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A review on thermo-physical properties of bio, non-bio and hybrid nanofluids

James Lau Tze Chen [1*], A. N. Oumer [1] and Azizuddin A. A[1]**

[1]Faculty of Mechanical Engineering, Universiti Malaysia Pahang,
26600 Pekan, Pahang, Malaysia
*Email: jameslautzechen@gmail.com
**Email: ahmnur99@gmail.com, nurye@ump.edu.my
Phone: +6094246231; Fax: +6094246222

ABSTRACT

The pressure drop and thermal performance of various nanofluids can be affected by their thermo-physical properties. However, there are many different parameters that need to be considered when determining the thermo-physical properties of nanofluids. This paper highlights a detail reviews on the thermo-physical properties of nanofluids with different material type and effect of some process parameters (such as material type, temperature and concentration) on the thermo-physical properties of nanofluids. Four thermo-physical properties mainly density, viscosity, thermal conductivity and specific heat capacity from different literatures were summarized, discussed and presented. The lowest viscosity value of nanofluids in literature was mango bark water-based nanofluid (0.81cP). On the other hand, the maximum thermal conductivity value of nanofluids in the literature was GNP-Ag water-based nanofluid (0.69W/mK). The density and specific heat capacity are strongly dependent on the material type. Meanwhile, the viscosity and thermal conductivity are greatly affected by temperature and concentration. The most influential parameters on thermo-physical properties of nanofluids are material type followed by temperature. Most of the literatures confirmed bio nanofluids have low viscosity value and hybrid have high thermal conductivity values.

Keywords: Nanofluids; bio-nanoparticles; heat transfer; thermophysical properties.

INTRODUCTION

Nanoparticles can be defined as materials with one of its dimension is in the nanoscale (100 nm or less) [1]. Nanoparticles and nanotubes can be added to lubricants and engine coolants to create nanofluids that can improve the thermal conductivity for better heat exchange rates as well as fuel efficiency. The excellent friction reducing properties of nanoparticles also help in tribological research. Nanofluids were first introduced by Choi and Eastman in the early 1990s. They hoped to improve poor thermal conductivity of conventional fluids by adding metallic nanoparticles (<100 nm) to distilled water [2–3]. The resulting "nanofluids" have significantly high thermal conductivities compared to the conventional fluids. For instance, 5% volume concentration of copper oxide nanoparticles suspended in water results in 60% thermal conductivity enhancement [4]. In engineering applications, nanofluids can be applied in thermosiphons, electronics cooling, microchannel heat sink and automotive radiator [5– 9].

Generally, the flow and heat transfer performance of nanofluid is highly influenced by its thermophysical properties namely density, viscosity, thermal conductivity, and specific heat capacity. Various activities are being made to improve the performance of nanofluids by enhancing or degrading the thermophysical properties of the nanofluid. For instance, it is well documented that most of metallic nanoparticles have much higher thermal conductivity than conventional heat transfer fluids (HTFs) such as water and ethylene glycol. On the other hand, organic particles made of rice husk or wood have low density and low thermal conductivity than conventional HTFs. Thus, it is novel idea, trying to enhance the thermal conductivity of nanofluids by adding metallic particles and reduce the viscosity by adding organic particles into the conventional HTFs.

The word 'bio' actually means naturally degradable materials that can be obtained from plants (such as seed, leaf, bark, stem, root, etc.) [10]. Non-bio means metallic and non-metallic materials. There are various type of metallic particles used to prepare nanofluids such as Al, Ag, Au, Cu and Fe. Meanwhile, the common non-metal particles used to prepare nanofluids are SiC, CuO, TiO_2, Al_2O_3 and Fe_3O_4. [11]. The word "hybrid" means composite materials (metal matrix, ceramic matrix, polymer matrix) [12]. For instance, MgO/Fe, Al_2O_3/Cu, Mg/CNT and Al/CNT are metal matrix nanocomposites. CNT/Fe_3O_4, Al2O3/SiC Al_2O_3/SiO_2 and Al2O_3/TiO_2 are ceramic matrix nanocomposites. Polymer/CNT, Polyester/TiO_2 thermoset polymer/layered silicates are polymer matrix nanocomposites. The frequently used base fluids for nanofluids preparation are engine oil, glycol, ethylene/water mixtures, water and ethylene [12]. Huminic et al. (2016) found that conventional fluids have low heat transfer coefficients than nanofluids in curved tubes [13]. Low thermal conductivity of conventional fluids is a main limitation in the development of energy-efficient heat transfer fluids required in many industrial applications.

The main purpose of this review paper is to highlight the thermo-physical properties of bio, non-bio and hybrid nanofluids with different material type. Moreover, effect of some process parameters (such as material type, temperature and concentration) on the thermo-physical properties of nanofluids are presented. Four thermo-physical properties mainly density, viscosity, thermal conductivity and specific heat capacity from different literature reviews and experimental studies are summarized, discussed and presented. Most of the existing nanofluids are made of non-bio materials and they are known to exhibit high thermal performance with high pressure drop penalty. However, what about other types of nanofluids such as bio and bio/non-bio hybrid nanofluids? Is it possible to reduce the pressure drop penalty without compromising the heat transfer performance? Where bio nanofluids can be used?

