Mechanics and Mechanical Engineering
Vol. 22, No. 1 (2018) 207–220

https://doi.org/10.2478/mme-2018-0019

Thermal Conductivity of CNT - Wated Nanofluids: a Review

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Received (18 September 2017)
Revised (14 October 2017)
Accepted (18 November 2017)

In heat transportation applications, water is most commonly used fluid. The efficiency of equipment used in these applications depends on thermal characteristics of water used. The thermal characteristics of water could be upgraded by suspending high thermal conducting solid nanoparticles. In this paper an attempt has been made to know how the use of surfactants and functionalization of carbon nanotube walls can affect the thermal characteristics and stability of nanofluid. A thorough analysis of collected literature revealed that carbon nanotubes have much higher thermal conductivity than any other nanoparticles and hence improve the thermal properties of water when suspended in them. Further it is concluded that suspension of carbon nanotubes in water requires use of surfactant or functionalization of carbon nanotube walls with proper group. By setting optimum pH and better dispersion, better thermal conductivity is possible. Experimental studies in the literature survey reveal that chemical stabilization techniques and physical stabilization techniques together decide the stability of the nanofluid.

Keywords: thermal conductivity, CNTs', nanofluids, suspension.

1. Introduction

Thermal conductivity, which is the ability of substance to transfer heat, has great importance in engineering applications. Fluids used for heating and cooling are essential to many industrial applications, and the thermo-physical properties (Thermal conductivity, viscosity etc.,) of the fluids play a vital role in the development of energy-efficient heat transfer equipment. Fluids suffer with low thermal conductivity and thus low heat transfer rate. The advancements in electronic components, higher energy transportation rates within small area demand for better heat transfer fluids. There are continuous efforts all over the world to enhance heat transfer rates with minimal utilization of energy and different strategies have been found in their way. All these strategies may be broadly classified either as Passive technique or Active technique. Passive technique includes improving properties of the fluids and materials, design modifications etc., which doesn't need any secondary power for increasing heat transfer rate whereas active technique requires auxiliary power for enhancing heat transfer. Since saving energy is call for the better environment, passive techniques always gains attention first. An eminent passive technique for improving thermal properties of liquids is adding high thermal conductive solid particles to liquid. The resulting mixture of solid-liquid exhibits increased thermal conductivity than the pure liquid. Initially milli and micro sized solid particles were used to achieve better properties, but these solid-liquid mixtures linger behind by some negative characteristics. The solid particles dispersed in liquid form clusters and don't form a stable homogeneous mixture. These two-phase mixtures also limit the size of channels to be used, as they tend to block the channels. Moreover, they are highly abrasive in nature and cause erosion of components. Thus, even though the slurries have higher conductivities; they are hardly useable as heat transfer fluids from other technological considerations. All these limitations of micro and milli sized solid particles may be side-stepped with the use of nano sized particles. The homogeneous mixture of liquid and nanoparticles is referred as nanofluid. Choi[1] was the first the person to coin the word nanofluid. The nanofluids show noticeably prodigious thermal conductivity and have exceedingly improved longevity compared to any dispersion of micro-sized particles in fluid. Suspension of nanoparticles in fluid may even improve heat capacity of fluid for a given amount of mass flow rate

1.1. *Preparation of nanofluids*

Nanofluid preparation techniques are primarily classified as one step and two step techniques. Two step technique has achieved commercial success because of flexibilities associated with the processes involved in the preparation of nanofluid. In two-step method, nanoparticles are first produced by chemical or physical method, then they are suspended in base fluid with the help of dispersants or agitators and at the same time it is essential to use surfactant to activate the surface of nanoparticles whereas one-step method comprises making and dispersing the particles in the fluid simultaneously. Vacuum-SANSS (submerged arc nanoparticle synthesis system) and wet chemical reaction methods are some typical examples of one-step method. Zhu et al.[8] presented a novel one-step chemical method for preparing copper oxide nanofluids by reducing $Cu(CH_3COOH)_2H_2O$ with CH_3COOH in NaOH. Well-spread copper nanofluids were attained. On the other hand, there are some drawbacks too for one-step method. The utmost constraint is that the residual reactants persist in the nanofluids due to unfinished reaction or balance. It is unviable to clarify the nanoparticle effect with impurities.

