International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

Thermal Conductivity of Nanofluids-An Extensive Literature Review

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NOMENCLATURE:

α = Ratio of the thermal conductivities of particle and base fluid.
δ_T =Thickness of layer.
h = Coefficient of heat transfer.
k_{eff} = Effective thermal conductivity.
k_f = Thermal conductivity of base fluid.
k_{nano} =Thermal conductivity of nanoparticle.
k_m =Thermal conductivity of base fluid.
n = Shape factor.
ϕ = Particle volume fraction.
R_k = Kapitza resistance.
P_r = Prandtl No.
R_e =Reynolds No.

Abstract

Nanofluid, a new concept in nanotechnology has already got the attention of the research communities all over the universe due to its unique properties such as thermal conductivity. Numerous experiments have been done on this particular property of nanofluids and still they are going on. Researchers have found the dependence of thermal conductivity of nanofluid on its material, shape, size, temperature, viscosity. Nanofluids applied in various engineering fields critically require the suitability of thermal conductivity particularly in heat transfer applications. Most of the previous works are concentrated on the role of thermal conductivity in several application areas but a very less information found on how the thermal conductivity of nanofluids can be determined either theoretically or experimentally. This article presents an extensive review on theoretical and experimental works done on thermal conductivity of nanofluids.

Key words: nanofluids, preparation, stability, thermal conductivity

1. Introduction

Nanofluid which is regarded as the most promising transport fluid for various scientific and engineering applications was first prepared by Choi et al. of Argonne National Lab. Nanofluids which are prepared by mixing nanoparticles of various materials such as Al, Cu, Al_2O_3, CuO, SiC, and CNT with the base fluids such as water, engine oil, ethylene glycol etc. High surface to volume ratio, less clogging, stability make such fluid suitable for heat transport in MEMS/NEMS, heat exchanger, and other thermal applications. Authors have categorized nanofluids in many ways. Nanofluids can be of two kinds such as metallic nanofluids and nonmetallic nanofluids .Metallic nanofluids are prepared by dispersing nanoparticle made from metals such as aluminum ,copper, nickel etc. and non metallic nanoparticles are made by dispersing nanoparticles of non metals i.e. metal oxides, various allotropes of carbon (Graphene, CNT)etc.

Thermal conductivity signifies the inherent ability of heat transfer and it is very important property for all thermal applications involving fluids. Heat conduction is depends upon thermal conductivity. Furthermore, Nusselt number, an important parameter in convective heat transfer is directly related to the thermal conductivity of fluids. So comprehensive study of thermal conductivity of nanofluids is of paramount importance. Previous reports have described about the measurement methods of thermal conductivity of nanofluids. Furthermore those also have given description on how the various parameters such as shape, size, volume fraction and temperature of nanofluids individually affect the thermal conductivity of nanofluids.

The following part of this article gives a brief idea about preparation, stability, characterization and application of nanofluids with an intense focus on the important theoretical as well experimental studies of thermal conductivity of nanofluid.

1.1Preparation of Nanofluids:

Preparation of nanofluids is the first key step in experimental studies with nanofluids. There are several techniques has been adopted for the preparation of nanofluids. They can be broadly classified into two categories a) Two-step method and b) One-step method.

In two-step method first nanoparticles, nanofibres, nanotubes or other nanomaterials are first produced as powder by physical and chemical methods then they are dispersed into a fluid in the second step with the intense magnetic force agitation, ultrasonic agitation, high shear mixing etc. Presently two-step method is adopted for the preparation of nanofluids in industrial scale due to their cheap cost of preparation. Although this technique works good for oxide nanoparticles, it is ineffective for metal nanoparticles such as copper, Aluminum etc. due to high surface to volume ratio the nanoparticles always have a tendency to aggregate[1,2].

One step method is of three kinds such as single step direct evaporation method, single-step physical vapor condensation method and Vacuum-SANSS (Submerged arc nanoparticles synthesis) method.

Single-step direct evaporation approach was developed by Akoh et al. [3].The process is also popular as VEROS (Vacuum Evaporation onto a Running Oil Substrate). Although the idea was to produce nanoparticles but it was difficult to separate nanoparticles from fluids [2].

