A Review on Nanofluids: Properties and Applications

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ABSTRACT

A Nanofluid is a fluid containing nanometer sized particles. The Nanofluids are obtained by dispersing nanometer sized particles in a conventional base fluids like water, oil, ethylene glycol etc. Nanoparticles of materials such as metallic oxides (Al_2O_3, CuO), nitride ceramics(AlN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, Au), semiconductors (TiO_2, SiC), single, double or multi walled carbon nanotubes, alloyed nanoparticles ($Al_{70,}$ Cu_{30}) etc. have been used for the preparation of nanofluids. This paper presents a procedure for preparation of Nanofluids, Properties of Nanofluids and their applications in various fields including energy, mechanical and biomedical fields. Then identifies parameter which challenges for the use of nanofluids to various applications and in last suggest directions for future research of nanofluids. The Nanofluids are enhanced Thermal Conductivity at very low volume fraction (<0.1%) of the suspended particles. Nowadays nanofluids are efficiently used in Non Conventional Energy Resources in Solar Absorption, for increasing the Temperature.

Keywords: Nanoparticles, Nanomaterials, Base Fluids, Temperature.

1.INTRODUCTION

Nanofluid, a name conceived by Dr.choi, in Argonne National Laboratory, to describe a fluid consisting of solid nanoparticles with size less than 100nm suspended on it with solid volume fractions typically less than 4% [34]. Nanofluids are synthesized by suspending nanoparticles of metals and metal oxides [1]. The term "nanomaterials" encompasses a wide range of materials including nanocrystalline materials, nanocomposites, carbon nanotubes and quantum dots. Xuan and Li [12] explained that due to its nanostructural features, nanomaterials exhibit enhanced properties (mechanical, thermal, physical, chemical), phenomenon and processes than conventional materials. In general, there are four types of nanomaterials: Carbon based nanomaterials (eg: Carbon nanotubes), Metal based nanomaterials (metal oxides such as aluminium oxides), Dendrimers (nanosized polymers) and Composites (nanosized clays) [2].

Micro sized particles helps to improve thermal conductivity and convective heat transfer of liquids when mixed with base fluids [6]. Meanwhile the fluid path is disturbed and high pressure drop occurred due to sedimentation, excessive wear, and clogging due to micro-sized particles. These problems are overcoming and improvements in thermal properties are achieved by using nano fluids. In nano fluids the nano particles of (1-100nm) and base fluid mixed thoroughly is identified by Choi in the year 1995 [7]&[8] at the Argonne National Laboratory.

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This is the first mile stone in nano fluid heat transfer technology which provides better thermal properties than micro-sized particles [3]. In recent years, nanofluids have attracted more and more attention. The main driving force for nanofluids research lies in a wide range of applications of engineering including, automotive and air conditioning cooling, solar and power plant cooling, cooling of transformer oil, improving diesel generator efficiency, in nuclear reactor and defense and space as reported by Xiang and Arun [11].

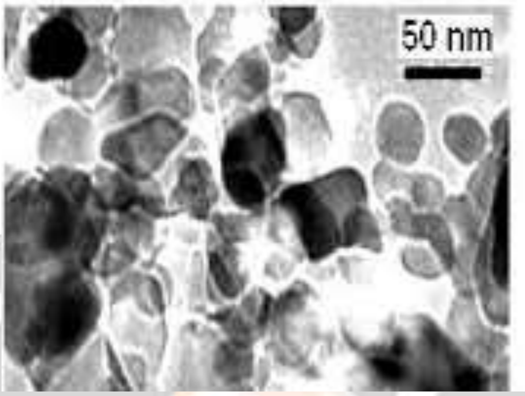

Fig1: Schematic view of Nanofluid.

Nanofluids can be used as coolants in micro-electronic devices where the sizes have been diminishing resulting in high heat generation which need to be removed efficiently for the optimal functioning of these devices[9]&[10]. In the automobile industries nanofluids can play a very important role in removal of excess energy that is generated due to the combustion of the fuel. When flowing through the tubes of the radiator nanofluids can lose its heat to the surrounding air through its walls. In all manufacturing processes which require heat transfers, the conventional fluids can be replaced by nanofluids. Understanding the underlying mechanisms which cause the enhancements, it is important to investigate the properties and flow characteristics of nanofluids [4].

By suspending nanophase particles in heating or cooling fluids, the heat transfer performance of the fluid can be significantly improved. The main reasons may be listed asfollows [5]:

1. The suspended nanoparticles increase the surface area and the heat capacity of the fluid.
2. The suspended nanoparticles increase the effective (or apparent) thermal conductivity of the fluid.
3. The interaction and collision among particles, fluid and the flow passage surface are intensified.
4. The mixing fluctuation and turbulence of the fluid are intensified.
5. The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.

2. PROPERTIES OF NANOFLUIDS

The concept of adding small solid particles into a base fluid to increase the thermal conductivity of the suspension has been practiced for a long time [13]. The Properties of nanofluids are Viscosity, Specific heat, Thermal Conductivity and Stability. These properties play a very important role in preparation of Nanofluids. The Properties are discussed below:

2.1 Viscosity

Even though the literature on heat convection in nanofluids is limited compared to that in thermal conductivity, the results and approaches in the field are quite diverse, and worth mentioning [17]. However, the understanding of the issues of convection is strictly related to the viscosity of the nanofluids.

In first place we need to understand that whether nanofluids are Newtonian or shear thinning is important. This question was addressed by the first work ever done on heat convection in nanofluids in 1998, by Pak and Cho [14]. They reported that the nanofluids behaved as Newtonian when 13 and 27 nm nanoparticles of γAl_2O_3 and TiO_2 were suspended in water, but only for very low particle volume fractions. Shear thinning behavior was, however, detected with an increase of particle volume fraction. In particular, the Al_2O_3-water nanofluid started showing shear thinning behavior at 3% particle volume fraction onward, while TiO_2-water behaved as Newtonian up to 10%. Pak and Cho also observed a large increase in the viscosity of both nanofluids, and showed that this behavior was not predicted by standard empirical models for suspension viscosities, such as the one developed by Batchelor in 1977 [17,47]. In 1999, Lee et al. [15] reported similar substantial increase in viscosity for water- and ethylene glycol-based nanofluids with Al_2O_3 nanoparticles. They also mentioned that the confirmation of this finding might offset the enhanced heat transfer observed in nanofluids.