1.2. *Characteristics of CNTs:*

Metals possess high thermal conductivity ranging from 10 to few 100 W/m-K. This thermal conductivity is far less than thermal conductivity of diamond which has thermal conductivity of 2000 W/m-K (approx.). Metal oxides on other hand possess thermal conductivity higher than the thermal conductivity of their metals. When these high thermal conducting materials are reduced to nanoscale they show even more thermal conductivity. Thermal conductivity of single walled nanotubes is as higher as 6000 W/m-K because of high aspect ratio and show excellent thermal conductivity in length direction, other Carbon nanotubes possess thermal conductivity of order 2000-4000 W/m-K. A wide variety of nanofluids comprising nanoparticles of metallic oxides and carbides like Al_2O_3, CuO, ZnO, SiC etc., were successfully used for augmenting heat transfer. Parallelly equal works' have been carried by researchers to study the possibility of carbon nanotube in various liquids owing to hyper thermal conductivity of CNTs'. In addition to hyper thermal conducting properties of CNTs', they possess high radiation absorbing properties. K. Muzuno, et al. [2] showed that CNTs' behave similarly to the black body are best NPs' for Direct Absorption Solar Collectors due to their higher thermal absorption coefficient. Carbon nanotubes have drawn much significant concentration in the sphere like hydrogen storage media, field emission displays, solar radiation absorbing systems, composites and nanoscale semiconductor probes [2].

1.3. *Parameters influencing nanofluid characteristics*

Experimentations disclose that thermal conductivity of nanofluids depend on several factors especially, the chemical configuration of the base fluid, solid nanoparticle and surfactant, nanoparticle shape, nanoparticle concentration, surfactant concentration and relative concentration of surfactant to nanoparticle. Nevertheless, how exactly these parameters influence the heat transportation characteristics are yet to be established. Unlike above parameters which remain invariant during real time application of nanofluid for heat transportation, temperature differs from one section of conduit to other section of the conduit, which ultimately influences the convective heat transportation defining characteristics like thermal conductivity, viscosity, density of the nanofluid as they are of temperature. Many research works have been carried to understand the influence of temperature on the thermal conductivity of the nanofluids [3-7]. Those studies reveal approximately linear proportional relationship between thermal conductivity and temperature. Thermal conductivity of nanofluids could also be determined by using theoretical relations like Maxwell model and Hamilton-Crosser model. Though Brownian movement of nanoparticles is considered as the reason behind the temperature dependence of thermal conductivity of nanofluids, theoretical models of thermal conductivity are not yet accurate enough to calculate its influence of Brownian motion on thermal conductivity [3-5]. This limitation of theoretical thermal conductivity prediction models led experimentalists to set correlations for future application of nanofluid [3, 5]. However, all those correlations give best results only within experimental range of conditions and it is not encouraged to use in other contests. Correlations established from experiments are very sensitive to the level that, they may fail even for same nanofluids, if preparation process carried out is different.

1.4. *Thermal conductivity measuring techniques for nanofluids:*

The power required to pump fluid to achieve given heat transfer rate depends mainly on thermal conductivity and viscosity of the fluid. Thermal conductivity measurement of nanofluids is associated with many complications as convection in fluid takes place when it is heated, this problem could be avoided if heat is added from top surface rather than from bottom. While measuring thermal conductivity homogeneous dispersion of solid particles is mandatory as any heterogeneous local concentrations could lead to serious errors. A good number of measuring techniques have been developed for measuring thermal conductivity of liquids avoiding above problems. Thermal conductivity measuring techniques for liquids may be classified broadly as steady-state techniques and transient techniques which are depicted in Fig. 1. Study by G. Das et al. [9], reported that Transient-Hot Wire (THW) is the most popular technique used to determine the thermal conductivity of nanofluids.

