10 vol.% of Al2O3, which increased the viscosity and pumping power of the fluid. Study of the energy transport in NFs with low concentration (<1 vol.%) containing metallic particles is important since pure metallic nanoparticles possess thermal conductivity which is 100 times above that of the oxide nanoparticles. Studies should be conducted in future on convective heat transfer using metallic nanoparticles having differences in geometries and concentrations so that heat transfer enhancement considerations can be done in laminar, transition and turbulent regions. Considerable reduction in thermal resistance has been achieved by the application of NFs in heat pipes and it further increased the performance as well. Current researchers found that use of NFs resulted in aggregation of particles and further causes deposition in micro-channel heat sinks. Studies should be initiated in future to determine the factors affecting particle deposition and to tackle the situation. The applicability of NFs as refrigerants has not been exploited much by researchers. Improvement of heat transfer abilities of condensers and evaporators which are essential elements of refrigeration applications by application of nanoparticle refrigerant dispersions in two-phase heat transfer can be extensively studied. More research is expected in NFs which will revolutionize the field of heat transfer.

Long-term stability of nanoparticles dispersion

Major difficulties faced during preparation of homogeneous suspension is that aggregate formation of nanoparticles occurs due to the presence of strong Van der Waals interactions. To obtain stable NFs, it is essential to modify the structure by physical or chemical treatments such as incorporation of surfactants, surface modification of the suspended particles or applying strong force on the breakdown of clusters of suspended particles by application of strong forces. Dispersion of fine particles of materials in aqueous solutions which are hydrophobic in nature can be achieved by use of surface active and dispersing agents. Nanoparticles should remain stable in liquid for long time which is an essential requirement for applications of NFs. Generally, long-term stability of nanoparticles dispersion is one of the basic requirements of NFs applications. Stability of NFs has a good corresponding relationship with the enhancement of thermal conductivity, better dispersion behavior and higher thermal conductivity of NFs [16].

Increased pressure drops and pumping power

Pressure drop developed during the flow of coolant is one of the important parameters determining the efficiency of NFs application. There is a close association between pressure drop and pumping power of coolant. Density and viscosity have direct influence on coolant pressure drop and higher pressure drop is found in coolants possessing higher viscosity and density, which is a notable drawback on application of NFs as liquid coolant. Lee., *et al.* [24] and Yu., *et al.* [7] conducted studies on viscosity of water-based Al_2O_3 NFs and ethylene glycol based ZnO NFs and results clearly showed that the viscosity of NFs is higher than base fluid. Namburu., *et al.* [30] stated that the density of NFs is found to be higher than the base fluid base fluid. Both properties are found proportional to nanoparticles volume fraction.

Conclusion

In spite of having tremendous potentiality in nanofluids to become a heat transfer fluid, a long way research is needed to make them suitable in every aspect of heat transfer and its application. The extensive research needs to be carried out in the field of nanoparticle and base fluids to predict the performance and efficiency of nanofluids. The nanofluid preparation method must be economical in every aspect to reduce the cost of operation. There is a lot of scope for the application of nanofluids for cooling application in dairy and food industry.

Bibliography

1. Li Y., *et al*. "A review on development of nanofluid preparation and characterization". *Powder Technology* 196.2 (2009): 89-101.
2. Prasher R., *et al*. "Thermal conductivity of nanoscale colloidal solutions (nanofluids)". *Physical review letters* 94.2 (2005): 25901.
3. Maxwell JC. "Treatise on electricity and magnetism". Oxford: Clarendon Press (1873).
4. Pak BC and Cho YI. "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles". *Experimental Heat Transfer an International Journal* 11.2 (1998): 151-170.
5. Einstein A. "Eine neue bestimmung der moleküldimensionen". Annalen der Physik, 324.2 (1906): 289-306.
6. Sundar LS., *et al*. "Investigation of thermal conductivity and viscosity of Fe3O4 nanofluid for heat transfer applications". International communications in heat and mass transfer 44 (2013): 7-14.
7. Yu, W., *et al*. "Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid". *Thermochimica Acta* 491.1 (2009): 92-96.
8. Nguyen CT., *et al*. "Viscosity data for Al_2O_3–water nanofluid—hysteresis: is heat transfer enhancement using nanofluids reliable". *International Journal of Thermal Sciences* 47.2 (2008): 103-111.
9. Li H., *et al*. "Experimental investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluids". *Applied Thermal Engineering* 88 (2015): 363-368.
10. Setia H., *et al*. "Stability of NFs". In Materials Science Forum Trans Tech Publications 757 (2013): 139-149.
11. Teng TP., *et al*. "Preparation and characterization of carbon nanofluid by a plasma arc nanoparticles synthesis system". *Nanoscale research letters* 6.1 (2011): 29.
12. Vajjha RS and Das DK. "Measurements of Specific Heat and Density of Al2O3 Nanofluid". In AIP Conference Proceedings 1063.1 (2008): 361-370.
13. Das P K. "A review based on the effect and mechanism of thermal conductivity of normal nanofluids and hybrid nanofluids". *Journal of Molecular Liquids* (2017) 420-446.
14. Saidur R., *et al*. "A review on applications and challenges of nanofluids". *Renewable and sustainable energy reviews* 15.3 (2011): 1646-1668.