Eastman et al. developed single-step physical vapor condensation method, in which simultaneous mixing and dispersing of particles occurs [4].This method is suitable to prepare Cu/ethylene glycol nanofluid.

Vacuum-SANSS (Submerged arc nanoparticles synthesis) method handles undesired particle aggregation very well. This technique has been employed by Lo et al.(2005) to prepare Cu-based nanofluids with different dielectric liquids such as de-ionized water, with 30%, 50%, 70% volume solutions of ethylene glycol and pure ethylene glycol [5]. Recently, a Ni nano-magnetic fluid and silver nanofluid were also produced by Lo et al.

(2006) using the SANSS method. The spherical silver nanoparticles formed in the ethylene glycol and the mean particle size is about 12.5 nm, which more closely resembles Newtonian fluids[1].In 2009 Liang et al. Prepared a suspension ofTiO2nanoparticles of diameter of 65 nm using a submerged electrode with a working temperature of up to 6000◦C.They found that the electric current required for preparing the nanoparticle suspension had significant impact on the size, distribution and surface sphericity of nanoparticles [6].

1.2Stabilization of Nanofluids:

The agglomeration of nanoparticles results in not only settlement and clogging but also the decrement of thermal conductivity of nanofluids. So stability analysis is a matter of importance in context to application of it. Stabilization of nanofluids is mainly done by stability evolution and stability enhancement.

Sedimentation method, centrifugation method, spectral absorbency analysis and zeta potential analysis are the four basic methods which are required for evaluating stability of nanofluids.

Sedimentation is a very simple method for evaluating the stability of nanoparticles in their base fluids. The sediment weight of nanoparticles under an external force is an indication of the characterized nanofluid. Zhu et al. [9] used sedimentation balance method for the stability of nanofluids. Centrifugal method is another method; developed to evaluate the stability of nanofluids [10].Singh et al. applied the centrifugation technique to observe the stability of silver nanofluid [11].

Zeta potential analysis is also very important for stabilization of nanofluids. Zeta potential is the potential difference between the dispersion medium and the stationary layer of fluid attached to the particle. The zeta potential indicates the degree of repulsion between adjacent, similarly charged particles in dispersion. For molecules and particles that are small enough, a high zeta potential will confer stability. Nanofluids with zeta potential from 40-60 mV are believed to have excellent stability. Zhu et al. [12] measured the zeta potential of Alumina-water based nanofluids under different pH values.

Spectral absorbency analysis is a very efficient way to evaluate the stability of nanofluids. In general there is a liner relationship between the absorbency intensity and the concentration of the nanoparticles in the fluids [13].For example. Huang et al.[14] found out the dispersion characteristics of Al and Cu suspension using the conventional sedimentation method with the help of absorbency analysis using a spectrophotometer after the suspension deposited for 24 hours.

The stability of nanofluids can be enhanced by adding suitable surfactants or by controlling pH or by ultra sonic agitation. Addition of surfactants can reduce the surface tension and increase particle immersion. Several literatures have told about adding surfactant to nanofluids to avoid fast sedimentation. Several types of surfactants such as Sodium dodecylsulfate (SDS)[73,74],Salt and oleic acid[75], Cetyltrimethylammoniumbromide(CTAB)[76,77], Dodecyl trimethylammonium bromide (DTAB)[78] sodiumoctanoate[78],Hexadecyltrimethylammoniumbromide (HCTAB)[79], Polyvinylpyrrolidone (PVP)[80], Gum Arabic[81] have been utilized as stabilizing agents. But this technique cannot be applicable for nanofluids working in high temperature on account of probable damage of bonding between surfactant and nanoparticle, causing hindrance to stability of nanofluids [9]. Some researchers [15] reported above 60^{o}C as critical temperature by doing some experiments.

pH control of nanofluids can increase stability.pH change creates strong repulsive forces between the particles and causes better agitation which intern stabilizes the suspension .As an example, simple acid treatment done by Xie et al.[16] caused nice stability of CNT in water .Lee et al. investigated various pH values for Al2O3 nanofluid and observed decrease or increment of agglomeration by changing pH [17]. It was found that optimized pH value is different from one sample to another. For instance, suitable pH value for alumina, copper and graphite dispersed in water are around 8, 9.5 and 2, respectively [18].