In 2003, however, Das et al. [16] conducted a similar study for a water- Al_2O_3 nanofluid, but reported no observation of shearthinning behavior. In particular, they confirmed Newtonian behavior of the nanofluid with 1% to 4% concentrations by volume. They also showed a linear trend of viscosity versus shear rate, even though viscosity values are still higher than the ones of pure water. Viscosity is also reported to increase with nanoparticle loading, but remains Newtonian in nature.

As already discussed for thermal conductivity, nanofluids with carbon nanotubes (CNTs) behave quite differently than their nanoparticle counterparts, and this applies also to viscosity [17]. Ding et al. [18] in 2006 showed an interesting linear shear thinning behavior for water-CNTs nanofluids at lower shear rates, whereas the base fluid had a nonlinear trend.

Hence, there are some discrepancies in the literature on the nature of the rheology of nanofluids: some believe that nanofluids are Newtonian [19], while others found non-Newtonian shear-thinning behavior [20]. In the hope to explain these discrepancies, Chen et al. [21] in 2007 conducted both experimental and theoretical analysis of ethylene glycol-based nanofluids with TiO_2 nanoparticles at concentrations from 0.5% to 8.0% by weight at 20– 60^0C. They observed Newtonian behavior under their conditions, with shear viscosity being a strong function of temperature and nanoparticle loading.

However, the relative shear viscosity (obtained by normalizing with respect to the shear viscosity of the base liquid) depends nonlinearly on the nanoparticle loading, and is surprisingly independent of temperature. The high shear viscosity of nanofluids was shown to be in line with the prediction of the Krieger-Dougherty equation [22] if the nanoparticle volume fraction is replaced by the concentration of nanoparticle clusters.

The shear thinning behavior sometimes reported in the literature is mainly attributed to three factors: the effective particle loading, the range of shear rate, and the viscosity of the base fluid. Such non-Newtonian behavior can be characterized by a characteristic shear rate that decreases with increasing nanoparticle loading, with increasing viscosity of the base fluid, or with increasing nanoparticle cluster size. Chen et al. claim that this might explain the reported controversy in the literature. At ambient temperature, the relative high shear viscosity is independent of temperature due to a reduced Brownian diffusion in comparison to convection in high shear flows. Nevertheless, the characteristic shear rate can still have a strong temperature dependence; hence affecting the shear thinning behavior of the nanofluid.

The rheological nature of nanofluids can be categorized into four groups: (i) dilute nanofluids ($0 \leq \varphi \leq 0.001$ with φ being the nanoparticle volume fraction) with well dispersed nanoparticles the nanofluid shows no shearthinning behavior and the viscosity increase fits the Einstein model [23]; (ii) semidilute ($0.001 \leq \varphi \leq 0.005$) with nanoparticle clusters, the nanofluid viscosity is more in line with the modified Krieger-Dougherty equation and still shows Newtonian behavior; (iii) semiconcentrated ($0.05 \leq \varphi \leq 0.1$) with nanoparticle clusters, the viscosity still fits the modified Krieger-Dougherty equation but is obviously non-Newtonian; and (iv) concentrated nanofluids ($\varphi \leq 0.1$) with interpenetration of particle aggregation, but is out of the standard nanoparticle loading range of nanofluids.

In 2010, Tavman et al. [24] investigated TiO_2, SiO_2, and Al_2O_3 nanoparticles in water and also reported a dramatic increase in nanofluid viscosity with an increase in the nanoparticle concentration; they also showed that classical empirical theories, such as the Einstein model [23], were unable to predict the correct viscosity increase in nanofluids. Kole and Dey [25] presented experimental results for viscosity measurements of a car engine coolant (50% water and 50% propylene glycol) with a dispersion of alumina nanoparticles. The nominal diameter of the nanoparticles was below 50 nm, while the volume fraction between 0.001 and 0.015. They concluded that the addition of such a small amount of nanoparticles transforms the Newtonian behavior of the pure engine coolant to a non-Newtonian one, unlike what Chen et al. [26] predicted, and it behaves as a Bingham plastic with small yield stress. In addition, yield stress versus shear strain rate data showed a power-law dependence on the particle volume fraction.

The viscosity of the nanofluid, μ_{nf}, appears to depend on temperature T according to an empirical correlation of the type $\log(\mu_{nf}) = A \exp(BT)$, where A and B are curve-fit parameters [27]. Kole and Dey also showed good agreement with the model derived by Masoumi et al. [28] with regard to the viscosity dependence on the nanoparticle concentration. Considering the fact that the model Masoumi et al. derived is mainly based on the effects of Brownian diffusion on the nanofluid viscosity, this agreement might signify that Brownian motion plays a key role in the viscosity increase in nanofluids. A year later, Kole and Dey [29] reported similar results, but for 40-nm diameter spherical CuO nanoparticles in gear oil. Viscosity showed a strong dependence both on nanoparticle concentration and temperature between 10 and 80^0C. They reported an increase in viscosity of approximately 300% of the base fluid, for a CuO volume fraction of 0.025. However, viscosity decreased significantly with increasing temperature. The Newtonian nature of gear oils appeared to change to non-Newtonian with increase in nanoparticle loading, and shear thinning was observed for a CuO volume fraction above 0.005. CuO nanoparticles also appeared to aggregate into clusters with average size of about seven times the nanoparticle diameter. The modified Krieger and Dougherty model [30], derived by taking into account nanoparticle clustering, appeared to predict well the viscosity increase in the nanofluid. The temperature variation of the viscosity follows the modified Andrade equation [31].

The statistical analysis of viscosity trends in the literature conducted by Sergis and Hardalupas [32] shows that the viscosity of nanofluids increases with decreasing temperature, and increasing nanoparticle loading. In addition, there is a slight hint of an effective viscosity increase with decreasing nanoparticle size.