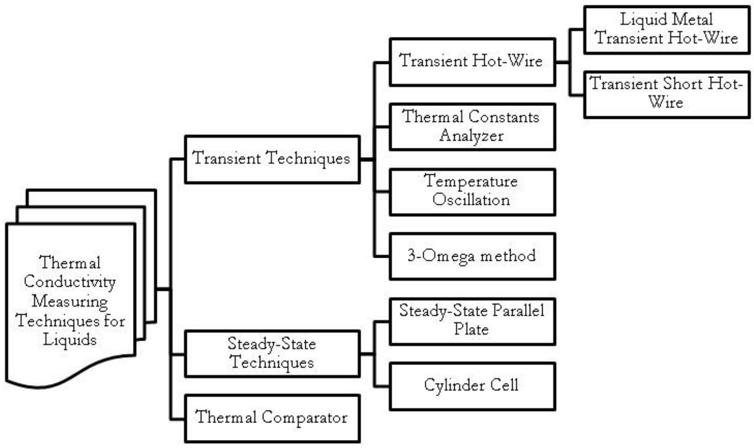

Figure 1 Different techniques for measuring thermal conductivity of nanofluids

Standard instruments using this THW are available for purchase. Usually, a THW setup comprises of a probe which is to be inserted into the nanofluid for the measurement. A typical THW setup may be as shown in the Fig. 2. A metallic wire serves as the probe which works as a straight source of heat accompanied by a thermometer. A steady current supply acts as a source of heat which in turn raises the temperature of the wire. The thermal conductivity of nanofluid is found by variation of temperature with time.

2. Literature review

Single-walled carbon nanotubes (SWNTs) have excellent electrical, thermal and mechanical characteristics [10]. Choi [1] in 1995 introduced the concept of nanofluid and he was the first person to coin the word nanofluid. Since then CNT's have attracted in applications like hydrogen storage media and nanoscale semiconductor probes [11], storage media and field emission displays. Nanofluid studies have focused mostly on the thermal performance, examining the influence of nanoparticle material, concentration, particle size, shape, surfactant or dispersant, base fluid properties, temperature and preparation methods [12–21]. Applications of nanofluids in a heat exchanger shows an improved heat transfer coefficient on comparison to its base fluid [13–14]. Nanofluids could be utilised in micro channel heat sinks to improve the heat transfer without penalizing to affects like clogging of channels and sedimentation [15–16].