This review could help researchers to get some idea of thermophysical properties (density, viscosity, thermal conductivity and specific heat capacity) of bio, non-bio and hybrid nanofluids. The first section discuss on nanoparticles preparation followed by nanofluids preparation, stability measurement methods of nanofluids and stability enhancement methods of nanofluids. Then, thermophysical properties of bio, non-bio and hybrid nanofluids were discussed. Finally, the factors affecting thermophysical properties of nanofluids were discussed.

PREPARATION OF BIO AND NON-BIO NANOPARTICLES

Bio nanoparticles were widely used in medical and biological fields. In medical and biological fields, bio nanofluids can be used as nanodrug delivery, cancer therapeutics, cryopreservation, nanocryosurgery, sensing and imaging [14]. Grapheme and CNTs are some advanced structural materials which achieve the significant high increment on the thermal conductivity of the nanofluids. Au, Ag, Cu and Fe are few kind of metallic simple with high thermal conductivity that achieves noticeable strengthening property. Then, CuO, Al_2O_3, TiO_2, ZnO, SiC and SiO_2 are some of the metal or non-metallic compound with different thermal conductivity [15].

The most common type of bio nanoparticle preparation method is grinding the raw materials by using ball milling machine. For instance, Sharifpur et al. (2017) prepared bio-nanoparticles from the mango bark and leaves by ball milling after the raw material are dried under the hot sun [16]. Moreover, Awua et al. (2016) used ball mill continuously for 48 hours to reduce dried palm kernel fibre to nanoscale powder [17].

Non-bio nanoparticle can be prepared using top-down and bottom-up methods. In top-down methods, suitable bulk material crushed into small particles using different methods such as milling, grinding, thermal/laser ablation, sputtering, etc [18]. In the bottom-up methods, nanoparticles can be prepared using chemical and biological methods by self-assembling of atoms to new nuclei that grow into a nanoscale particle [19].

There are many different ways that have been used for preparation of non-bio (metal and non-metal) nanoparticles such as physical, chemical, green biological and other green methods as shown in Figure 1 [20]. However, preparation of bio nanoparticles in most the literature reviews using physical method (ball milling).

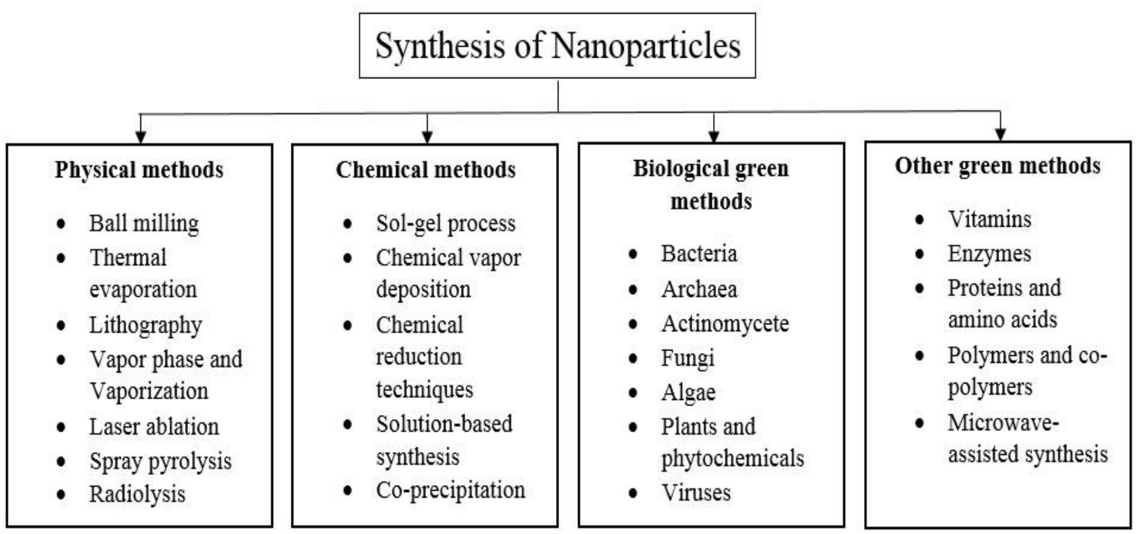

Figure 1. Various methods for metal-nanoparticles preparation.

BIO AND NON-BIO NANOFLUID PREPARATION

Nanofluids are prepared by combining nanoparticles into base liquids [21]. Synthesis of nanofluids are broadly divided into two main categories: one-step method and two-step methods [22]. One-step method is the method that the nanoparticles are spread over with a base fluid directly and mostly by chemical methods. Meanwhile, two-step method is the technique that nanoparticles are produced first in powders form either in physical or chemical methods, later spread over a base fluid [23].

One-step Method

The method which combines the manufacturing of nanoparticles with the base fluids in a joint process called one-step method [24]. The common one step methods are liquid chemical, direct evaporation and physical vapor deposition methods [25]. The advantages of this method include uniform dispersion, minimized agglomeration and enhanced stability without any process of storage, transportation, drying, and dispersion of nanoparticles. However, the disadvantages of this method are high production cost, slow process of production and limited low pressure fluids can be prepared through this process [26]. Synthesis of nanofluid by one-step method is suggested for metal particles with high thermal conductivity to prevent oxidation effect. However, this method cannot be applied for commercial use because of the slow process of production. Thus, it is only practical for research purposes. [27].

