Preparation Techniques for Nanofluids

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ABSTRACT

Nanofluids belong to new class of fluids with enhanced Thermophysical properties and heat transfer performance. In present days, nano material occupies the major area in engineering field. Nanofluid is an environmental friendly and also provides better efficiency than the fluids using currently. Nanofluid is a colloidal mixture of nano sized particles in a base fluid to enhance the heat transfer characterstics suited for practical applications. This paper presents procedure for preparing a nanofluid which is a suspension consisting of nanophase powders and a base liquid and Mathematiclal expression for the nanofluid properties. The nanofluid shows great potential in enhancing the heat transfer process. One reason is that the suspended ultra-fine particles remarkably increase the thermal conductivity of the nanofuid. The nanofluids are efficiently used in different applications. Nanofluids increase the Absorption of solar enegy will be maximized with change of the size, shape, material and volume fraction of the nanoparticles.

Keywords: Nanoparticles, base fluids, nanophase powders, Thermal Conductivity, Properties.

1.Introduction

Nanofluids are colloidal suspensions, i.e., a fine dispersion of nano-sized solid particles in a liquid. Before the advent of nanotechnology, the study of colloidal suspensions with micron-sized particles was quite common, but their size posed significant corrosion and erosion hazards in engineering applications. When the manufacture of nano-sized particles became possible, it was noticed that, unlike micron-sized particles, nano-suspensions could form stable systems with very little settling under static conditions. Most importantly, recently conducted experiments have indicated that nanofluids tend to have substantially higher thermal conductivity than the base fluids [1].

Low thermal conductivity of process fluid hinders high compactness and effectiveness of heat exchangers, although a variety of techniques is applied to enhance heat transfer. Improvement of the thermal properties of energy transmission fluids may become a trick of augmenting heat transfer. An innovative way of improving the thermal conductivities of fluids is to suspend small solid particles in the fluids. Various types of powders such as metallic, non-metallic and polymeric particles can be added into fluids to form slurries. The thermal conductivities of fluids with suspended particles are expected to be higher than that of common fluids. An industrial application test was carried out by Liu et al. and Ahuja [2,3], in which the effect of particle volumetric loading, size, and flow rate on the slurry pressure drop and heat transfer behavior was investigated. In conventional cases, the suspended particles are of l m or even mm dimensions. Such large particles may cause some severe problems such as abrasion and clogging. Therefore, fluids with suspended large particles have little practical application in heat transfer enhancement [22].

Though attempts have been made to explain the physical reasons for such enhancement in nanofluids, there are still many conspicuous inconsistencies [4]. There are at least four reasons why a definitive theory on nanofluids still does not exist [5,6]:

- The thermal behavior is too different from solid-solid composites, or standard solid-liquid suspensions. Just to mention an example, the thermal conductivity of solid-solid composites is reduced when the grain size of a solid constituent gets smaller. However, the thermal conductivity of nanofluids goes up, as the nanoparticle size is reduced.
- The thermal transport in nanofluids, besides being surprisingly efficient compared to standard solid-liquid suspensions, depends on nontraditional variables, such as particle size, shape, and surface treatment.
- The understanding of the physics behind nanofluids requires a multidisciplinary approach: it involves aspects from the fields of material science, colloidal science, physics, chemistry, and engineering. Developing a theory that requires such a diverse knowledge, can be very challenging.
- Probably the most daunting difficulty is related to multiscale issues. In fact, nanofluids involve at least four scales: the molecular scale, the microscale, the mesoscale, and the macroscale. The molecular scale is characterized by the mean free path between molecular collisions, the microscale by the smallest scale at which continuum theories still apply, the mesoscale by the smallest scale that can describe a set of averaged properties of interest, the macroscale by the length scale proper of the domain of interest [6].