The significance of investigating the viscosity of nanofluids has been emphasized recently [29], but much more still needs to be done [33]. Viscosity is as critical as thermal conductivity in assessing adequate pumping power as well as the heat transfer coefficient in engineering systems with fluid flows [29]. In fact, Abu-Nada et al. [35] discussed the important correlation between viscosity and the Nusselt number. Higher nanoparticle volume fractions cause the fluid to become more viscous, attenuating the velocity, and resulting in a reduced convection. The reduction of velocity and convection will cause an increase of the thermal boundary layer thickness; thus reducing the temperature gradients, and lowering the Nusselt number. Abu-Nada et al. mentioned that most of the numerical studies in heat convection of nanofluids underestimate the effective viscosity of nanofluids, despite the fact that it plays a major role in their overall heat transfer behavior. For instance, Escher et al. [36] demonstrated that the relative thermal conductivity enhancement must be larger than the relative viscosity increase in order to gain any benefit in using nanofluids for electronic cooling.

2.2 Specific Heat

The specific heat for each nanofluid was measured in a Differential Scanning Calorimeter (DSC), model DSC1 (Mettler Toledo, USA). The calculation of the specific heat capacity is based in the DIN standard (DIN 51007), The sequence used in the determination was as follows: isotherm of 5 minutes at 25 ^{0}C, dynamic segment from 25ºC to 95ºC at heating rate of 10 ^{0}C/min and isotherm of 5 minutes at 95 ^{0}C.

Literature on experimental specific heats of nanofluids is very limited, In 2009, Namburu [37] reported that several ethylene glycolbased nanofluids exhibit lower specific heat than their respective base fluids. Similarly, Bergman [38] reported experimental evidences that a water-alumina nanofluid appeared to have enhanced thermal conductivity, but lower specific heat, relative to the base fluid. Vajjha and Das [39] studied nanofluids with 2–10% by volume of Al_2O_3, SiO_2, and ZnO nanoparticles in a 60:40 ethylene glycol-water mixture. They reported that the specific heat of all their nanofluids decreases substantially as the volumetric concentration of nanoparticles increases, and it increases moderately with temperature. Lower specific heat has also been reported in the numerical work of Puliti et al. [40]. In one case [63], no anomalous specific heat was observed, and classic theories were able to predict the nanofluid density and specific heat within a 10% deviation.

Conflicting results to the ones mentioned above, however, have also been reported. Nelson et al. [41] observed that the specific heat of polyalphaolefin is increased by 50% with a dispersion of exfoliated graphite nanoparticles at a concentration of 0.6% by weight. Similarly, Shin and Banerjee [42] reported a 26% enhancement of the specific heat of a molten salt (eutectic of 62% lithium carbonate and 38% potassium carbonate) with a suspension of silica nanoparticles at a concentration of 1% by weight. However, other contradictory results were reported by Zhou and Ni [43]; they observed that the specific heat of an alumina-water nanofluid decreased by 40–50% at a concentration of 21.7% by volume of nanoparticles. Shin and Banerjee [44] commented on the results by Zhou and Ni, pointing out that alumina nanoparticles tend to cluster, and the authors did not report if the nanoparticles were well dispersed.

In fact, agglomerated alumina nanoparticles tend to precipitate out of the water solution; consequently degrading the thermal properties of the nanofluid. More recently, Shin and Banerjee [45] reported a 14.5% enhancementin the specific heat of a chloride salt eutectic, using a dispersion of 1% by weight of silica nanoparticles (20–30 nm nominal diameter). In this case, the dispersion behavior of the nanoparticles wasconfirmed by scanning electron microscopy.

Shin and Banerjee [42] proposed three independent thermal transport mechanisms to explain the unusual enhancement of the specific heat they observed:

(1) Mode 1: the specific heat is enhanced due to higher specific surface energy of the surface atoms of the nanoparticles, as compared to the bulk material. The surface energy is higher because of the low vibration frequency and higher amplitudes of the vibrations at the surface of the nanoparticles.
(2) Mode 2: the enhancement of the specific heat can also be due to additional thermal storage mechanisms due to interfacial interactions between nanoparticles and the liquid molecules, which act as virtual spring-mass systems. This interfacial effect is present due to the extremely high specific surface area of the nanoparticles.
(3) Mode 3: a third mechanism potentially involved is liquid layering, already discussed earlier with regards to the thermal conductivity enhancement. Solidlike liquid layers adhering to the nanoparticles are more likely to have an enhanced specific heat due to a shorter intermolecular mean free path compared to the bulk fluid.

Because the specific heat is a key thermal property for many engineering applications, there is a great need for additional experimental results on this fundamental property for nanofluids [54].

2.3 Thermal Conductivity of Nanofluids

The thermal conductivity of all nanofluids was measured using a KD2 Pro conductimeter (Decagon Devices Inc.). The KD2 Pro is the commercial device that measures the thermal conductivity with the help of the transient hot wire technique. Nanofluids exhibit superior heat transfer characteristics to conventional heat transfer fluids. One of the reasons is that the suspended particles remarkably increase thermal conductivity of nanofluids. The thermal conductivity of nanofluid is strongly dependent on the nanoparticle volume fraction. So far it has been an unsolved problem to develop a sophisticated theory to predict thermal conductivity of nanofluids, although there exists some semiempirical correlation to calculate the apparent conductivity of two-phase mixture. On the basis of the following definition of the effective thermal conductivity for a two-component mixture

$$k_{eff} = \frac{k_p \alpha_p (dT/dx)p + k_f \alpha_f (dT/dx)f}{\alpha_p (dT/dx)p + \alpha_f (dT/dx)f}, \quad (1)$$

Hamilton and Crosser [105] proposed a model for liquid - solid mixtures in which the ratio of conductivity of two phases is larger than 100, i.e.,

$$\frac{k_{eff}}{k_f} = \frac{k_p + (n-1)k_f - (n-1)\alpha(k_f - k_p)}{k_p + (n-1)k_f + \alpha(k_f - k_p)}, \quad (2)$$

where k_p is the thermal conductivity of the discontinuous particle phase, k_f is the thermal conductivity of the fluid, n is the volume fraction of particles, and n is the empirical shape factor given by

$$n = \frac{3}{\varphi}, \quad (3)$$

where φ is the sphericity defined as the ratio of the surface area of a sphere with a volume equal to that of the particle to the surface area of the particle. Their experimental research showed satisfactory coincidence between the theoretical predictions and the experimental data for special particles in the range of volume fractions up to 30%. For particles of other shapes, the factor n can be allowed to vary from 0.5 to 6.0.