Two-step Method

Two-step method is the more used technique compared to the one-step method according to the available information from the commercial nano-powders supplied by several companies [28]. These nano-powders are first produced through milling, grinding, chemical and sol-gel processes. In the second processing step, the nano-particles are prepared separately and dispersed into the base fluid using high shear mixing equipment or ultra-sonication using ultrasonic vibrator [29]. Two step preparation process of nanofluids is illustrated in Figure 2 [30]. The advantages of this method include economical affordability and large scale production. However, the drawbacks of this method are aggregation of nanoparticles due to Van der wall and cohesive forces between particles [31].

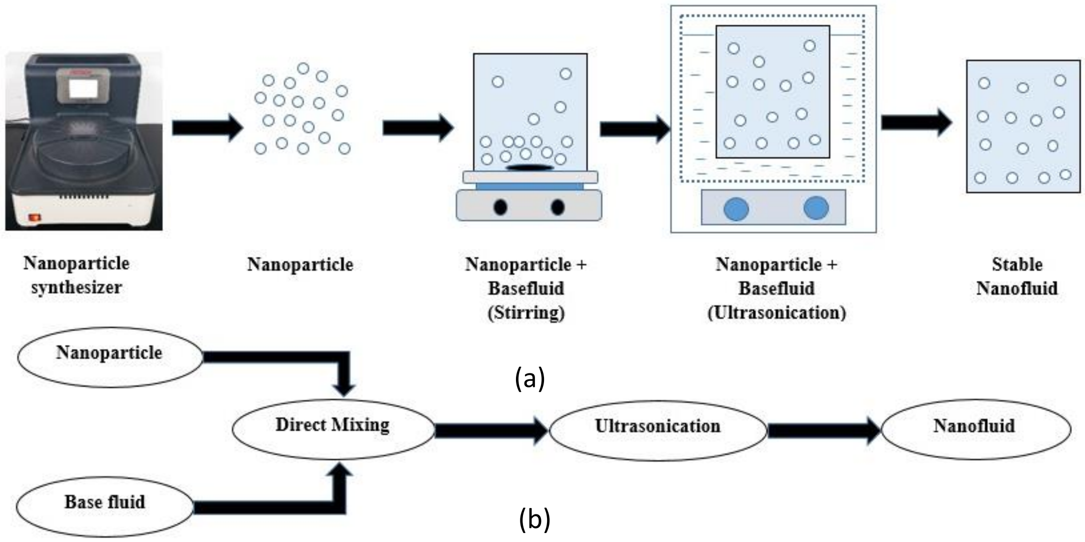

Figure 2. Two step preparation method (a) nanoparticles produced by nanoparticle synthesizer and distributed in a base fluid using stirrer (b) nanoparticles and base fluid mixed directly then dispersant addition and ultrasonication.

STABILITY

One of the important factor that affects the performance of nanofluid is its stability [32]. Thermodynamic unstable occurred in nanofluids as nanofluids are multi-phase dispersion system with high surface energies. When nanoparticles are dispersed in the base fluid, they will have strong Brownian motion. The mobility of the nanoparticles can offset their sedimentation caused by the gravity field. Moreover, the van der Waals forces between molecules may deteriorate dispersion of nanoparticles in the fluids with time. At working conditions of the nanofluid, it is important that there have no chemical reactions occurred either between the base fluid and nanoparticles or between the suspended nanoparticles. Thus, aggregation and sedimentation are two phenomena that are critical to the stability of nanofluid [33].

Stability Measurement Methods

The biggest challenge in nanofluid technology is the maintenance of colloidal stability [34]. Two mechanisms can be used to enhance stability of nanofluids which are electrostatic stabilization and steric stabilization. Electrostatic stabilization can be done by absorbing ions to the electrophilic metal surface to create a Columbic repulsion force between the nanoclusters. Meanwhile, steric stabilization of nanoparticles can be achieved by attaching macromolecules such as surfactants to the surface of the particles which provide steric barrier to prevent agglomeration of nanoparticles [24]. Fortunately, many researchers have invented various techniques for stability analysis such as zeta potential, sedimentation, centrifugation, spectral analysis, electron microscopy and light scattering [35].

Zeta potential

The potential difference between charged nanoparticles and base fluid that defines the degree of repulsion between charged particles in the fluid is called Zeta potential. The nanofluid is considered as unstable it contains colloids with low zeta potential (negative or positive). On the other hand, colloids with high zeta potential are stable [35]. Zeta potential (ζ) represents the repulsion force between two particles based on the electrophoresis theory [36]. To increase zeta potential, it can be altered by managing the pH of the nanofluid. By looking at the zeta potential value, if it shows value of 60 mV and above then the nanofluid is considered as highly stable, (60 mV and above), stable (above 30 mV), unstable (below 20mV) and agglomeration (lower than 5 mV) as reported by Sadeghinezhad et al. (2014) [37].