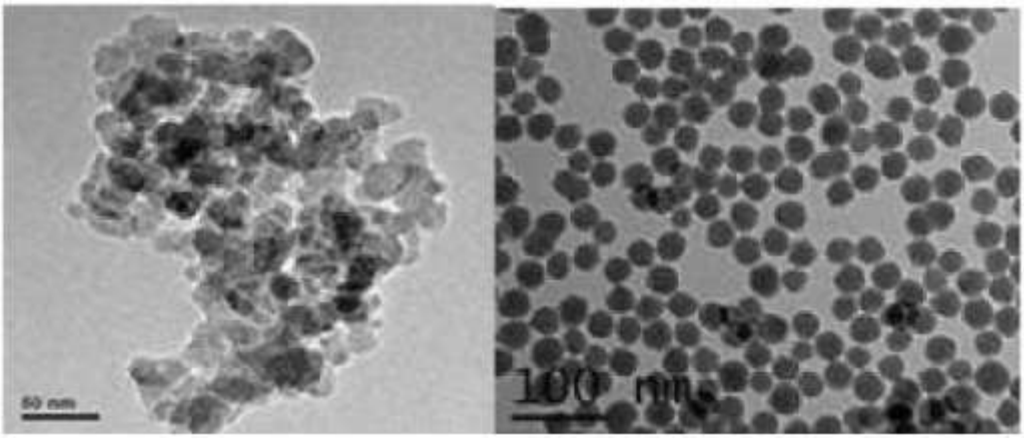


Fig 1: Schematic cross section of nanofluid structure.

Three possible approaches have been pursued for the study of nanofluids: experimental, empirical and numerical. While the number of experimental works has been constantly increasing since 1993, very few works have been published on empirical or numerical studies of nanofluids [5]. The current lack of understanding of the basic mechanism of energy transport at the nanoscale makes the published empirical works on nanofluids. In particular, two of these works use MD with a simple Lennard–Jones (LJ) potential to study a solid copper particle in liquid argon. No experiment with such materials is available; thus validating the results is impossible. Furthermore, such a simple potential is incapable of capturing surface effects (liquid layering, particle clustering, etc.) properly for polar fluids, such as water, which has been used extensively in experimental studies.