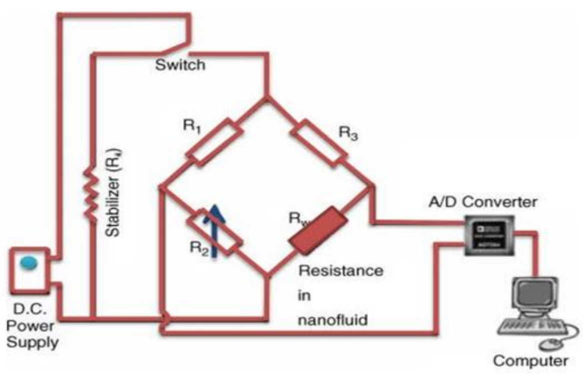

Figure 2 Schematic of transient hot-wire experimental setup

Nanofluids containing CNT's have been studied owing to excellent thermal characteristics of CNT's [17–19]. An efficiency augmentation of 10% was reported by using nanofluids based Direct Absorption Solar Collectors in contrast to conventional flat-plate collector [20]. CNT's have hydrophobic ends and therefore CNT's tend to agglomerate in water owing to strong forces between CNT's. Many dispersants like Cethyl Trimethyl Ammonium Bromide (CTAB), Sodium Dodecyl Benzene Sulfonate (SDBS), Gum Arabic (G.A), Sodium Dodecyl Sulfate (SDS), Triton X-100, Polyvinyl Pyrrolidone (PVP), etc., were used to stabilize the CNT's in polar liquids like water. On the way to eschew the unfavourable effects of stabilizers on thermal conductivity of the nanofluids, CNT's were functionalized with polar groups like COOH to obtain much better thermal performance and good stability [21]. Thermal conductivity and stability can be improved by changing the pH values of suspension mixture [22]. Most of the studies show that better thermal properties could be obtained at pH of 8-9 without causing damage to the structure of CNT's. A comparison of surfactants SDS and SDBS in multi-walled carbon nanotubes dispersed in water spots the superior characteristics of nanofluid stabilized by SDBS (Sodium Dodecylbenzene Sulfonate) over the SDS (Sodium Dodecyl Sulfate) [22]. In this work, they proposed a suitable technique to obtain much stabilized nanofluids and enhanced thermal conducting nanofluid by comparing the effect associated by the addition of surfactant SDBS or SDS. Multi-Walled carbon nanotubes (MWCNT's) at different weight ratios in range 0.1% wt to 1% wt were dispersed in 50 ml of base fluid distilled water, and either of the surfactants SDBS or SDS were mixed to obtain different solutions with relative weight ratios (nanoparticles/surfactant) from 1:1 to 4:1, respectively. Initially, the surfactant is added and dispersed suitably into distilled water by vibrating for 2 min by means of ultrasonic mixing system (Model 1510E-DTH, 47KHZ), and later the related weight of CNTs' are mixed to the surfactant. Finally, nanoparticle solutions with surfactant were properly stirred and vibrated by ultrasonic dispersing system for 20 min. 0.1 mol/L HCL and 0.1 mol/L NaOH were added to determine the influence of P¬H on the heat conductivity of nanofluid.

The heat conductivity of suspensions was found based on the principles of hot wire method employing a platinum wire of 0.1 mm diameter as a source of heat, which also serves as a temperature sensor. They found that nanofluid-containing CNT to surfactant ratio 1/1 decreases the heat conduction by 4.3% on mean compared with that of distilled water. Thermal conductivity was improved with the increase in CNT/surfactant ratio i.e. for 2/1, 3/1 and 4/1. Maximum enhancement was obtained for 2/1 followed by 4/1 and 3/1. This maximum at 2/1 is due to sedimentation of CNTs at loading above the 2/1. The similar trends were obtained for both SDBS and SDS, but SDBS has better enhancement. Hence, SDBS was used for further tests. 0.5 wt % of CNT and 0.25 wt % (2/1 ratio) has greater heat conductivity as compared to that of other nanofluid suspensions of 2/1. This mixture of 2/1 was optimized and pH effect on thermal conductivity was conducted for this optimized nanofluid suspension and it was found that at pH of 9. The thermal conductivity nanofluid improved over 2.8% wholly at optimum weight ratio and pH condition compared with that of distilled water.

Some strange irregular enhancements in heat conductivity were observed at very minor volume fraction below theoretical clarification limit, which are independent of temperature [23]. The experimental study was focused on stably dispersed nanofluids of MWCNT (1.5 μm in mean length; 9.2 nm in mean diameter) in a mixture of SDBS (surfactant) and de-ionized water (base fluid). The initial solution consisted nanotubes by 1% weight fraction and SDBS by 2% weight fraction. Nanofluid solutions with lower concentration nanotube were obtained by diluting the initial solution with de-ionized water. The experiment was mainly emphasized on heat conduction of nanofluid in the volume fraction range 5.5 $\times$ 10-4% and 0.55%. Mechanical agitator used to stir the mixture ensures a good dispersion. Measurement of heat conductivity was based on the principle of Transient hot-wires technique (KD2 Pro thermal property analyzer equipped with KS-1 probe). At lowest concentrations, heat conductivity ratio is uniform up to 0.055%, any enhancement in this range is not significant. Volume fraction above 0.055%, the heat conductivity ratio improved parallelly with the volume fraction. The highest value of thermal conductivity ratio observed by them was at highest tested volume where the enhancement is about 50%. At low volume fraction 1.1 $\times$ 10- 4% a peculiar behavior was found where thermal conductivity enhancement was at about 28%. This enhancement is similar at high volume fraction at about 0.1%. They studied the distribution and morphology of nanofluids by scanning electron microscopy. These results disclose that the preferable morphology of nanofluid is decided by molecular distribution of nanoparticles associated with the molecular interactions, aspect ratio of the nanoparticles and number of contacts.