An alternative expression for calculating the e€ective thermal conductivity of solid - liquid mixtures was introduced by Wasp [46]

$$\frac{k_{eff}}{k_f} = \frac{k_p + 2k_f - 2\alpha\left(k_f - k_p\right)}{k_p + 2k_f + \alpha\left(k_f - k_p\right)}, \quad (4)$$

The volume fraction α of the particle defined as

$$\alpha = \frac{V_p}{V_f + V_p} = m \, \frac{\pi}{6} d^3{}_p, \quad (5)$$

Where m is the number of the particles per unit volume and dp is the average diameter of the particles. Comparison between Eqs. (2) and (4) reveals that Wasp's model is a special case with the sphericity 1.0 of the Hamilton and Crosser's model.

Both these formulas are applicable for the two-phase mixtures that contain powders with particle diameters on the order of micrometer or even millimeters. In the case of the absence of a suitable formula for predicting the thermal conductivity of nanofluids, the above-mentioned formulas may approximately be applied to obtain a rough estimation.

Applying the Hamilton and Crosser model to a wate - alumina nanoparticles suspension, the effective thermal conductivity k_{eff} is estimated for the values of φ from 0.3 to 1.0. The effects of particle volume fraction and sphericity on the thermal conductivity are shown in Fig.2. In addition, the calculated results are compared with the preliminary experimental results (Eastman et al., 1997) in Fig.2. For a given particle shape, the effective thermal conductivity of suspensions containing solid particles increases with the volume fraction of the solid particles.

If the sphericity of alumina nanoparticles is 0.3, a dramatic improvement in the thermal conductivity of nanofluids is expected with a factor 1.2 at the volume fraction 2% to a factor 1.5 at the volume fraction 5%. Besides, the effective thermal conductivity of suspensions can be increased by decreasing the sphericity of the particles under the condition of the same volume fraction. For the particle volume fraction 5%, the thermal conductivity of nanofluids can be enhanced with a factor 1.2 at the sphericity 1 to a factor 1.5 at the sphericity 0.3. The dimensions and properties of nanoparticles exert over whelming effects on the thermal conductivity of suspensions. These results predict that nanoparticles increase the thermal conductivity of conventional heat transfer fluids.

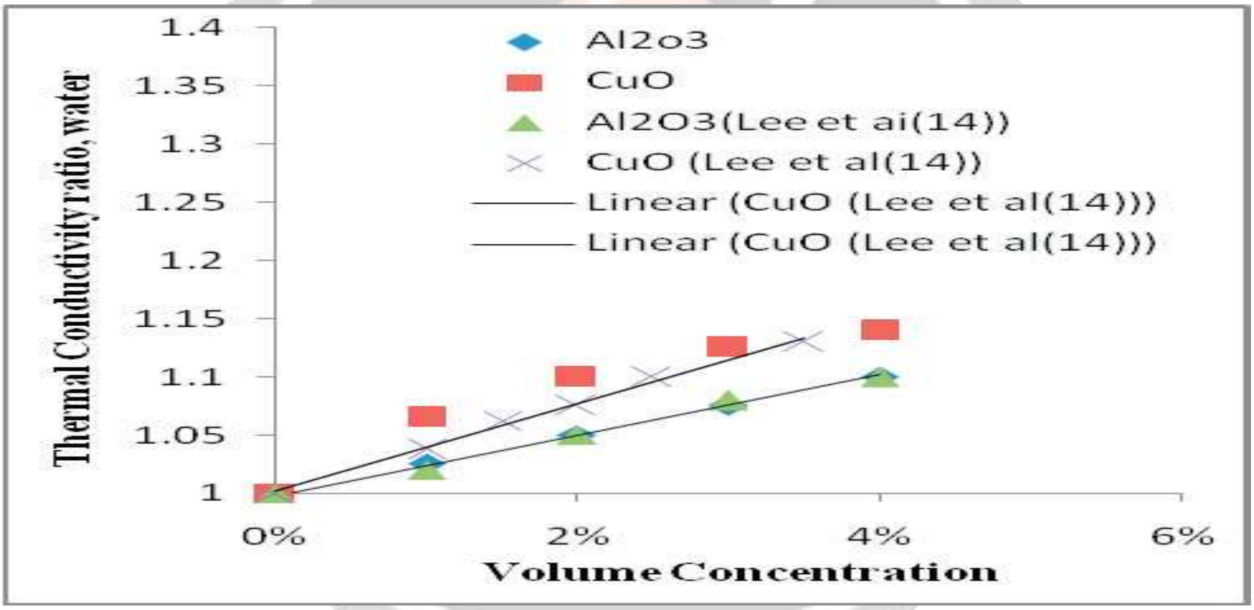

Fig 2: Thermal conductivity ratio of Cu – water nanofluid.

Table 1: Thermal conductivity of some materials, Base Fluids and Nanofluids.

	Materials	**Thermal Conductivity (W/mK)**
Mettalic Materials	Copper	401
	Silver	429
Nanometallic Materials	Silicon	148
	Aluminia (Al_2O_3)	40
Carbon	Carbon Nano Tubes	2000
Base fluids	Water	0.613

	Ethylene Glycol (EG)	0.253
	Engine Oil	0.145
Nanofluids (Nanoparticle concentration %)	Water/Al_2O_3 (1.50)	0.629
	EG/ Al_2O_3 (3.00)	0.278
	EG-Water/ Al_2O_3 (3.00)	0.382
	Water/TiO_2 (0.75)	0.682
	Water/CuO (1.00)	0.619

2.4 Stability of Nanofluids

The stability of the nanofluids was analysed through the evolution of the amount of light backscattered by the nanofluid from an incident laser beam. A Turbiscan Lab Expert (Formulaction SA, France) was used to carry out the tests. Measurements are based on the multiple light scattering theory. This equipment consists of a pulsed near-infrared light source and a detector that measures the light backscattered by the sample. For each nanofluid, the backscattering profiles were obtained along the height cell. To analyse the stability of nanofluids the measurements were carried out at different time intervals up to a total time of 48 hours.