15. Eastman JA., *et al*. "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles". *Applied physics letters* 78.6 (2001): 718-720.

16. Wen D., *et al*. "Review of nanofluids for heat transfer applications". *Particuology* 7.2 (2009): 141-150.

17. Akoh, H., *et al*. "Magnetic properties of ferromagnetic ultrafine particles prepared by vacuum evaporation on running oil substrate". *Journal of Crystal Growth* 45 (1978):495-500.

18. Eastman JA., *et al*. "Enhanced thermal conductivity through the development of nanofluids". *MRS Online Proceedings Library Archive* 457 (1997): 3-11.

19. Zhu HT., *et al*. "A novel one-step chemical method for preparation of copper nanofluids". *Journal of colloid and interface science* 277.1 (2004): 100-103.

20. Lo CH., *et al*. "Fabrication of copper oxide nanofluid using submerged arc nanoparticle synthesis system (SANSS)". *Journal of Nanoparticle Research* 7.2 (2005): 313-320.

21. Murshed SMS., *et al*. "Enhanced thermal conductivity of TiO_2-water based nanofluids". *International Journal of Thermal Sciences* 44.4 (2005): 367-373.

22. Xuan Y and Li Q. "Heat transfer enhancement of nanofluids". *International Journal of heat and fluid flow* 21.1 (2000): 58-64.

23. Kwak K and Kim C. "Viscosity and thermal conductivity of copper oxide nanofluid dispersed in ethylene glycol". *Korea-Australia Rheology Journal* 17.2 (2005): 35-40.

24. Lee JH. "Convection performance of NFs for electronics cooling". PhD thesis. Stanford University (2009).

25. Wei X and Wang L "Synthesis and thermal conductivity of microfluidic copper nanofluids". *Particuology* 8.3 (2010): 262-271.

26. Zhu HT., *et al*. "Novel synthesis and thermal conductivity of CuO nanofluid". *The Journal of Physical Chemistry C* 111.4 (2007): 1646-1650.

27. Chen Y and Wang X. "Novel phase-transfer preparation of monodisperse silver and gold nanoparticles at room temperature". *Materials Letters* 62.15 (2008): 2215-2218.

28. Feng X., *et al*. "Aqueous– Organic Phase-Transfer of Highly Stable Gold, Silver, and Platinum Nanoparticles and new route for fabrication of gold nanofilms at the oil/water interface and on solid supports". The Journal of Physical Chemistry B 110.25 (2006): 12311-12317.

29. Pantzali MN., *et al*. "Effect of nanofluids on the performance of a miniature plate heat exchanger with modulated surface". *International Journal of Heat and Fluid Flow* 30.4 (2009): 691-699.

30. Namburu PK., *et al*. "Numerical study of turbulent flow and heat transfer characteristics of NFs considering variable properties". *International Journal of Thermal Sciences* 48 (2009): 290-302.

31. Wang QX and Mujumdar AS. "Heat transfer characteristics of NFs: a review". International Journal of Thermal Sciences, 46.1 (2007): 1-19.

32. Xie H., *et al*. "Nanofluids containing multiwalled carbon nanotubes and their enhanced thermal conductivities". *Journal of Applied physics* 94.8 (2009):4967-4971.

33. Demirbas MF. "Thermal energy storage and phase change materials: an overview". Energy Sources, Part B: Economics, Planning, and Policy 1.1 (2006): 85-95.

34. Xie H and Chen L. "Adjustable thermal conductivity in carbon nanotube nanofluids". Physics Letters A, 373.21 (2003): 1861-1864.

35. Ravi P. "Development of NF based cooling module for raw milk cooling, M. Tech thesis, NDRI, Karnal" (2016).

36. Vekas L., *et al*. "Magnetic nanoparticles and concentrated magnetic NFs: synthesis, properties and some applications". *China Particuology* 5.1 (2007): 43-49.

37. Rosensweig RE. "Magnetic fluids". *Annual review of fluid mechanics* 19.1 (1987): 437-461.

38. Zhang, L., *et al*. "Investigation into the antibacterial behaviour of suspensions of ZnO nanoparticles (ZnO nanofluids)". *Journal of Nanoparticle Research* 9.3 (2007): 479-489.

39. Jalal R., *et al*. "ZnO nanofluids: green synthesis, characterization, and antibacterial activity". *Materials Chemistry and Physics* 121.1 (2010): 198-201.

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