Sedimentation method

Sedimentation method is the most reliable and easy technique [38]. Variation of particle size or concentration of supernatant particle with sedimentation time is acquired by special apparatus in this method. If the particle size or concentration of supernatant particles keeps constant, the nanofluids are assumed to be stable. The stability of nanofluids can be observed through the images of sedimentation of nanoparticles inside test tubes taken by digital camera. However, the con for this method is the long period of observation needed to analyze the stability for the prepared nanoparticles. Shao et al. reported that sedimentation rates of 1.0 wt. % of TiO_2/water nanofluids are lower than 0.1 wt. % of TiO_2/water nanofluids due to the higher viscosity of 1.0 wt. % of TiO_2/water nanofluids [39].

Centrifugation method

By using centrifugal force, centrifuge rotates quickly to separate denser materials suspended in a liquid medium is called centrifugation method. The drawbacks of this method are rowdy functioning and it requires high initial cost [31]. Singh et al. (2008) used this technique to evaluate stability of Ag/ethanol nanofluid. The result of their findings shows that the nanofluid was stable when kept in stationary state over a month at room temperature. In other research work by Singh et al. (2008), the stability was maintained for more than 10 hours under 3000 rpm centrifugation [40]. Li and Kaner (2005) investigated stability of polyaniline colloids using centrifugation technique. Li and Kaner (2005) reported that it was stable for long period and even more stable after few times of centrifugation because the particles inside the fluid become purer that lead to stronger electrostatic repulsive forces between them [41].

Spectral analysis method

One of the important approaches for stability investigation is the application of Ultraviolet-visible spectrophotometer (UV–Vis spectrophotometer) [42]. The advantage of this method is that it gives concentration of nanofluids in quantitative form [31]. The function of UV–Vis spectrometer is to analyze the dynamics of the dispersion [23]. Meanwhile, UV–Vis absorption spectrum is used to measure the light absorption and the dispersion characteristics of distributions. Well distributed nanoparticles in the base fluid shows higher absorbency (lower transmittance) [43]. Yang et al (2015) reported that the transmittance of nano-refrigerants decreased with higher mass fraction and addition of dispersant. However, the transmittance of nano-refrigerants increases at level about 20% after 50 hours. Transmittance of nano-refrigerants is its effectiveness in transmitting radiant energy. This shows that the stability of nano-refrigerants can be improved by increasing mass fraction and addition of dispersant because the lower the transmittance of nano-refrigerants, the higher the stability of nano-refrigerants [44].

Electron microscopy and light scattering method

Microscopy and light scattering techniques can be used to measure particle size distribution for observing particle aggregation. Scanning Electron Microscopy (SEM) and Transmission Electron Microscope (TEM) are high resolution microscope used to take the digital image of nanoparticles [43]. For instance, Xiaoke Li et al. (2015) inspected the microstructure of silicon carbide nanofluids using SEM after the nanofluid was stored for 24 hours. The result shows that there are few small agglomerates existed but spread evenly in the nanofluids [45]. In separate study, Khaleduzzama et al. (2015) using TEM captured the particle distribution and microstructure of Al_2O_3-water nanofluid [46]. Kim et al. (2015) investigated the suspension stability of Al_2O_3 by measuring the intensity of light transmitted by each nanofluid using a laser-scattering method. [47]. The result shows that the photons transmitted constantly through the nanofluids with brick-shaped Al_2O_3 nanoparticles. Meanwhile, the photons transmitted decreased through the nanofluids with platelet-shaped Al_2O_3 nanoparticles and decreased even more through the nanofluids with blade-shaped Al_2O_3 nanoparticles. This shows that blade-shaped Al_2O_3 nanoparticles suspended in water are aggregated faster than nanoparticles of other shapes, while brick-shaped Al_2O_3 nanoparticles stable when suspended in water.

Table 1. Summary of nanofluid stability measurements methods.

Nanofluids	**Method**	**Findings**	**References**
Al_2O_3/water	Zeta potential	- The method to determine the stability of nanofluid, but it is more expensive method compared to other methods. - The nanofluid possesses good stability with zeta potential greater than 40 mV or less than −40 mV.	[48]
Al_2O_3/water	Spectral analysis	- Well distributed nanoparticles in the base fluid shows higher absorbency - Absorption and particle concentration showed linear relation. - From the relation, the relative stability of nanofluids was estimated.	[49]
TiO_2/water	Sedimentation	- Simplest method to determine the stability of nanofluid by visual inspection. - Long waiting time to study nanofluid stability without particle clustering information.	[39]
Ag/ethanol	Centrifugation	- Rowdy functioning and it requires high initial. - Nanofluid was stable if the nanoparticles seem to be well distributed in base fluid after centrifugation by visual inspection.	[40]
TiO_2/water	Electron microscopy and light scattering	- Nanofluid stabilities were estimated by FESEM image. - Nanofluids were stable if the nanoparticles seem to be well distributed	[50]

Stability enhancement techniques

Some techniques have been used to enhance the stability of nanofluid [51]. Generally, there are three techniques applied to achieve stable suspension of the nanoparticles which are adding surfactants, using ultrasonic vibration and managing the pH value of the suspension. All of these methods aim to prevent the formation of clustering particles and varying the surface properties of suspended nanoparticles and so that stable suspension can be obtained [47].