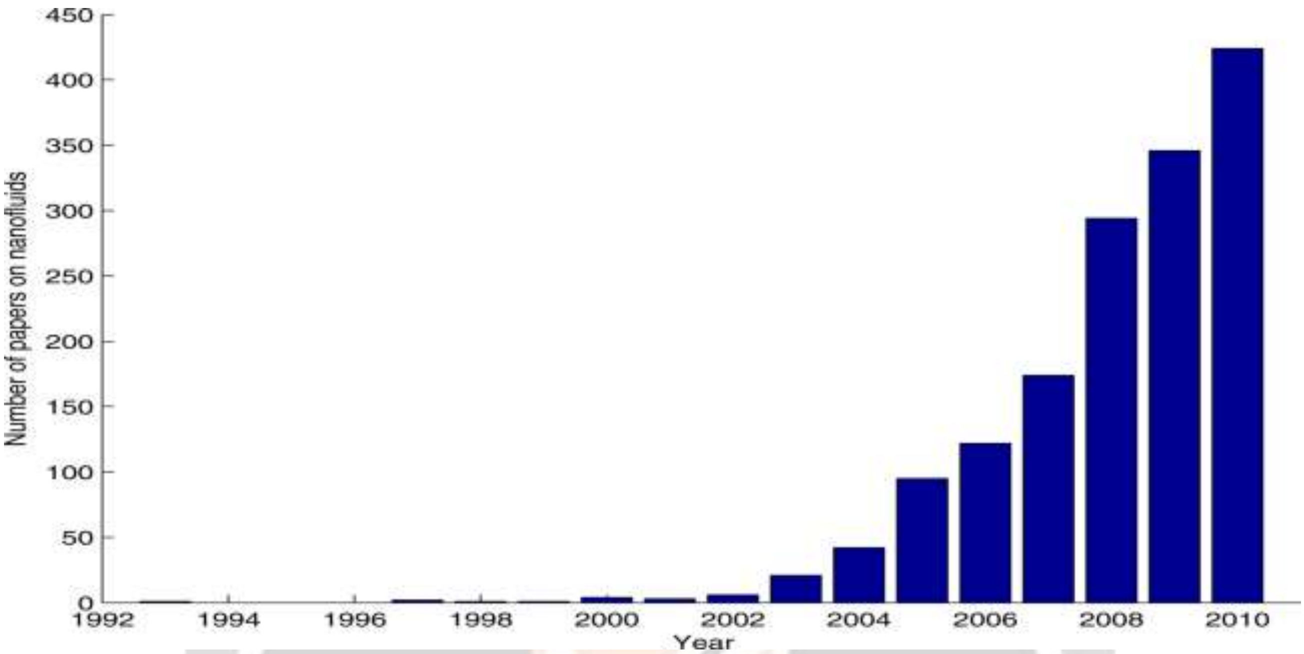


Fig 2: Growth of publications on nanofluids. (Data:ISI Web of Knowledge).

Figure 2 shows the rapid growth of the number of papers on nanofluids since 1993 worldwide. The potential market for nanofluids in heat transfer applications is estimated to be over 2 x 10^9 dollars per year, likely to grow even further in the next 5–10 yrs [7].

2. Preparation Technique for Nanofluids

To prepare nanofluids by suspending nanoparticles into base fluids, some special requirements are necessary such as even suspension, durable and stable suspension, low agglomeration of particles and no chemical change of fluid. There are three general methods used for preparation of stable nanofluid: (1) Addition of acid or base to Change the pH value of suspension (2) Adding surface active agents and/or dispersants to disperse particles into fluid (3) Using ultrasonic vibration.

Preparation of nanofluids presents several challenges, both technical and financial. The main technical difficulty is in the production of an homogeneous suspension of nanoparticles, mostly because the particles always tend to aggregate due to the strong vander Waals interactions [7,8]. To obtain a stable nanofluid physical and chemical modifications of experiments are necessary. This involves the addition of surfactants to the fluid (such as SDBS), special coatings to the nanoparticles (such as citrate on gold), or physically applying some disturbance to the clusters. Among these physical techniques, ultrasonic vibration mixing is the most common [9].

However, the duration and the intensity of the vibrations will affect the quality of the dispersion of nanoparticles. Furthermore, clusters start forming again immediately after the ultrasonic vibrations are stopped. [10]. This means that the same nanofluid sample can give different experimental results depending on how much time passes between the sonication and the measurements [9]. Unfortunately, the stability of nanofluids is a necessary condition for their applicability to engineering applications (e.g., to avoid clogging of passages) and; furthermore, the better dispersion behavior, the higher thermal conductivity enhancement of the nanofluid [11].

Besides aggregation, nanoparticle deposition is the next challenge. As reported by Eastman et al. [12], the thermal conductivity of ethylene glycol-based nanofluids with a suspension of 0.3% by volume of copper nanoparticles decreased slightly with time over an interval of two months.

The most obvious explanation for this finding is in the loss of stability of the dispersion over time. Lee and Mudawar [13] did a visual study of the stability of Al_2O_3 nanoparticles over a one-month period, and reported some settlement and a concentration gradient happening over time. Unfortunately, the usage of surfactants or other chemical and physical treatments of the nanofluids might not be the best solution towards the production of stable nanoparticle suspensions. In fact, it has been reported [14,25&26] at least once that an excessive usage of surfactant can have harmful effects on the viscosity, thermal properties, and on the chemical and physical stability of the nanofluid.

Another difficulty in the production of nanofluids involves their poor characterization. The manufacture of nanofluids can take place either through a one-step or a two-step method: the one-step method simultaneously produces and disperses nanoparticles into the base fluids, while the two-step method disperses previously manufactured nanoparticles in a base fluid.