After preparation of nanofluids, agglomeration might occur over the time which results in fast sedimentation of nanoparticles due to enhancement of downward body force. Manson et al. [19] investigated two different nanofluids; carbon black/water and silver/silicon oil and they utilized high energy of cavitations for breaking clusters among particles.

As it was mentioned before, all three methods might be used for one specific sample during synthesis and preparation; yet, it is difficult to make stable nanofluid and rare to maintain nanofluids synthesized by the traditional methods in a homogeneous stable state for more than 24 h [20].

1.3Particle Size Characterization:

Structural characterization is a very important part for the study of nanomaterials as the structural properties has a direct impact on the mechanical, thermal chemical, electrical properties of materials.

X-Ray diffraction technique is the fundamental technique to examine the crystal structure of nanomaterials. It helps to obtaining informations such as lattice parameter, crystal structure, sample orientation, and particle size of nanomaterials. Optical spectroscopy uses the interaction of light with matter as a function of wavelength or energy in order to obtain information about the material. Optical spectroscopy is attractive for materials characterization because it is fast, nondestructive and of high resolution.

Raman Spectroscopy process is used to describe the excitation of vibration modes (phonons) in the sample using light. Raman spectroscopy has been used to characterize the carbon nanotubes.

Transmission Electron Microscopy (TEM) and Scanning Electron Microscope (SEM) are reckoned as the most important tools to determine the size, distribution and the morphology of the synthesized nanoparticles. They use electron beam to create the image of samples.

Another method named, DSL (Dynamic light Scattering) technique is used by several researchers for measuring particle size distribution [68].

2. Thermal Conductivity of Nanofluids:

2.1Theoretical Models:

Maxwell was the first who analytically investigated the thermal conductivity of an colloid solution .His investigation led him to generate an mathematical model which is famous as Maxwell's Equation [21].This model is applicable to homogeneous and low-volume fraction liquid -solid suspension with randomly dispersed, uniformly sized and non interacting spherical particles. The Maxwell equation is:

$$\boxed{\frac{k_{eff}}{k_f} = \frac{3(\alpha-1)\phi}{(\alpha+2)-(\alpha-1)\phi}}$$

k_{eff} Is the effective thermal conductivity of solid -liquid mixture, k_f is the thermal conductivity of base fluid,$\alpha$is the ratio of the thermal conductivities of particle and base fluid and $\varphi$is the particle volume fraction.

A great number of extensions to Maxwell's mathematical model have been carried out since its foundation. These equations take into account various factors related to effective thermal conductivity including particle shape, structure, volume concentration etc.

Hamilton and Crosser [22] extended the Maxwell model to take into account irregular particle geometries by introducing a shape factor.

$$\boxed{\frac{k_{eff}}{k_f} = \frac{\alpha+(n-1)-(n-1)(1-\alpha)\phi}{\alpha+(n-1)+(1-\alpha)\phi}}$$

Where n is the shape factor .Here $n = 3/\psi$ and $\psi$is the particle sphericity, defined as the ratio of the surface area of a sphere with the same volume as the particle equal to the surface area of the particle.

Another expression, presented by Davis [23] is applied to spherical suspensions and given by:

$$\boxed{\frac{k_{eff}}{k_f} = \frac{3(\alpha-1)\phi}{(\alpha+2)-(\alpha-1)\phi}\left[\phi + f(\alpha)\phi^2 + 0(\phi)^3\right]}$$

Hesselman and Johnson [24] derived an expression for the effective thermal conductivity of composites, taking into account the thermal barrier resistance at the interface between the materials and the relations for spherical, cylindrical and flat plate for low concentration of dispersion. The resulting expression for spherical particles can be arranged as:

$$\boxed{\frac{k_{eff}}{k_f} = \frac{\left[\alpha(1+2\beta)+2\right]+2\phi[\alpha(1-\beta)-1]}{\left[\alpha(1+2\beta)+2\right]-\phi[\alpha(1-\beta)-1]}}$$

Where $\beta = R_k k_m / k_{nano}$ and R_k is the Kapitza resistance.Hasselman and Johnson found that the effective thermal conductivity depends upon the volume fraction of the dispersed phase as well as the dispersion size.