Addition of surfactants1

In order to avoid fast sedimentation, surfactant addition to the base fluid can decrease its surface tension and enhance the immersion of the particles [43]. This method is known to be the simplest and cost effective technique used to increase the stability of nanofluids [52]. Although addition of surfactant is an effective way to improve the dispensability of nanoparticles, this technique is unsuitable because of bonding damage between surfactants and nanoparticles at high temperature [31].

Conventional surfactants has been used by many researchers. Some of the conventional surfactants include: Sodium Dodecylbenzene Sulfonate (SDBS) [53], Sodium Dodecyl Sulfate (SDS) [54], Cetyl Trimethyl Ammonium Bromide (CTAB) [55] and Polyvinyl Pyrrolidone (PVP) [53]. Paramashivaiah and Rajashekjar reported that SDBS performs better than SDS for stable dispersion of graphene/simarouba biodiesel nanofluid [56]. Al-Waeli et al. reported that CTAB is the best surfactant for use in SiC/water nanofluid. The maximum stability time was 93 days with 1.0ml of CTAB [57]. Zhai et al. reported that PVP performs better than SDS for stabilize Al_2O_3/EG nanofluid (stable for exceeding 30 days) [58].

pH of nanofluid

Electro-kinetic properties of nanofluid affect its stability. Thus, controlling the pH value of nanofluids can increase their stability because of strong repulsive forces between suspended particles. There are various methods of pH controlling mechanisms in nanofluids and one of them is acid treatment. A study by Wen et al. (2009) shows that good stability of CNT in water can be produced by simple acid treatment [59]. However, different nanofluids have different optimized pH values. For instance, Leong et al. (2018) evaluated the optimized pH value of Cu-TiO_2 hybrid nanofluid for neutral pH of base fluid is 7 for maximum thermal conductivity [53]. Esfe et al. found that Ag-MgO hybrid nanofluids become stable for several hours with pH value 5.74 [55]. Akilu et al. (2015) reported TiO_2-CuO/C hybrid nanofluid has more stability in higher pH value [60].

Ultrasonic agitation

Ultrasonication is a common technique applied by researchers for nanofluids stabilization. Nanoparticles can be uniformly disperse in the base fluid without variation in surface properties of the nanoparticles using high frequency ultrasonic vibration. The optimum sonication time depends on size of nanoparticle, concentration of nanoparticles and type of nanofluid. There are two categories of ultrasonication process which are direct and indirect sonication. For direct sonication, which is the most common way, ultrasonic probe is put directly into the vessel containing nanofluid. In this case, Energy is transmitted from the probe directly into the nanofluid with high intensity and the nanofluid sample is processed quickly. For indirect sonication, the nanofluid in the container is subjected to ultrasonic wave through some liquid in container that submerged. The ultrasonic vibrations can be transmitted by using ultrasonic bath, ultrasonic cleaner, ultrasonic vibrator, ultrasonic probe and homogenizers [31].

THERMO-PHYSICAL PROPERTIES OF BIO/NON-BIO NANOFLUIDS

Many researches have been carried out to determine the properties of the hybrid nanofluids at various operating conditions. Some of them indicated that the thermal properties of the nanofluids are enhanced compared to the conventional fluids [61]. The properties of the hybrid nanofluid are directly related to the performance of heat transfer [62]. Density, viscosity, thermal conductivity and specific heat are the main thermophysical properties that change their values with addition of nanoparticle to the base fluid [63].

Density

In nanofluid, density is an important parameter as it affects pump loss, Reynolds number, friction factor and other properties. Thus, density gives huge implication towards the evolution of thermal performance and pressure drop [62]. Askari et al. (2016) used Pycnometer to determine the density of ultra-stable kerosene-based Fe_3O_4/Graphene nanofluids [64]. Said et al (2017) reported that the density of nanofluid was measured using Density Metre DA-130N [65]. The density of nanofluids and hybrid nanofluids are estimated using the following equations [66].

$$\rho_{nf} = \emptyset\rho_{np} + [1 - \emptyset] \times \rho_{bf} \tag{1}$$

where ρ_{nf} is density of nanofluid, ρ_{np} is density of nanoparticle, ρ_{bf} is density of base fluid, $\emptyset$ is volume concentration.

Addition of nanoparticles will increase the density of nanofluids. At higher concentration of nanoparticles, the increase of density could be very small and is insignificant. This is because the addition of nanoparticles to base fluid increase the mass of the nanofluid without changing its volume. As the result, the density increase as the mass per volume increase [64]. Besides, the reasons that density increase is because of the interface effects on the bulk fluid properties caused by the solid nanoparticle surface as well as the interactions among the nanoparticles themselves. However, the increment of the density is very small that usually considered negligible [67].