No matter which one of these two methods is employed, the production of nanoparticles inherently involves reduction reactions or ion exchange. Ions and other reactions products are then dispersed in the fluid together with the nanoparticles, since they are almost impossible to separate from their surrounding [7]. Furthermore, a recent numerical investigation [15] showed that the effective thermal conductivity of nanofluids is strongly affected by the presence of different sized nanoparticles in the fluid.

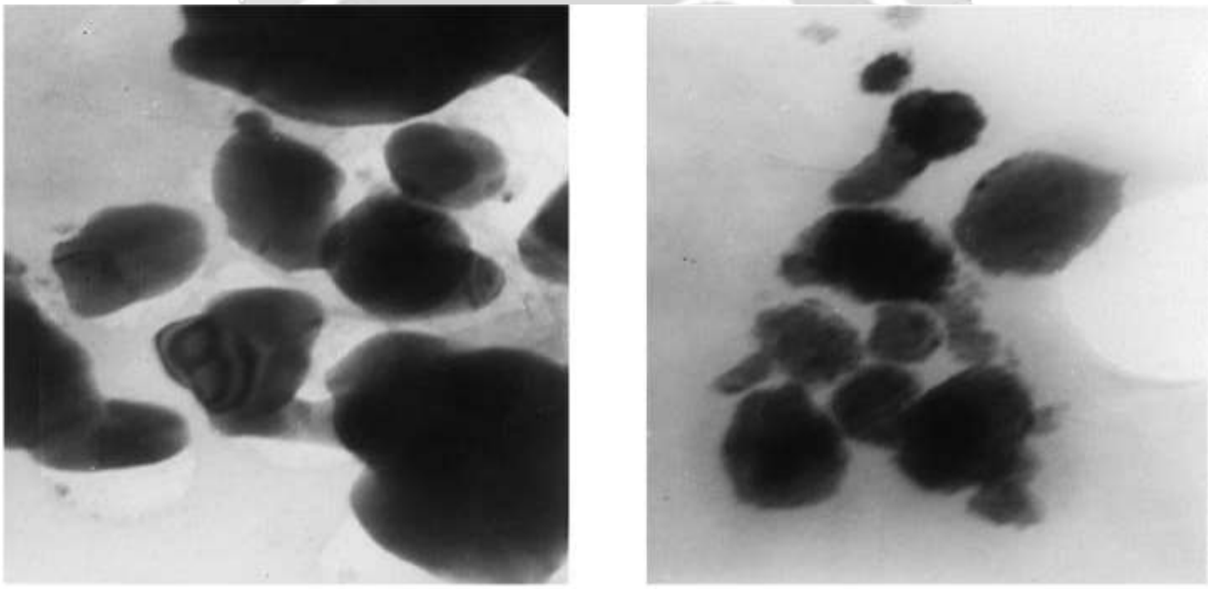
Table 1: Preparation methods of different nanofluids.

S.No	Nanofluid	Method	Surfactant	Stability	Reference
1.	Al_2O_3- Water	Two – Step	No	24h	Eastman et al (1997)
2.	TiO_2- Water	Two – Step	Oleic Acid and CTAB		Murshed et al (2010)
3.	Cu- Water	Two – Step	Laurate salt	30h	Xuan and Li (2000)
4.	MWCNT- Water	Two – Step	SDS		Hong et al (2000)
5.	Ag- Water	Two – Step	No	24h	Godson et al (2005)

While preparing the suspensions, different types and percentages of activators or dispersants have been tried and tested.

Example 1: (Transformer oil - Cu nanoparticles suspension). Cu nanoparticles are mixed with the transformer oil by 2 and 5 vol%, respectively. To stabilize the suspension, oleic acid is selected as the dispersant to cover the nanoparticles. The amount of mixed oleic acid is calculated with weight percentage of Cu particles. Several percentages of oleic acid have been tested.