P. Estelle et al. [24], for the first time measured the thermal conductivity and viscosity of CNT water-based nanofluids comprising surfactant lignin. In their study, they used lignin (a by-product of wood having many molecular structure of OH branched groups) as surfactant to stabilize the MWCNT's (1.5 μm in mean length, 9.2 nm in mean diameter and thermal conductivity 3000 W/m-k) in distilled water. In the solution, the surfactant weight fraction (2%) is fixed and the initial solution prepared by Nanocyl contains carbon nanotubes by 1% in weight and 0.55% by volume fraction. Lower nanofluid concentrations up to 0.0055% were prepared by diluting the initial solution. They performed dilution in such a manner that the weight ratio, surfactant to carbon-nanotube remains same in all solutions. Nanoparticles dispersion in the base fluid was completed by mechanical stirring operation. Scanning electron microscopy (SEM-JOEL-JSM-6301F) was used for characterizing morphology of initial solution 0.55% volume fraction. Viscosity and heat conduction studies of nanofluid were carried out with the help of a stress controlled rheometer (Malvern Kinexus Pro) with a cone and plate fixture (60 mm diameter and 1o conical angle) and transient hot wire method (KD2 Pro thermal analyzer, Decagon Devices Inc.) respectively. Their viscosity studies showed that the viscosity of prepared nanofluid is higher than that of base fluid (distilled water). However, on comparison with SDBS under same identical conditions of temperature and amounts of surfactant and CNT in distilled water viscosity of lignin stabilized nanofluid is less than that of that of SDBS stabilized nanofluid and lignin nanofluids shows less shear thinning behavior. Thermal conductivity studies show that lignin stabilized nanofluids has slightly less thermal conductivity enhancement on comparison with SDBS stabilized. At the highest nanoparticle concentration within the experimental range increase in thermal conductivity at 20° C is around 22%. The experimental results of thermal conductivity were also compared with Hamiliton-Crosser(H-C) model and Walvekar model. Experimental results of enhanced thermal conductivity are in good agreement with H-C model at low volume fractions and the results estimated by Walvekar et al model over predict the thermal conductivity enhancement at high volume faction.

A. Amrollahi et al [25], reported that the dual treatment of both dispersant and ions may perhaps enhance the thermal conductivity. They used distilled water as base fluid and single-walled carbon nanotubes as nanoparticle to obtain nanofluid. Nanoparticles were produced by catalytic decomposition of 20% methane in hydrogen over Co– Mo/MgO catalysts at 1000° C. The inner diameter and outer diameter of SWNTs are 0.8–1.1 nm and 1–4 nm, respectively. The concentration of SWNTs in solution is below 1% by weight. The heat conduction of nanofluid were measured by a modified transient hot wire method (KD2 thermal property meter). Turbidity, Zeta potential, and sedimentation photographs were used to characterize colloidal permanency of the dispersion numerically. Various parameters influence was studied which include mass fraction, effect of various surfactants, temperature and pH, and effect of various physical treatment techniques were discussed. A transient hot wire method based KD2 thermal property meter (Labcell Ltd, UK) was used to the heat conductivity of nanofluids. The results show that SWNTs dispersed nanofluids have noticeably much higher heat conductivity than the base fluid. They found that the effective heat conductivity improves with the rise in temperature and SWNTs concentration. Unlike at 20°C and 25°C, at 30°C significant thermal conductivity enhancement takes place above the weight fraction 0.5%, indicating that fluid is capable of holding more particles at elevated temperatures. The size of the nanoparticle was found to be reduced by employing various physical stabilization methods. Stirrer has no influence on particle morphology, whereas ultrasonic disruptor and ultrasonic bath could bring down the agglomerated particles size and number of particles in cluster if time of operation and power of device are chosen in accordance. Low powered ultrasonic mixing devices cannot in complete break down all the primary particle sediments. Since particle size has great stimulus effect on thermal characteristics of nanofluid, the reduced particle size help to increase heat conductivity of nanofluid, thus the nanofluids dispersion achieved by 100 W ultrasonic disruptor device show more thermal conductivity enhancement than the 50 W ultrasonic disruptor device for same weight fraction and temperature. Increasing surfactant concentration and pH value decrease the zeta potential of single walled carbon nanotube suspensions, indicating formation of more stable suspensions in result. This decrease in zeta potential of suspensions with the addition of dispersant could be accorded to intense electro-static repulsions among nanoparticles. The noticeable outcome from zeta potential study is that irrespective of pH value, with the addition of dispersant the overall zeta potential value of suspension retains at low minus range demonstrating that surfactant's hydrophilic part was negatively ionized. SDS surfactant reduces zeta potential substantially than surfactant G.A. In this way by modifying surface characteristics of the non-polar solid particles, surfactants help to disperse in polar liquids. As increase in surface charge improves the molecular interaction, thus high pH value promotes the heat conductivity of the nanofluid. Maximum enhancement of 35% in heat conductivity was found at 0.5 weight % suspension.