Shoghl et al. (2016) investigated the effect of nanoparticle concentration and temperature on the density of metal oxide nanofluids. According to their findings, the density increased with concentration and decreased with temperature [68]. For Fe_3O_4 and hybrid Graphene-Fe_3O_4 nanofluids at room temperature, Askari et al. (2016) showed that the density of fluids increases by adding particles concentration [64]. The density of hybrid GNP–Pt/water nanofluids decreased when the temperature increased. Meanwhile, the density of hybrid GNP–Pt/water nanofluids increased when particle concentrations increased [69]. Yarmand et al. (2015) reported that the density increment of the hybrid GNP-Ag nanofluid about 0.09% for 0.1% fraction of nanoparticles with different temperatures (20°C to 40°C) [70]. Yarmand et al. (2016) reported that the density of the f-GNP nanofluid increased about

0.06% for 0.1% volume fraction of nanoparticles [71]. The reason that density of nanofluids decreased with temperature is behaviour of fluids that increase in fluid volume by increasing the temperature. The reason that density of nanofluids increased with particle concentration might be because the nanoparticles lie between the layers of base fluid that increase the mass of the base fluid without changing its volume.

The variations of density with concentration studied by various researchers are compared in Figure 3. As can be easily seen from the graph, the density of the nanofluid increases with concentration for all nanofluids. This is because the addition of nanoparticles to base fluid increase the mass of the nanofluid without changing its volume [64]. As the result, the density increase as the mass per volume increase. The density of nanofluids strongly depends on the density of nanoparticles and base fluids. As can be easily seen from the graph, kerosene based nanofluids have higher density than water based nanofluids. The significant function of density is to design a piping system because density of nanofluids will affect the pressure drop and pumping power of the system. In order to get required density, it is important to know the properties of the base fluids and nanoparticles.

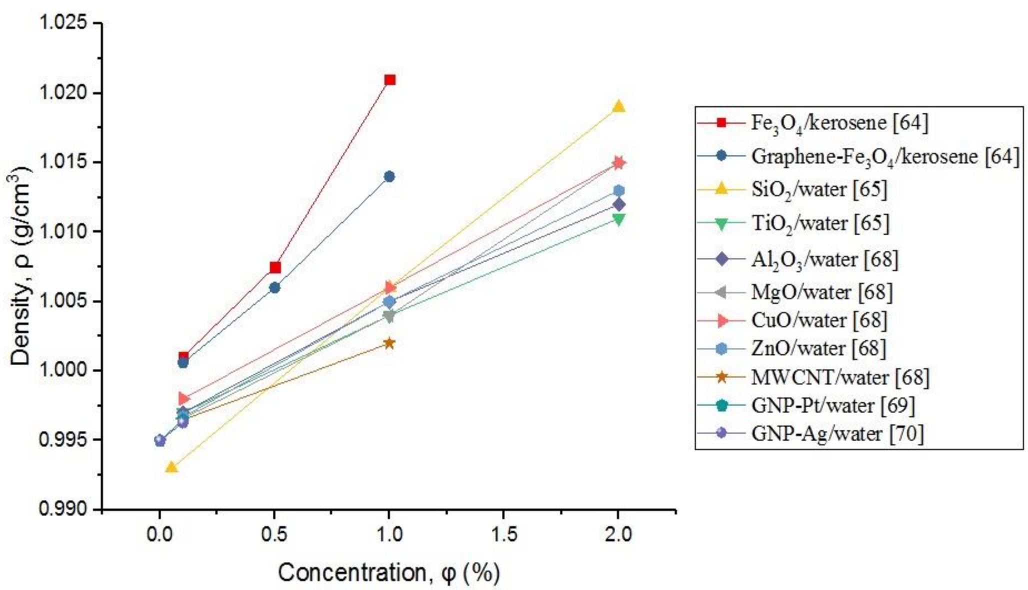

Figure 3. Variation of density as a function of concentration.

Viscosity

Viscosity is defined as the stickiness of the fluids. In nanofluids, viscosity is the internal resistance force for the fluid which is an influential parameter for heat transfer applications [72]. In engineering systems involving fluid flow, viscosity is as important as thermal conductivity [73]. This is because the increment of pressure drop significantly depends on viscosity which in turn affect the total the pumping power. On the other hand, viscosity diminishes exponentially as the nanofluid temperature increases because of a weakening of inter-molecular forces and inter-particle forces between molecules. In addition, nanofluids possess higher viscosity with higher nanoparticle concentrations.

Sharifpur et al. (2017) investigated that mango bark nanofluid with 0.5% concentration has lower viscosity than water at temperature 15°C to 35°C using sine-wave vibro-viscometer SV-10 [16]. Kallamu et al. (2016) using a constant shear rate vibro-viscometer (SV-10) to measure the viscosity of banana-fibre/water nanofluids and reported that viscosity of the nanofluids slightly increases with the increment of volume fraction and decreasing exponentially with an increase in the nanofluid temperature [74]. Adewumi et al. (2018) investigated viscosity of 60:40% ethylene glycol (EG) and water (W) nanofluids containing coconut fibre using sine-wave vibro-viscometer SV–10. The viscosity of the nanofluids decreased with temperature, while increased with concentration [75].