Many methods have been developed to evaluate the stability of nanofluids. The simplest method is sedimentation method [48]. The sediment weight or the sediment volume of nanoparticles in a nanofluid under an external force field is an indication of the stability of the characterized nanofluid. The variation of concentration or particle size of supernatant particle with sediment time can be obtained by special apparatus [17]. The nanofluids are considered to be stable when the concentration or particle size of supernatant particles keeps constant. Sedimentation photograph of nanofluids in test tubes taken by a camera is also a usual method for observing the stability of nanofluids [17]. Zhu et al. used a sedimentation balance method to measure the stability of the graphite suspension [50]. The tray of sedimentation balance immerged in the fresh graphite suspension. The weight of sediment nanoparticles during a certain period was measured. The suspension fraction of graphite nanoparticles at a certain time could be calculated.

For the sedimentation method, long period for observation is the defect. Therefore, centrifugation method is developed to evaluate the stability of nanofluids. Singh et al. applied the centrifugation method to observe the stability of silver nanofluids prepared by the microwave synthesis in ethanol by reduction of $AgNO_3$ with PVP as stabilizing agent [51]. It has been found that the obtained nanofluids are stable for more than 1 month in the stationary state and more than 10 h under centrifugation at 3,000 rpm without sedimentation. Excellent stability of the obtained nanofluid is due to the protective role of PVP, as it retards the growth and agglomeration of nanoparticles by steric effect. Li prepared the aqueous polyaniline colloids and used the centrifugation method to evaluate the stability of the colloids [52]. Electrostatic repulsive forces between nanofibers enabled the long-term stability of the colloids.

3.METHODS FOR PREPARATION OF NANOFLUIDS

Preparation of nanofluids is the first key step in applying nanophase particles to changing the heat transfer performance of conventional fluids. The nanofluid does not simply refer to liquid - solid mixture. Some special requirements are necessary, such as even suspension, stable suspension, durable suspension, low agglomeration of particles, no chemical change of the fluid. In general, these are effective methods used for preparation of suspensions: (1) To change the pH value of suspensions; (2) To use surface activators and/or dispersants; (3) To use ultrasonic vibration. Generally we are using two types of Technique. The following Techniques are discussed below:

3.1 Two - Step Method

Two-step method is the most widely used method for preparing nanofluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method are first produced as dry powders by chemical or physical methods. Then, the nanosized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Two-step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled up to industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications.

Due to the difficulty in preparing stable nanofluids by two-step method, several advanced techniques are developed to produce nanofluids, including one-step method. In the following part, we will introduce one-step method in detail. The most common Two-Step preparation process is shown figure 3.

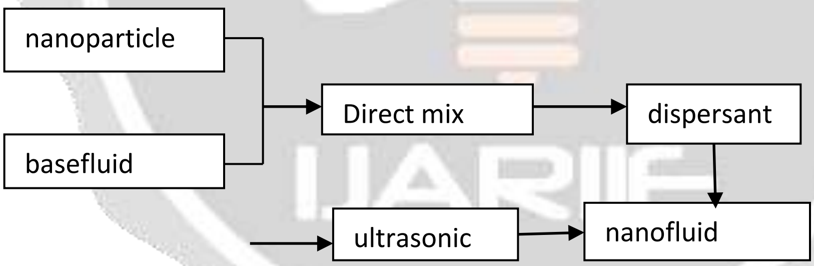

Fig 3: Two step preparation process of nanofluid

3.2 One – Step Method

To reduce the agglomeration of nanoparticles, Eastman et al. developed a one-step physical vapor condensation method to prepare Cu/ethylene glycol nanofluids [53]. The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method, the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized, and the stability of fluids is increased [17].

The one-step processes can prepare uniformly dispersed nanoparticles, and the particles can be stably suspended in the base fluid. The vacuum-SANSS (submerged arc nanoparticle synthesis system) is another efficient method to prepare nanofluids using different dielectric liquids [55]. The different morphologies are mainly influenced and determined by various thermal conductivity properties of the dielectric liquids. The nanoparticles prepared exhibit needle-like, polygonal, square, and circular morphological shapes. The method avoids the undesired particle aggregation fairly well.

One-step physical method cannot synthesize nanofluids in large scale, and the cost is also high, so the one-step chemical method is developing rapidly. Zhu et al. presented a novel one-step chemical method for preparing copper nanofluids by reducing $CuSO_4{\cdot}5H_2O$ with $NaH_2PO_2{\cdot}H_2O$ in ethylene glycol under microwave irradiation [56]. Well-dispersed and stably suspended copper nanofluids were obtained. Mineral oil-based nanofluids containing silver nanoparticles with a narrow-size distribution were also prepared by this method. The particles could be stabilized by Korantin, which coordinated to the silver particle surfaces via two oxygen atoms forming a dense layer around the particles.

The silver nanoparticle suspensions were stable for about 1 month. Stable ethanol-based nanofluids containing silver nanoparticles could be prepared by microwave-assisted one-step method. In the method, poly vinyl pyrrolidone (PVP) was employed as the stabilizer of colloidal silver and reducing agent for silver in solution. The cationic surfactant octade cylamine (ODA) is also an efficient phase-transfer agent to synthesize silver colloids [57]. The phase transfer of the silver nanoparticles arises due to coupling of the silver nanoparticles with the ODA molecules present in organic phase via either coordination bond formation or weak covalent interaction.