Newer models have been developed in the past few years .This models are nothing but the modified versions of the old models Like Maxwell model and H-C model.

Jang and Choi model [25] is one of the latest developments based on Brownian motion. The mathematical model is expressed as follows:

$$\boxed{k_{eff} = k_f + (1-\varphi) + k_{nano}\phi + \phi h \delta_T}$$

Where,k_{nano} is thermal conductivity of nanoparticles, h is coefficient of heat transfer and δ_T is thickness of layer.

Prasher et al. [26] developed a model based on experimental results by modifying Maxwell-Garnett model. The effective thermal conductivity is given by:

$$\boxed{\frac{k_{eff}}{k_f} = 1 + AR_e P_r^{0.33}\phi\frac{2(1-\phi)}{(2+\phi)}}$$

Where,R_e=Reynolds number and P_r= Prandtl number.

Other Models:

- A fractal model based on the Maxwell model, developed by Wang and his co researchers [27].
- A model based on the average polarizing theory, takes into account the effect of liquid layering and uses an effective dielectric constant and a depolarization factor along the axis of symmetry. This model is developed by Xue [28].
- Xuan et al. [29] derived a model taking into account the Brownian motion and clustering of nanoparticles and also viscosity, specific heat and temperature.
- Koo and Kleinstreuer [30] recently produced another model, based on micro convection and is a function of volume fraction and inner particle interactions.
- A very recent model that combines Maxwell's model and one third power law can predict temperature dependent thermal conductivity. This model is developed by Maheta et.al [31].

2.2Experimental Investigations:

2.2.1Measurement of Thermal Conductivity of nanofluids:

Transient hot-wire method, Steady-state parallel-plate method, cylindrical cell method, Temperature oscillation technique and, 3ω method and Thermal comparator method are generally used to measure thermal conductivity of nanofluids.

Transient Hot-wire method is the oldest and most regular method. Many researchers have applied this technique for measuring thermal conductivity [34, 35, 36]. It is known as more appropriate than steady-state technique due to a number of advantages such as elimination of natural convection effect, easier setup and faster experimental response.

The details of the experiment and measurement process can be found in the various research papers [32, 33].

Transient Plane Source Method utilizes a plane sensor and a special mathematical model to measure Thermal Transport Properties. This method has been used by some researchers Zhu et al. [37] and Jiang et al. [38].

Challoner and Powel[39]described and used a guarded hot-plate design which is the basis of constructing an apparatus using steady-state parallel-plate method for measuring thermal conductivity. Wang et al.[40]used the method to measure thermal conductivity of $Al_2O_3$and CuO, dispersed in water, vacuum pump fluid, engine oil, and ethylene glycol.

Cylindrical Shell is a very common steady state method used for measuring thermal conductivity of nanofluids[41].Kurt et al.[42] utilized cylindrical cell method to measure thermal conductivity of water and ethylene glycol and compare the results with outcomes of artificial neural networks (ANNs)predictions which may be an important investigation in engineering prospective.

Temperature oscillation method uses oscillation method proposed by Roetzel et al.[43] for the first time, measures temperature response of the sample when a temperature response or heat flux is imposed. Detailed about this method can be found in reference [41].

Thermal comparator method is extensively used for the measurement of thermal conductivity of bulk material of high thermal conductivity. Paul et al.[41] first used thermal comparator method to determine thermal conductivity of nanofluids. They reported it as a reliable method when they tested some samples such as water and ethylene glycol.

3 ω method is quite similar to THW method. It also uses same material as heater as well as the thermometer. But the main difference is that TWH method utilizes time dependence response while it uses electric current frequency (ω) dependence response. The details of this method can be found in the references [44, 46, 47, and 48].Some researchers [45] used this method measuring thermal conductivity of Al_2O_3-DI and Al_2O_3-ethylene glycol nanofluids.