Namburu et al. (2007) conducted viscosity measurements of CuO nanofluid with various concentrations at various temperatures in the range of 35°C to 50°C using Spindle SC-18 viscometer. The results shown that the viscosity of the nanofluids increased with concentration and decreased with temperature [76]. Said et al (2017) shows similar trends for viscosity measurements of SiO_2/water and TiO_2/water nanofluids using Brookfield viscometer (DV-II + Pro Programmable Viscometer), which was connected with a temperature controlled bath. The results determined that viscosity diminished exponentially with temperature. Furthermore, the nanofluids possess higher viscosity with concentration [65]. The viscosity increased with concentration because bigger nano-clusters form due to the van der Waals forces between nanoparticles and base fluids. Furthermore, the viscosity decreased with temperature due to the intermolecular interactions between the molecules become feeble [77]. Sunder et al. (2014) proved viscosity for MWCNT-FE_3O_4 hybrid nanofluid increased (0.3%) 1.27 times and 1.5 times compared to base fluid at different temperatures (20°C to 60°C) [78]. Yarmand et al. (2015) investigated GNP–Ag hybrid nanofluids for different concentrations and at different temperatures (20°C to 40°C). At 40°C, it shows about 30% increase in viscosity for 0.1% concentration of nanofluids compared to base fluid [70].

The viscosity of nanofluids also depends on material type and base fluids. As can be easily seen from the graph, bio nanofluids such as mango/water and banana/water have lowest viscosity following by hybrid non-bio nanofluids and single non-bio nanofluids. The mixture of ethylene glycol and water based nanofluids have higher viscosity than water based nanofluids. For instance, at 0.5% concentration, the viscosity of Coconut/water-EG nanofluid is 60.0%, 264.5% and 338.2% higher that of TiO_2/water, SiO_2/water and Mango/water nanofluids On the other hand, at 30°C, mango bark/water nanofluid with higher concentration of 0.5% has 21.8% lower viscosity value than GNP-Ag/water nanofluid (0.1% concentration) and 26.7% for TiO_2/water nanofluid (0.05% concentration). The significant function of viscosity is to design a piping system because viscosity of nanofluids will affect the pressure drop and pumping power of the system.

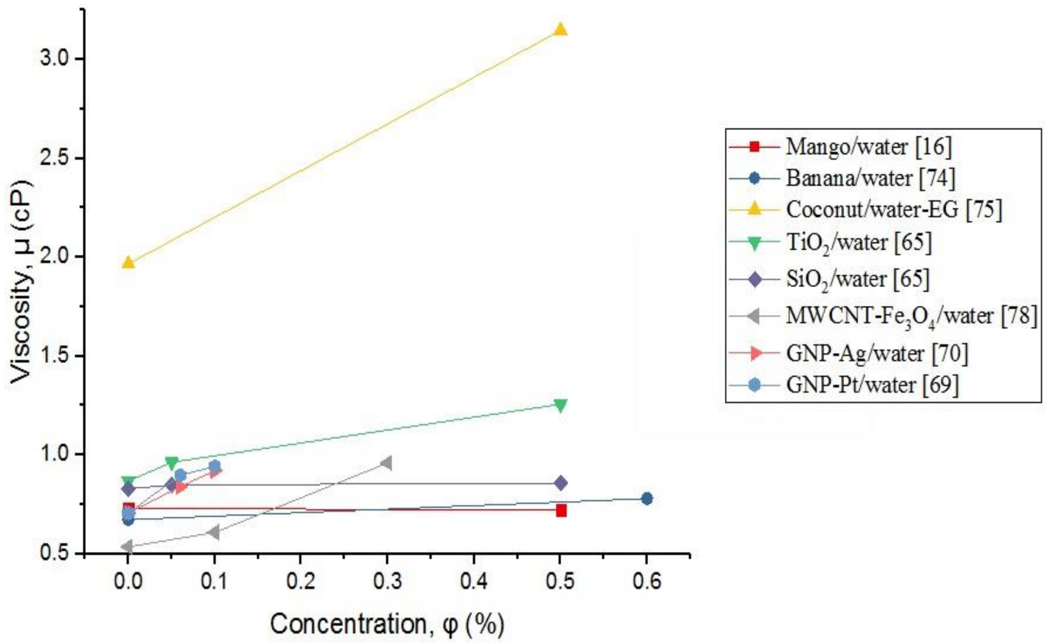

Figure 4. Variation of viscosity as a function of concentration.

Thermal conductivity

Thermal conductivity is the primary properties for nanofluids application investigated by most researchers. Although many experimental investigations related to thermal conductivity of nanofluids are carried out, the obtained results are different from each other in many ways. For instance, the measured values of thermal conductivity are quite different in different works even with same kind of nanofluid. Besides, particles' parameters (particle type, loading, size and shape), environmental parameters (pH value, temperature and the standing time etc) as well as base fluid also cause variation on thermal conductivity [15]. Thermal conductivity of the nanofluids can be estimated using Equation 2 with transient hot-wire technique [79]. Issa (2016) estimate the thermal conductivity of Al_2O_3/water nanofluids using Equation 3 and the temperature history obtained by the thermal property analyser [80].

$$k = \left[\frac{q}{4\pi(\Delta T_2 - \Delta T_1)}\right] \ln\frac{t_2}{t_1} \tag{2}$$

$$\lambda = \frac{q}{4\pi L}\frac{d\ln t}{d\Delta T} \tag{3}$$

where k, λ are the fluid thermal conductivity of the nanofluid, q is the heating energy in the needle sensor, L is the length of the hot wire, t is time, and T is temperature.