3.3 Other Novel Methods

Wei et al. developed a continuous-flow microfluidic microreactor to synthesize copper nanofluids. By this method, copper nanofluids can be continuously synthesized, and their microstructure and properties can be varied by adjusting parameters such as reactant concentration, flow rate, and additive. CuO nanofluids with high solid volume fraction (up to 10 vol%) can be synthesized through a novel precursor transformation method with the help of ultrasonic and microwave irradiation [58]. The precursor $Cu(OH)_2$ is completely transformed to CuO nanoparticle in water under microwave irradiation. The ammonium citrate prevents the growth and aggregation of nanoparticles, resulting in a stable CuO aqueous nanofluid with higher thermal conductivity than those prepared by other dispersing methods.

Phase-transfer method is also a facile way to obtain monodisperse noble metal colloids [59]. In a water-cyclohexane two-phase system, aqueous formaldehyde is transferred to cyclohexane phase via reaction with dodecylamine to form reductive intermediates in cyclohexane. The intermediates are capable of reducing silver or gold ions in aqueous solution to form dodecylamine-protected silver and gold nanoparticles in cyclohexane solution at room temperature. Feng et al. used the aqueous organic phase-transfer method for preparing gold, silver, and platinum nanoparticles on the basis of the decrease of the PVP's solubility in water with the temperature increase [60].

Phase-transfer method is also applied for preparing stable kerosene-based Fe_3O_4 nanofluids. Oleic acid is successfully grafted onto the surface of Fe_3O_4 nanoparticles by chemisorbed mode, which lets Fe_3O_4 nanoparticles have good compatibility with kerosene. The Fe_3O_4 nanofluids prepared by phase-transfer method do not show the previously reported "time dependence of the thermal conductivity characteristic". The preparation of nanofluids with controllable microstructure is one of the key issues. It is well known that the properties of nanofluids strongly depend on the structure and shape of nanomaterials.

The recent research shows that nanofluids synthesized by chemical solution method have both higher conductivity enhancement and better stability than those produced by the other methods [61]. This method is distinguished from the others by its controllability. The nanofluid microstructure can be varied and manipulated by adjusting synthesis parameters such as temperature, acidity, ultrasonic and microwave irradiation, types and concentrations of reactants and additives, and the order in which the additives are added to the solution.

4. ADVANTAGES OF NANOFLUIDS

The following Advantages are posses using of Nanofluids, which makes them suitable for various applications.

1. Absorption of solar energy will be maximized with change of the size, shape, material and volume fraction of the nanoparticles.
2. The suspended nanoparticles increase the surface area and the heat capacity of the fluid due to the very small particle size.
3. The suspended Nanoparticles enhance the thermal conductivity which results improvement in 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 environment.
5. The mixing fluctuation and turbulence of the fluid are intensified.
6. The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.
7. To make suitable for different applications, properties of fluid can be changed by varying concentration of nanoparticles.
8. Nanofluids increase the Temperature of Solar Thermal Applcations.

5. APPLICATIONS OF NANOFLUIDS

Nanofluids can be used in broad range of engineering applications due to their improved heat transfer and energy efficiency in a variety of thermal systems.

5.1 Heat Transfer Intesification

Since the origination of the nanofluid concept about a decade ago, the potentials of nanofluids 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 nanofluids [62], including preparation and characterization, techniques for the measurements of thermal conductivity, theory and model, thermophysical properties, and convective heat transfer.

5.1.1 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 and Choi designed a new cooler, combined microchannel heat sink with nanofluids [64].

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 ultrahigh 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 Al_2O_3 nanoparticles at various concentrations [49].

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 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. Silicon microchannel heat sink performance using nanofluids containing Cu nanoparticles was analyzed [65]. It was found that nanofluids could enhance the performance as compared with that using pure water as the coolant. The enhancement was due to the increase in thermal conductivity of coolant and the nanoparticle thermal dispersion effect. The other advantage was that there was no extra pressure drop, since the nanoparticle was small, and particle volume fraction was low.

5.1.2 Transportation

Nanofluids have great potentials to improve automotive and heavy-duty engine cooling rates by increasing the efficiency, lowering the weight and reducing the complexity of thermal management systems. The improved cooling rates for automotive and truck engines can be used to remove more heat from higher horsepower engines with the same size of cooling system. Alternatively, it is beneficial to design more compact cooling system with smaller and lighter radiators. It is, in turn, beneficial the high performance and high fuel economy of car and truck. Ethylene glycol-based nanofluids have attracted much attention in the application as engine coolant [66] 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.

The nanofluids has a high boiling point, and it can be used to increase the normal coolant operating temperature and then reject more heat through the existing coolant system [67]. Kole et al. prepared car engine coolant (Al_2O_3 nanofluid) using a standard car engine coolant (HP KOOLGARD) as the base fluid [60] and studied the thermal conductivity and viscosity of the coolant. The prepared nanofluid, containing only 3.5% volume fraction of Al_2O_3 nanoparticles, displayed a fairly higher thermal conductivity than the base fluid, and a maximum enhancement of 10.41% was observed at room temperature. Tzeng et al. [68] applied nanofluids to the cooling of automatic transmissions. The experimental platform was the transmission of a four-wheel drive vehicle. The used nanofluids were prepared by dispersing CuO and Al_2O_3 nanoparticles into engine transmission oil. The results showed that CuO nanofluids produced the lower transmission temperatures both at high and low rotating speeds. From the thermal performance viewpoint, the use of nanofluid in the transmission has a clear advantage.

5.1.3 Industrial Cooling Applications

The application of nanofluids in industrial cooling will result in great energy savings and emissions reductions. For US industry, the replacement of cooling and heating water with nanofluids has the potential to conserve 1 trillion Btu of energy [69]. For the US electric power industry, using nanofluids 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 [70].

Experiments were performed using a flow-loop apparatus to explore the performance of polyalphaolefin nanofluids containing exfoliated graphite nanoparticle fibers in cooling [66]. 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.

5.1.4 Heating Building and Reducing Pollution

Nanofluids can be applied in the building heating systems. Kulkarni et al. evaluated how they perform heating buildings in cold regions [71]. 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.

5.1.5 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. [69] and Vassalo et al. [72] 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/m^2. 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.