The suspension is vibrated for 10 h in a ultrasonic vibrator. The experimental results show [18] that in the case that the percentage of oleic acid amounts to 22 wt% of the particles, the stabilization of the suspension can last about 1 week in the stationary state and no sediment is found. The distribution and cluster of the ultra - fine copper particles have been examined by a HITACHI H-8 electron microscope.



(a) (b)

Fig 3: TEM micrographs of nano Cu particles –transformer oil at pH = 6.3. (a) 2 vol% suspension (scale times: 100,000). (b) 5 vol% suspension (scale times: 100,000).

Fig. 3 gives TEM photographs of the suspension of transformer oil - Cu nanoparticles. The electron micrographs show that the particles are dispersed in the fluid and some clustering occurs [19,27].

Example 2 (Water -Cu nanoparticles suspension). The suspension contains 5 vol% Cu nanoparticles. The laurate salt is used to enhance stability of the suspension. Several percentages of the laurate salt (2, 4, 6, 8, 9 wt% via the particle) have been tested. The best case corresponds to the percentage of 9 wt%, which means that 9 wt% may be the minimum value for forming a stabile water - Cu particle suspension in this case. After the suspension has been vibrated in a ultrasonic vibrator, the stabile suspension [20] can last more than 30 h in the stationary state. Fig. 4 gives TEM photographs of the suspension of water - Cu nanoparticles. Both these micrographs show that the particles are dispersed in deionized water and some clustering occurs.

Comparison between Figs. 3 and 4 observation of the suspensions reveal that with respect to dispersion behavior and stability, the suspension of Cu particles in transformer oil has superior characteristics to the suspension of Cu particles in water. This explains that the viscosity of fluids may be an important factor affecting the dispersion of ultra-fine particles and the stability of suspensions. The properties of activators and dispersants also play a role in preparing the suspensions [21,28 &29].

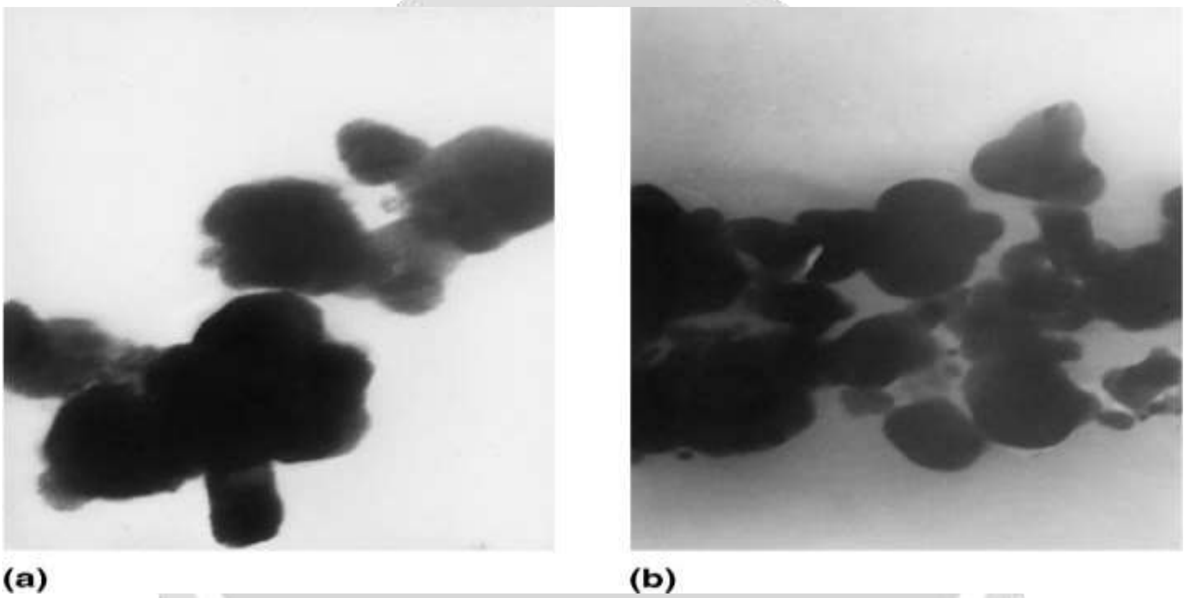


Fig 4: TEM micrographs of nano Cu particles –deionized water at pH = 6.8. (a) 5 vol% suspension (scale times: 50,000). (b) 7.5 vol% suspension (scale times: 30,000).