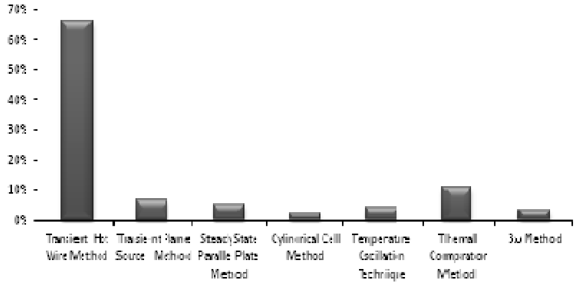


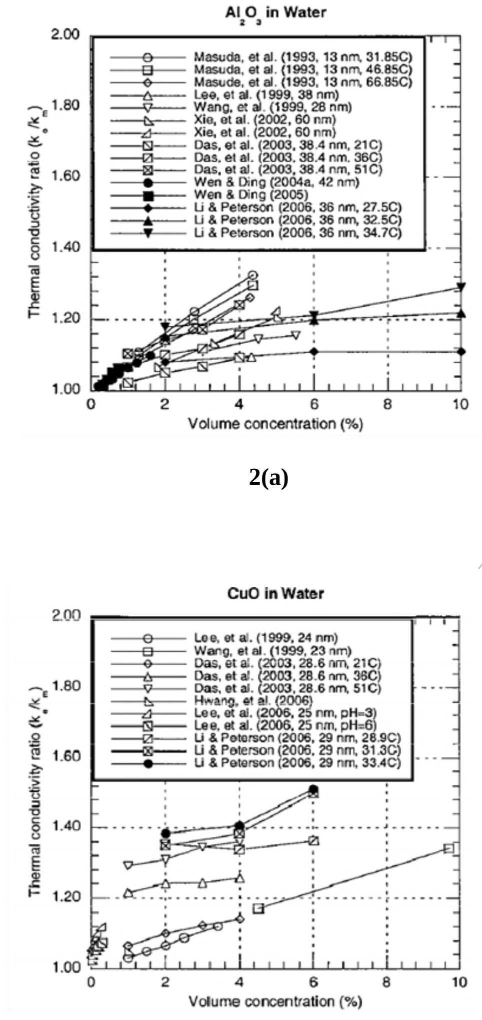
Figure 1: Share of different methods in literatures

2.2.2Parameters affecting Thermal conductivity of nanofluids:

Several papers have been published showing that volume concentration, shape, size, temperature, viscosity etc. have direct impact on the conductivity of nanofluids.

2.2.2.1Effect of particle volume concentration:

Particle volume concentration is regarded as the most significant factor affecting the thermal conductivity of nanofluids. The increases in concentration of nanoparticles in base fluids increase the thermal conductivity of nanofluid. According to fig-2(a and b) Al_2O_3 in water and CuO in water have found increment in thermal conductivity with the increase in particle concentration. However at higher particle concentration, arrogation will start and the enhancement diminished.



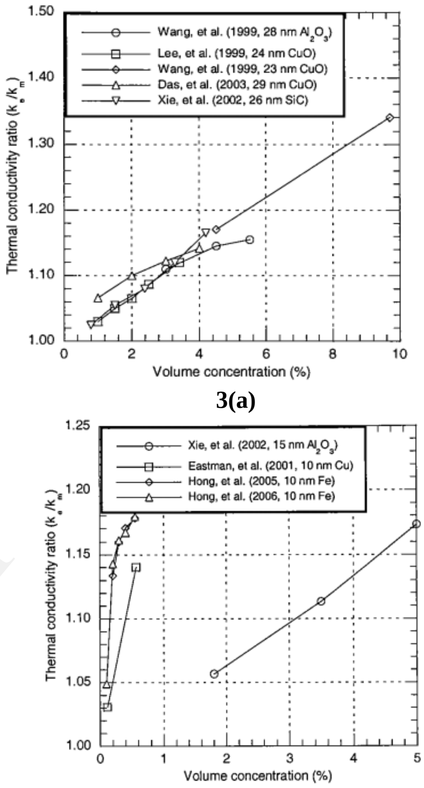
2(a)

2(b)

Figure 2: Effect of particle volume concentration for (a) Al2O3 in water and (b) CuO in water [69]

2.2.2.2Effect of particle material:

Most of the researchers considered particle material as an important parameter that affects the thermal conductivity of nanofluids. Lee et al. [53] reported that a nanofluid with CuO nanoparticles has higher thermal conductivity than the nanofluids with Al_2O_3.Fig-3(a and b) show effect of particle material on its thermal conductivity.