Long and high aspect ratio single-walled nanotubes suspensions show the maximum thermal conductivity [26]. In this work, authors examined the effect of Surfactant, CNTs aspect ratio, concentration (0.05-0.48 Vol %) and temperature (10-60^{o}C) on the thermal conductivity of nanofluid. They used three kinds of CNT's namely long SWNTs (L-SWNTs), Short SWNTs(S-SWNTs) and MWNTs with different aspect ratios 5-30,1-3 and 30 respectively. Hexadecyl trimethyl ammonium bromide (CTAB) was used as a dispersant. The heat conduction measuring device was based on the principle of the transient hot-wire method. They observed that the conductivity increases as the nanoparticle loading increases and by increasing temperature. Finally based on the experimental results, they fitted one relationship as a function of volume fraction and thermal conductivity and another correlation between thermal conductivity, temperature and mass fraction. For all type of nanoparticle suspensions, maximum enhancement was observed at highest volume fraction 0.48 vol% and highest temperature 60 °C. The maximum enhancements for nanosuspensions of different short SWNTs, long-SWNTs and MCNTs' are 8.1%, 16.2% and 5.0% respectively. From above results following it could be concluded that special surface area and high aspect ratio of long-SWNT facilitates L-SWNT nanofluid for highest thermal conductivity of all other nanoparticles suspended nanofluids. The influence particle concentration and temperature on thermal conductivity was high in case of L-SWNT nanofluids.

Heat transfer characteristics of SWNT-nanofluids as future coolants in both laminar and turbulent flow regimes was investigated in [27]. In this study, SWNT-nanofluid (0.1-1 wt %) with good stability and better dispersion were produced by strategic use of chemical and physical methods. In this study, base fluid is de-ionized water, and surfactant is CTAB. The amount of surfactant CTAB in nanofluid is 1th of the mass fraction of SWNT nanoparticles. Thermal conductivity of nanofluid was determined from apparatus based on transient hot wire method (TC3010L, XI-

ATECH Co.Ltd.). Densimeter and Vibrating wire viscometer are used to measure density and dynamic viscosity of the nanofluid respectively. The maximum enhancement of thermal conductivity (16.2 %) was at maximum loading of nanoparticles (1 wt%) and highest temperature (60°C). Particle concentration has positive effect on viscosity and on other hand temperature has negative effect on viscosity. This behavior is usual as molecular activity and shearing action increases with addition of nanoparticles and surfactant which increases viscosity of the fluid and however at elevated temperature weak molecular attractive forces in liquid decrease which in turn reduces the viscosity.

The improved thermal conductivity of the nanofluid could be valuable if the ratio viscosity enhancement coefficient(C) to thermal conductivity enhancement coefficient(CK) is less than four. C and CK values could be determined from the following relations:

$$\mathrm{C_k} = [\Delta\mathrm{K}/(\mathrm{Kbf} \times \Phi)]$$

$$\mathrm{C}_\mu = [\Delta\mu/(\mu\mathrm{bf} \times \Phi)]$$

where ΔK is change in thermal conductivity, Kbf is thermal conductivity of base fluid, $\Delta\mu$ is change in viscosity and bf is viscosity of base fluid and Φ is the volume fraction of nanoparticles. SWCNT's-nanofluid can show better performance in laminar regime than in turbulent regime, however with increasing temperature and correct concentration of SWNT, nanofluids of SWNT can be also be used in transient regime.