3. Mathematical Expression for Nanofluid Properties

The Properties of the nanofluids are play a very important role in increase of heat transfer phenomena. The Properties of the Nanofluids are density, viscosity, specific heat and thermal conductivity [24,30]. The Mathematical correlations for these properties are expressed below:

$$\mu_{nf} = \mu_f(1 + 2.5\varphi) \tag{1}$$

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s \tag{2}$$

$$\beta_{nf} = ((1-\varphi)\rho_f\beta_f + \varphi\rho_s\beta_s)/\rho_{nf} \tag{3}$$

$$C_{nf} = \frac{(1-\varphi)\rho_f c_f + \varphi\rho_s c_s}{\rho_{nf}} \tag{4}$$

$$K_{nf} = k_f(k_s + 2k_f - 2\varphi(k_f - k_s)/(k_s + 2k_f + \varphi(k_f - k_s) \quad (5)$$

Where;

ρ_{nf} represents the density of the nanofluid.
φ is the volume fraction of the nanoparticles suspended in base fluid
ρ_f is the density of the base fluid
ρ_s is the density of the nanoparticle.
μ_{nf} is the viscosity of the nanofluid
μ_f is the viscosity of the base fluid.
β_{nf} is the coefficient of volume expansion of the nanofluid
β_f is the coefficient of volume expansion of the base fluid
β_s is the coefficient of volume expansion of the nanoparticle
C_{nf} is the specific heat capacity of nanofluid at constant pressure
c_f is the specific heat capacity of base fluid at constant pressure
c_s is the specific heat capacity of nanoparticle at constant pressure
K_{nf} is the thermal conductivity of the nanofluid
k_f is the thermal conductivity of the base fluid
k_s is the thermal conductivity of the nanoparticle
The values of the properties have been adopted from literature [16,17&23].

Table 1: Properties of the Nanoparticles.

Nanoparticle	Thermal Conductivity (W/mk)	Density (kg/m^3)	Specific Heat (J/kgK)	Coefficient of Volume Fraction (10^5)/k
Cu	401	8933	385	1.16
Al_2O_3	40	3970	765	0.9
TiO_2	8.95	4250	686.2	0.9
Au	314.4	19320	128.8	1.4

Table 2: Properties of Base fluid.

Base fluid	Thermal Conductivity (W/mk)	Density (kg/m^3)	Specific Heat (J/kgK)	Coefficient of Volume Fraction (10^5)/k	Viscosity (Pa s)
Water	0.613	997.2	4179	21	0.0011