3(a)

3(b)

Figure 3: Effect of particle material for (a) particle in water (b) particles in ethylene glycol [69]

2.2.2.3 Effect of particle size and shape:

Particle size is another important parameter that affects thermal conductivity of nanofluids. Chopkar et al. was first to show that thermal conductivity bears a non linear relationship with the nanoparticle size [49].Chon et al. [50] and Hong et al. [51] observed that thermal conductivity of nanofluids increases with decrease in particle size. Most recently, Kim et al. [52] showed that the thermal conductivity of nanofluids increases linearly with decrease in particle size. The reason behind such behavior is the increase in SSA (specific surface area) with the decrease in size contributes to the enhancement in thermal conductivity .However other experimental data also shows a significant decrease in thermal conductivities corresponding to the decrease in particle size.

Spherical and cylindrical nanoparticles are very frequently used for experiments. Experiments [53, 54] revealed that cylindrical nanoparticles have higher thermal conductivity than spherical particles.

2.2.2.4 Effect of base fluid material:

Base fluids are also responsible to influence thermal conductivity[54,55,56].According to fig-4 most surprisingly least enhancement has been found for water as base fluids whereas for pump oil the increment is the highest [68].So it's very encouraging to us that heat transfer effectiveness can also be increased by using relatively poorer heat transfer fluids.

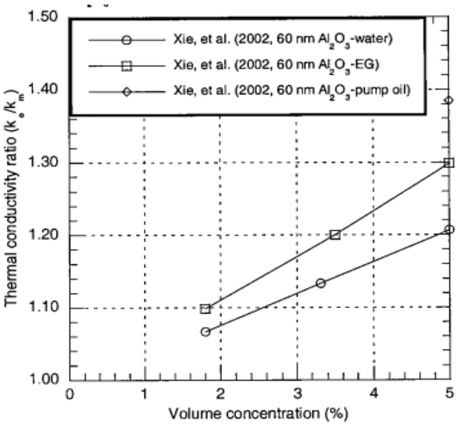
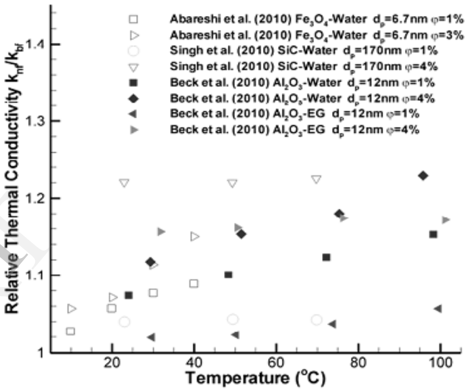


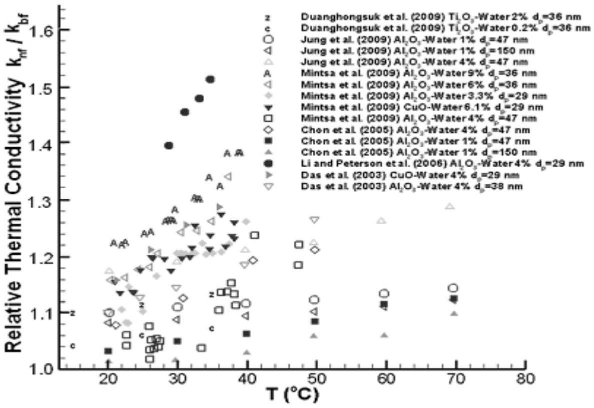
Figure 4: Effect of base fluid material for Al_2O_3[69]