5.2 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 NH_3/H_2O absorption system [71]. The addition of nanoparticles enhances the absorption performance up to 3.21 times. Then, they visualized the bubble behavior during the NH_3/H_2O absorption process and studied the effect of nanoparticles and surfactants on the absorption characteristics [73]. 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 thermodiffusion and diffusionthermo on convective instabilities in binary nanofluids for absorption application were conducted. Mass diffusion is induced by thermal gradient. Diffusionthermo implies that heat transfer is induced by concentration gradient [73]. Ma et al. studied the mass transfer process of absorption using CNTs-ammonia nanofluids as the working medium [74].

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.

5.3 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, another is the absorption properties of nanofluids.

5.3.1 Energy Storage

The 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 [75]. Latent heat storage is one of the most efficient ways of storing thermal energy. Wu et al. evaluated the potential of Al_2O_3-H_2O nanofluids as a new phase change material (PCM) for the thermal energy storage of cooling systems. The thermal response test showed the addition of Al_2O_3 nanoparticles remarkably decreased the supercooling degree of water, advanced the beginning freezing time, and reduced the total freezing time. Only adding 0.2 wt% Al_2O_3 nanoparticles, the total freezing time of Al_2O_3-H_2O 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 TiO_2 nanoparticles in saturated $BaCl_2$ aqueous solution [76].

5.3.2 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) [77].

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. Theoretical investigation on the feasibility of using a nonconcentrating direct absorption solar collector showed that the presence of nanoparticles increased the absorption of incident radiation by more than nine times over that of pure water [78]. Under the similar operating conditions, the efficiency of an absorption solar collector using nanofluid as the working fluid was found to be up to 10% higher (on an absolute basis) than that of a flat-plate collector.

5.4 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.

5.4.1 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 [79]. Dispersion of solid particles was found to play an important role, especially when a slurry layer was formed.

Water-based Al_2O_3 and diamond nanofluids were applied in the minimum quantity lubrication (MQL) grinding process of cast iron. During the nanofluid MQL grinding, a dense and hard slurry layer was formed on the wheel surface and could benefit the grinding performance. Nanofluids showed the benefits of reducing grinding forces, improving surface roughness, and preventing workpiece burning. Compared to dry grinding, MQL grinding could significantly reduce the grinding temperature [81]. Wear and friction properties of surface modified Cu nanoparticles, as 50CC oil additive were studied.

The higher the oil temperature applied, the better the tribological properties of Cu nanoparticles were. It could be inferred that a thin copper protective film with lower elastic modulus and hardness was formed on the worn surface, which resulted in the good tribological performances of Cu nanoparticles, especially when the oil temperature was higher [80].

5.4.2 Magnetic Sealing

Magnetic fluids (ferromagnetic fluid) are kinds of special nanofluids. They are stable colloidal suspensions of small magnetic particles such as magnetite (Fe_3O_4). 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 nonpolar and polar carrier liquids [82]. 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 [83].

A ring magnet forms part of a magnetic circuit in which an intense magnetic field is established in the gaps between the teeth on a magnetically permeable shaft and the surface of an opposing pole block. Ferrofluid introduced into the gaps forms discrete liquid rings capable of supporting a pressure difference while maintaining zero leakage. The seals operate without wear as the shaft rotates, because the mechanical moving parts do not touch. With these unique characteristics, sealing liquids with magnetic fluids can be applied in many application areas. It is reported that an iron particle dispersed magnetic fluids was utilized in the sealing of a high-rotation pump. The sealing holds pressure of 618 kPa with a 1800 r/min [84].

5.5 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.

5.5.1 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 [85]. Electrochemical measurements suggest some direct interaction between ZnO nanoparticles and the bacteria membrane at high ZnO concentrations. Jalal et al. prepared ZnO nanoparticles via a green method. The antibacterial activity of suspensions of ZnO nanoparticles against Escherichia coli (E. coli) has been evaluated by estimating the reduction ratio of the bacteria treated with ZnO. Survival ratio of bacteria decreases with increasing the concentrations of ZnO nanofluids and time [86].

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 [87]. Recent research showed that ZnO nanoparticles exhibited impressive antibacterial properties against an important foodborne pathogen, E. coli O157 : H7, and the inhibitory effects increased as the concentrations of ZnO nanoparticles increased. ZnO nanoparticles changed the cell membrane components including lipids and proteins. ZnO nanoparticles could distort bacterial cell membrane, leading to loss of intracellular components, and ultimately the death of cells, considered as an effective antibacterial agent for protecting agricultural and food safety [88].

5.5.2 Nanodrug 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 [89]. The small-size, customized surface improved solubility, and multifunctionality of nanoparticles opens many doors and creates new biomedical applications. The novel properties of nanoparticles offer the ability to interact with complex cellular functions in new ways [90]. Gold nanoparticles provide nontoxic 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.

Another attractive feature of gold nanoparticles is their interaction with thiols, providing an effective and selective means of controlled intracellular release [91]. Nakano et al. proposed the drug-delivery system using nanomagnetic fluid [92], which targeted and concentrated drugs using a ferrofluid cluster composed of magnetic nanoparticles. The potential of magnetic nanoparticles stems from the intrinsic properties of their magnetic cores combined with their drug-loading capability and the biochemical properties that can be bestowed on them by means of a suitable coating. CNT has emerged as a new alternative and efficient tool for transporting and translocating therapeutic molecules. CNT can be functionalised with bioactive peptides, proteins, nucleic acids, and drugs and used to deliver their cargos to cells and organs. Because functionalised CNT display low toxicity and are not immunogenic, such systems hold great potential in the field of nanobiotechnology and nanomedicine [49]. Pastorin et al. have developed a novel strategy for the functionalisation of CNTs with two different molecules using the 1,3-dipolar cycloaddition of azomethine ylides [93].

The attachment of molecules that will target specific receptors on tumour cells will help improve the response to anticancer agents. Liu et al. have found that prefunctionalized CNTs can adsorb widely used aromatic molecules by simple mixing, forming “forest-scrub”-like assemblies on CNTs with PEG extending into water to impart solubility and aromatic molecules densely populating CNT sidewalls. The work establishes a novel, easy-to-make formulation of a SWNT-doxorubicin complex with extremely high drug loading efficiency [94].