[28] reports the heat transfer behavior of nanofluid obtained by COOH-MWCNT nanoparticles dispersed in water-ethylene glycol (60:40 vol%). In many applications, ethylene glycol is mixed with water to depress the melting point and to improve the boiling point of water. In this experiment a mixture of 60 vol.% water and 40 vol.% ethylene glycol was used as base fluid. Multi-walled carbon nanotubes (MWCNTs) factionalized with COOH in solid volume fractions range 0.025-1.0 vol.% were mixed in the base fluid and magnetic stirring for 2.5 h, ultrasonic processing (400 W, 24 KHz) for 6h were performed to stabilize the nanofluid. Sedimentation and deposition were observed in nanofluids at nanoparticle volume fraction above 1% as clusters form at high volume fraction. The thermal conductivity of the nanofluids were conducted by using a KD2 Pro (Decagon device, Inc, USA) which works on the principle of transient hot-wire technique. Reported apparently linear thermal conductivity enhancements trends with nanoparticle concentration and temperature. The increment in heat conduction due to rise in temperature could be attributed to Brownian motion and the increase in energy exchanges between the nanotubes. The thermal conductivity enhancement by nanoparticle concentration is due to an increase in ratio of surface to volume and collisions between particles. The maximum thermal conductivity enhancement of nanofluid is 34.7%, which occurs at the temperature of 50^{o}C and the solid volume fractions of 1.0%. At any temperature, by increasing the amount of ethylene glycol in the mixture, the thermal conductivity enhancement factor decreases as thermal conductivity of additive ethylene glycol is less than that of water.

Mohammad Hemmat Esfe et al [29] studied the effects of solid volume fraction and temperature on thermal conductivity of DWCNT (inner diameter of 3 nm)-ZnO (diameter of 10-30 nm)/water-ethylene glycol (60:40) nanofluids. The nanoparticles contains equal volume of ZnO and MWCNTs. They used a KD2 Pro conduct meter, Decagon device for measuring the thermal conductivity of nanofluids. This commercial device works on the principle of transient hot wire technique. As in earlier reports here, also thermal conductivity enhancement was found to be with increased with both solid volume fraction at all temperatures. At low solid volume fractions, less than 0.25%, the thermal conductivity enhancement is comparatively higher than that at higher volume fractions. The maximum thermal conductivity enhancement was found with the case of maximum temperature and maximum nanoparticle content. Their results indicated that the effect of temperature is more significant in high solid volume fraction range than in low solid volume fraction range.

M. Karami et al [30] studied the thermal and optical characteristics of MWNT (Diameter 10 nm, Length 5-10 nm) dispersed distilled water nanofluids. Carbon nanotube dispersed nanofluids exhibit good stability, better thermal properties and useful optical properties in solar collectors as direct sunlight absorbers. They for the first time studied the alkaline functionalized carbon nanotubes as an absorber fluid in sunlight gathering device DASC (direct absorption solar collector). CNTs were functionalized with carboxylate groups in order to avoid the use of surfactant. Different solid volume concentration solutions contain 150 ppm, 100 ppm, 50 ppm, 25 pm, 10 ppm, 5 ppm of f-CNTs. Optical transmittance spectra, thermal conductivity was measured by double-beam spectrophotometer (Perkin-Elmer Lambda 1050) and KD2 Pro thermal property analyzer (Decagon devices, Inc., USA) respectively. The results obtained to them show that the sample transmittance decreases with respect to pure water and enhance the overall absorbance of light. The strong absorption band exists for nanofluid at 900-1000 nm and again at 12000 nm. They found that the presence of 150-ppm carbon nanotubes increases the extinction coefficient of pure water by about 4.1 cm^{-1}. Thermal conductivity enhancement results are similar to that of our cases discussed. Thermal conductivity of samples increases with increase in solid volume concentration and temperature. The finest thermal conductivity enhancement was about 27.2% at a temperature of 60^oC and solid volume fraction 150 ppm.