2.2.2.5 Effect of temperature:

Most of the studies have demonstrated about temperature dependency of nanofluids. However there is considerable disagreement in the literature regarding the temperature dependence of their thermal conductivities. According to some research groups the thermal conductivity of nanofluid shows an enhancement with respect to temperature rise. For example Das et al. [53, 56] demonstrated enhancement of the thermal conductivities of water based Al_2O_3 and CuO nanofluids. Patel et al. [53, 56] reported the effective thermal conductivity of Cu nanofluid enhances with increase in temperature. Ding et al.[53] also reported about the thermal conductivity enhancement of carbon nanotubes corresponding to the temperature rise. Furthermore, Bobbo et al. [68] also supported this trend while investigating the thermal conductivity of water based TiO_2 nanofluids. But other research groups investigated the decrease in thermal conductivities with the increase in temperature. For example the experiment of Murshed et al.[53]with SiO_2 /water nanofluids showed the opposite of the above results. In fig-5(a and b) both show experimental results of several researchers working with different types of nanofluids. These graphs also tell us about the variation of thermal conductivity with respect to change of temperature.

5(a)





5(b)

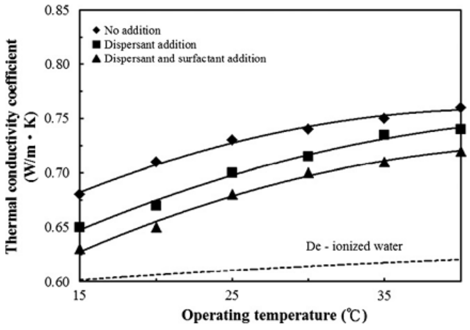
Figure5: Thermal conductivity vs. temperature relationship [33]

2.2.2.6 Effect of Base fluid viscosity:

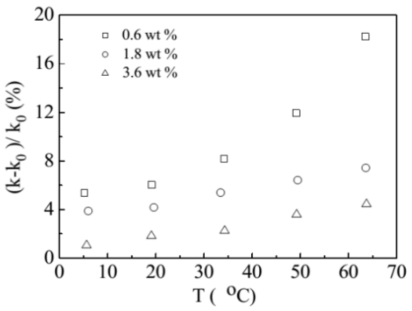
Very few investigations has been done till now on this topic. It has been found that viscosity has an impact on the thermal conductivity of these fluids. Tsai et al. [67] examined the effect of viscosity of the base fluid on the thermal conductivity of Fe_3O_4/diesel oil and Fe3O4/polydimethylsiloxane nanofluids and varied the result with Maxwell's equation. They observed that the measured thermal conductivity of nanofluids gradually approaches the value predicted by the Maxwell equation by increasing the viscosity. Further, they concluded that reduction of Brownian motion of suspended nanoparticles due to the viscosity rise is suitable in which Maxwell's equation gives good prediction about their thermal conductivities.

2.2.2.7 Effect of Surfactants:

Surfactants or dispersants are used to prevent settling of nanoparticles in their suspention.Thermal conductivity can vary in a wide range with respect to their types, concentrations etc. Addition of surfactants can increase the thermal conductivity. But excess addition of surfactants can hinder the thermal conductivity enhancement. A detailed study regarding the effect of surfactants can be found in the references [53, 56].Fig-6 (a and b) show the effect of adding dispersants and surfactants on thermal conductivity of nanofluids.



6(a)



6(b)

Figure 6: Effect of additives on the thermal conductivity (a) with required additives [72](b) hindrance with excess additive [56]

2.2.2.8 Effect of Acidity (pH):

Limited literatures are available regarding the effect of acidity upon thermal conductivity. Due to the high surface energy of nanoparticles, it is easy for nanoparticles to coagulate and difficult to disperse in the base fluids. Therefore controlling of coagulation is of paramount importance. Lee et al.[56]and Xie et al.[54]draw a conclusion showing that as long as the pH value diverges from the isoelectric point (PZC),the particles will acquire larger charge which will lead to better particle -particle repulsion ,thus making the suspension more stable and resulting in high thermal conductivity.

2.2.2.9 Other factors affecting thermal conductivity:

Thermal conductivity of nanofluids containing magnetic nanoparticles can be influenced by external magnetic field. A detailed study is given in the references [57, 58, 59].This finding can be very useful in MEMS/NEMS applications.