5.6 Other Applications

5.6.1 Intensify Microreactors

The discovery of high enhancement of heat transfer in nanofluids can be applicable to the area of process intensification of chemical reactors through integration of the functionalities of reaction and heat transfer in compact multifunctional reactors. Fan et al. studied a nanofluid based on benign TiO_2 material dispersed in ethylene glycol in an integrated reactor-heat exchanger [95]. The overall heat transfer coefficient increase was up to 35% in the steady state continuous experiments. This resulted in a closer temperature control in the reaction of selective reduction of an aromatic aldehyde by molecular hydrogen and very rapid change in the temperature of reaction under dynamic reaction control.

5.6.2 Nanofluids as Vehicle Brake Fluids

A vehicle's kinetic energy is dispersed through the heat produced during the process of braking and this is transmitted throughout the brake fluid in the hydraulic braking system [41], and now, there is a higher demand for the properties of brake oils. Copper-oxide and aluminum-oxide based brake nanofluids were manufactured using the arc-submerged nanoparticle synthesis system and the plasma charging arc system, respectively [87]. The two kinds of nanofluids both have enhanced properties such as a higher boiling point, higher viscosity, and a higher conductivity than that of traditional brake fluid. By yielding a higher boiling point, conductivity, and viscosity, the nanofluid brake oil will reduce the occurrence of vapor-lock and offer increased safety while driving.

5.6.3 Nanofluids – Based Microbial Fuel Cell

Microbial fuel cells (MFC) that utilize the energy found in carbohydrates, proteins, and other energy-rich natural products to generate electrical power have a promising future. The excellent performance of MFC depends on electrodes and electron mediator. Sharma et al. constructed a novel microbial fuel cell (MFC) using novel electron mediators and CNT-based electrodes [62]. The novel mediators are nanofluids which were prepared by dispersing nanocrystalline platinum anchored CNTs in water. They compared the performance of the new E.coli-based MFC to the previously reported E.coli-based microbial fuel cells with neutral red and methylene blue electron mediators. The performance of the MFC using CNT-based nanofluids and CNT-based electrodes has been compared against plain graphite electrode-based MFC. CNT-based electrodes showed as high as ~6-fold increase in the power density compared to graphite electrodes.

6. LIMITATIONS OF NANOFLUIDS

The development in the area of nanofluid application is hindered by many factors in which long term stability of nanofluid in suspension is major reason. Nanofluids possess the following Disadvantages are,

6.1 Poor long term stability of suspension

Long term physical and chemical stability of nanofluids is an important practical issue because of aggregation of nanoparticles due to very strong vander walls interactions so the suspension is not homogeneous. Physical or chemical methods have been applied to get stable nanofluids such as (i) an addition of surfactant; (ii) surface modification of the suspended particles; (iii) applying strong force on the clusters of the suspended particles. Lee and Choi [45] found that Al_2O_3 nanofluids kept after 30 days exhibit some settlement compared to fresh nanofluids. Particles settling must be examined carefully since it may lead to clogging of coolant passages.

6.2 Increased pressure drop and pumping power

Pressure drop development and required pumping power during the flow of coolant determines the efficiency of nanofluid application. It is known that higher density and viscosity leads to higher pressure drop and pumping power. There are many studies showing significant increase of nanofluids pressure drop compared to base fluid. One of the experimental study by Choi (2009) calculated 40% increase of pumping power compared to water for a given flow rate.

6.3 Lower Specific heat

An ideal heat transfer fluid should possess higher value of specific heat so the fluid can exchange more heat. Previous studies show that nanofluids exhibit lower specific heat than base fluid. It limits the use of nanofluid application.

6.4 High cost of nanofluids

Nanofluids are prepared by either one step or two step methods. Both methods require advanced and sophisticated equipments. This leads to higher production cost of nanofluids. Therefore high cost of nanofluids is drawback of nanofluid applications.

CONCLUSION

This paper presents overview about nanofluid, including the preparation methods, properties, the evaluation methods for their stability, and their potential applications in heat transfer intensification, mass transfer enhancement, energy fields, mechanical fields, biomedical fields and so forth. Nanofluid stability and its production cost are major factors in using nanofluids. So that they may be applied as more efficient and compact heat transfer systems, maintaining cleaner and healthier environment and unique applications.

Although nanofluids have displayed enormously exciting potential applications, some vital hinders also exist before commercialization of nanofluids. The following key issues should receive greater attention in the future. Firstly, further experimental and theoretical research is required to find the major factors influencing the performance of nanofluids. Up to now, there is a lack of agreement between experimental results from different groups, so it is important to systematically identify these factors. The detailed and accurate structure characterizations of the suspensions may be the key to explain the discrepancy in the experimental data.

Secondly, increase in viscosity by the use of nanofluids is an important drawback due to the associated increase in pumping power. The applications for nanofluids with low viscosity and high conductivity are promising. Enhancing the compatibility between nanomaterials and the base fluids through modifying the interface properties of two phases may be one of the solution routes.

Thirdly, the shape of the additives in nanofluids is very important for the properties; therefore, the new nanofluid synthesis approaches with controllable microscope structure will be an interesting research work.

Fourthly, stability of the suspension is a crucial issue for both scientific research and practical applications. The stability of nanofluids, especially the long-term stability, the stability in the practical conditions, and the stability after thousands of thermal cycles should be paid more attention.

Fifthly, there is a lack of investigation of the thermal performance of nanofluids at high temperatures, which may widen the possible application areas of nanofluids, like in high-temperature solar energy absorption and high-temperature energy storage. At the same time, high temperature may accelerate the degradation of the surfactants used as dispersants in nanofluids and may produce more foams. These factors should be taken into account.

Finally, the properties of nanofluids strongly depend on the shape and property of the additive. Nanofluids are very complex fluids, but with an extremely vast range of applications in every field of science and engineering. Even though many heat transfer mechanisms has explained, still the usage of nano fluid in practical application is critical because of sedimentation formation and clogging in flow path.

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