A, Nasiri et al [31] reported that as the number of number of nanotube wall increase, both stability and thermal conductivity decrease. In this experiment distilled water is base fluid and five different types of CNTs namely single walled carbon nanotubes, double walled carbon nanotubes, few walled carbon nanotubes, multi walled carbon nanotubes (<10 nm outer diameter), multi walled carbon nanotubes (10-20 nm outer diameter) are used as nanoparticles. It is reported that SWNT show the best thermal conductivity enhancement over other carbon nanotubes.

3. Discussions

Literature surveys reveal the excellent thermal properties of the carbon nanotube dispersed water based nanofluids. It is very clear that thermal conductivity increases as a function of solid volume fraction and temperature. Enhancement of thermal conductivity of nanofluid is influenced by many factors like structure of nanoparticle, techniques employed for dispersion of nanoparticle, the mean temperature of operation etc... Stability, which is main concern of two-phase mixtures, can be improved by chemical dispersion methods like use of surfactant, functionalization of nanoparticles and physical dispersion techniques like subjecting the nanofluid to magnetic stirring, ultrasonic vibrations. Different CNT's and surfactants used are categorized in Fig. 3 and Fig. 4 respectively.

Nanoparticles	Carbon Nanotubes	Single Walled [26],[27], [28], [32].
		Double Walled [30], [32].
		Few Walled [32].
		Multi Walled [23-25], [27], [29], [32].
	Functionalized Carbon Nanotubes Groups	COOH [29].
		ZnO [30].
		Carboxylate [31].
		Potassium Persulfate [32].

Figure 3 Categorization of CNT's used by researchers

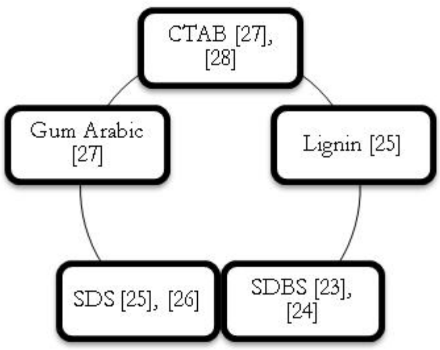

Figure 4 Surfactants used

Many works are associated with the use of single walled carbon nanotubes and multi walled carbon nanotubes. Out of single walled carbon nanotubes and multi walled carbon nanotubes, SWCNTs have excellent thermal properties, but it is difficult to disperse SWCNTs in water without causing much damage to its structure. Multi walled on other hand processes good stability and could be dispersed without much difficulty. Fig. 5 depicts enhancement in thermal conductivity obtained by researchers.

4. Major headings

Physical stabilization has equal importance as chemical stabilization. Xing et al. [27] reported that ultra-sonication by disruptor improves dispersion of nanoparticles in fluid when compared to mechanical stirrers. In addition, power of equipment, time of stirring or agitation through sonication influence the dispersion of nanoparticles.

5. Conclusions

The peer review on nanofluids clearly reflects the excellent thermal characteristics of nanofluids along with good stability. The effect of various surfactants, concentration of nanoparticles and surfactant, temperature are mainly focused in most of the works. Selection of surfactant and its concentration to be set in the solution depends on the concentration of nanoparticles in the solution. The addition of surfactant like SDS, SDBS at low volume fractions of nanoparticles diminishes the thermal conductivity of nanofluid and thermal conductivity increases with the amount of nanoparticle concentration and temperature. The undesirable characteristics observed with the use of surfactant could be reduced by functionalizing nanoparticles. The nanoparticle size and shape also affects the thermal conductivity of nanofluid. High aspect ratio, smallness of nanoparticle is desired for best enhancement, thus nanofluid holding SWNT with high aspect ratio dominate other nanofluids. The unexpected peaks observed in thermal conductivity shows that there exists a favoured three-dimensional spreading of nanotubes possibly related to their aspect ratio where the nanotubes energy exchange through interaction and the number of contacts are more significant that the formation of a percolated network. The thermal conductivity of nanofluid could be further enhanced by increasing the pH, as ions and electrons together accelerate the heat transfer. From the review, it is obvious that nanofluids could substitute existing heat transfer fluids.

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