Clustering effect is always present in nanofluids and is an influential parameter in thermal conductivity. According to some researchers [66] nanofluids with high particle volume fraction from cluster at higher rate resulting in nonlinearity between effective thermal conductivity and particle volume fraction.

3.Application of Nanofluids where Thermal Conductivity is Important:

Application of nanofluids is so wide that need separate review articles. Here we focus on some applications of it where thermal conductivity enhancement of nanofluids is very significant.

3.1Application in electronic cooling:

Advanced electronic devices like computers, laptops often faces over heating challenges from high level of heat generation from relatively compact area. So a reliable cooling source is vital for their smooth free operation.Jang and Choi observed higher cooling performance in their cooler, combined microchannel heat sink with nanofluids [70]. Nguyen et al. also got the same enhancement when he replaced the fluid (distilled water) of his cooling system with nanofluids [71]

.

3.2 Application in heat exchangers and boilers:

Nanofluid technology may help to accelerate the development of energy-efficient heat exchangers [60].Application of CNT-water nanofluids can increase the heat transfer rate in home commercial boilers [61].

3.3 Application in automobiles:

Ethylene glycol-water mixture and engine oil are very poor heat transfer fluids. Even they perform worse than water. Replacement of such poor cooling medium with nanofluids can be fruitful for automotive cooling system. Such improvement can be used to remove heat from relatively smaller size of coolant system. Smaller coolant system results in smaller and lighter radiators which lead to decrease engine weight to some extent .Lighter engine component can also increase fuel efficiency in cars and trucks [1].

3.4 Application in thermal absorption systems:

Application of nanofluids in thermal absorption systems is good alternative to increase the performance of absorption system**.** Researchers [62] showed that by adding nanoparticles such as Cu, CuO and Ah03 to NH31H20 solution improved the absorption performance by5.32 times.

3.5 Application in refrigerators:

Domestic refrigeration systems can be influenced by nanofluids. Now a day, in refrigeration equipment HFC134a is used as a refrigerant. Traditional mineral oil is avoided as a lubricant due to the strong chemical polarity of HFC134a in refrigeration equipment. POE (Polyol-ester) oil as a lubricant also has the problems of flow choking and severe friction in the compressor. Application of suitable nanoparticles with the mixture of HFC134a and POE oil has given fruitful result in this matter [63].Authors[64] reported that heat transfer coefficient of refrigerant based on nanofluids have higher heat transfer coefficient than that of pure refrigerants.

3.6 Applications in defense, space and navy:

A number of military devices and systems require high heat flux cooling. Various space and defense organizations use power electronics and high energy weapons. At this level cooling with conventional fluids is quite challenging. Nanofluids have proved to contain such potential. Nanofluids have the potential to provide the required cooling in military systems including military vehicles submarines and other defense related systems. In some cases it can have multi functionality in thermal energy storage or energy harvesting through chemical reactions. Waste heat from these systems can also be transported to the hull of the ships that will reduce drag of the ship ultimately saving the fuel costs [64].

3.7 Application in solar water heater:

Nanofluid technology can also be applied in the solar water heating purpose. Authors [65] say that efficiency of a DAC using nanofluids has 10 % higher efficiency than conventional flat plate collectors.

4. Conclusion:

The present review provides an outline of the very attractive research progress in the field of nanofluid with the emphasis on thermal conductivity. We have found the proposed models as well as the practical methods to measure the effective thermal conductivity of nanofluids. Besides this it also shows the results of the various experiments corresponding to the effective thermal conductivity of nanofluids. We can conclude that particle size, shape, temperature, viscosity, acidity etc. influence the thermal conductivity of such fluids. But there are some variations in the results of the researchers. Some research report also shows a conflict between the experimental and theoretical results. Further we can conclude outlining some issues that can be believed to attract greater attention in near future:

- No theoretical model is trustworthy as there are huge variations between experimental data and theoretical models.
- The experimental data on thermal conductivity are very scattered .Lots of research work should be done on this particular area.
- Stability of nanofluids is still now a very big issue. A considerable research work should be encouraged.
- Very less amount of mathematical simulation and analysis have been done so in future such works should be encouraged.

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