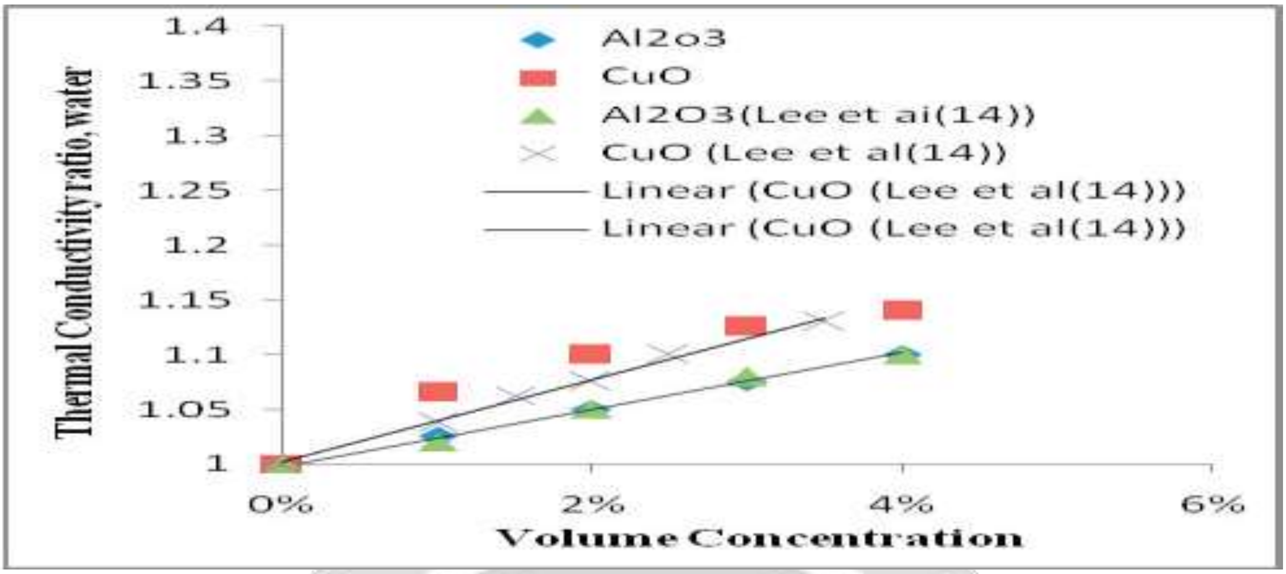


Fig 5: Thermal Conductivity as a function of Volume fraction.

4. Benefits of Nanofluid

Nanofluids possess the following advantages as compared to conventional fluids which makes them suitable for various applications involving heat exchange**.**

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 are efficiently used in Solar Thermal applications.

5. Limitations of Nanofluid

The major limitation in using nanofluid is poor long term stability of nano particle in suspension. Some of limitations while using nanofluid in practical applications are reviewed here.

5.1 Poor long term stability of suspension

Because of strong vander walls interaction between the nano particles the non-homogeneous suspension is formed due to agglomeration of nano particles. Stability can be controlled by using either physical means i.e. surface modification of the suspended particles or chemical methods i.e. adding some surfactant or applying strong force on the clusters of the suspended particles. Particles settling must be examined carefully since it may lead to clogging in flow paths.

5.2 Increased pressure drop and pumping power

More pumping power is to be provided to avoid pressure drop decreases the nanofluid efficiency. Higher density and viscosity leads to higher pressure drop and pumping power. Further researches are required to control the pressure drop.

5.3 Lower specific heat

The important requirement of ideal heat transfer fluid is high specific heat to exchange more heat. But nanofluid exhibits lower specific heat than base fluid. It limits the use of nanofluid application.

5.4 High cost of nanofluids

Nano fluids are prepared 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

Nanofluids are a new class of fluids engineered by dispersing nanometer-sized materials (nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheet, or droplets) in base fluids. In other words, nanofluids are nanoscale colloidal suspensions containing condensed nanomaterials. They are two-phase systems with one phase (solid phase) in another (liquid phase). Nanofluids have been found to possess enhanced thermophysical properties such as thermal conductivity, Density, Specific heat and Viscosity. A preparation method of nanofluid, by directly mixing nanophase powders and base fluids, which reveals the possibility of practical application of the nanofluid. The nanofluid shows great potential in enhancing the heat transfer process. One reason is that the suspended ultra-fine particles remarkably increase the thermal conductivity of the nanofluid. The volume fraction, shape, dimensions and properties of the nanoparticles affect the thermal conductivity of nanofluids.

The scope of the research on nano fluid is widely increased because of the wide application of nano fluid such as automotive system, domestic refrigerator, industrial cooling system, solar device etc.With respect to the complicated phenomena of Brownian diffusion, sedimentation, dispersion which may coexist in the main flow of a nanofluid, the dispersion model has been used to analyze the enhanced heat transfer mechanism of the nanofluids.

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