Sharifpur et al (2017) explored thermal conductivity of water and mango bark/water nanofluid at different concentrations (0.1%, 0.5% and 1.0%) and temperatures (10^{o}C to 40^{o}C) using KD2 Pro Thermal Property Analyser. From the result, mango bark/water nanofluid has no significant thermal conductivity enhancement compared to water [16]. Awua et al (2016) explored thermal conductivity of palm kernel fibre nanofluid with deionized water and ethylene glycol (50:50) as base fluids at different concentrations (0.1, 0.2, 0.3, 0.4 and 0.5 %)

and temperatures (10ºC to 50ºC) using KD2 Pro Thermal Property Analyser. Highest value was recorded at 50ºC with 0.5 % concentration. At 10ºC to 50ºC, lowest enhancement in thermal conductivity was recorded to be 2.7 % at 0.1 % concentration. Meanwhile, maximum average enhancement was 16.1 % at 0.5 % concentration [17].

In separate study, Ghanbarpour et al. (2014) found that the thermal conductivity of Al_2O_3/water nanofluid changes with temperature at different concentrations using Transient Plane Source (TPS) method [81]. Gangadevi et al. (2018) investigated CuO/water nanofluid using KD2 Pro thermal property analyzer and found that the thermal conductivity of CuO/water nanofluid increased with concentration, temperature and sonication time [82]. Syam Sundar et al. (2013) reported that thermal conductivity of Fe_3O_4/water nanofluid increases with an increase in concentration and temperature [83]. H.Li et al (2014) shows the distribution of thermal conductivities of ZnO/EG nanofluids with various concentrations (1.75% to 10.5%) and temperature (15°C to 55°C) respectively using transient hot-wire method. The results showed that the thermal conductivity of ZnO/EG nanofluids increased with concentration and temperature [84]. Batmunkh et al. (2014) shows the thermal conductivity of TiO_2/water nanofluid increased with concentration and temperature using thermal conductivity analyzer (15°C to 40°C). The reason that thermal conductivity of the nanofluids increased with temperature is the effect of enhanced Brownian motion at higher temperature. Meanwhile, the thermal conductivity of the nanofluids increased with concentration because the increasing amount of nanoparticles suspended in the base fluid [85].

Esfahani et al. (2018) reported that thermal conductivity of ZnO-Ag/water hybrid nanofluid increased with temperature and concentration. This is because increasing temperature causes increment of kinetic energy of nanofluid molecules. Thus, greater incidence of collisions between surface atoms with fluid molecules. However, the effect of temperature decreases with decreasing concentration as percentage of collisions between surface atoms with fluid molecules also depends on nanoparticles concentration in base fluid [86]. Nabil et al. (2017) investigated thermal conductivity of TiO_2-SiO_2 hybrid nanofluids for various temperatures (30°C to 80°C) and different volume concentrations (0.5 to 3.0%) using the KD2 Pro thermal property analyzer. At 3.0% concentration and temperature of 80°C, maximum enhancement was found with 22.8% higher compared to the base fluid. At higher temperature, rate of collision of particles occurred increased due to more kinetic energy carried by particles, leading to increment of thermal conductivity [87]. Yarmand et al. (2015) investigated thermal conductivity of GNP–Ag hybrid nanofluids for different concentrations and at different temperatures (20°C to 40°C). It shows about 14% thermal conductivity enhancement for 0.1% concentration of nanofluids compared to base fluid [70]. Yarmand et al. (2016) presents the thermal conductivity of water based functionalized GNP–Pt nanofluids at various temperatures (20 °C to 40 °C) and different concentrations. For temperatures of 20°C to 40°C, it shows about 9.3% thermal conductivity enhancement for 0.1% concentration of nanofluids [69]. The results shows thermal conductivity of nanofluids increased with temperature and concentration because micro-convection and Brownian motion of the particles in the base fluid [78]. Batmunkh et al. (2014) reported the thermal conductivity of TiO_2-Ag/water hybrid nanofluid increased with concentration and temperature. Besides, the thermal conductivity of TiO_2-Ag/water hybrid nanofluid is higher than TiO_2/water nanofluid as Ag nanoparticles have higher thermal conductivity than TiO_2 nanoparticles [85].

In the present study, the variations of thermal conductivity as a function of temperature for nanofluids that carried out by different researchers were shown in Figure 5. Thermal conductivity of the nanofluids increased with temperature is because of the effect of enhanced Brownian motion at higher temperature. As can be easily seen from the graph, bio-nanofluids such as palm kernel/water-EG nanofluids and mango/water nanofluid have relatively low thermal conductivity compared to non-bio nanofluids. Hybrid non-bio nanofluids have highest thermal conductivity even with low nanoparticles concentration of 0.1%. Single non-bio nanofluids has medium thermal conductivity. At 20°C, GNP-Ag nanofluid with lower concentration of 0.1% has 8.3% higher thermal conductivity value than CuO/water nanofluid (1.0% concentration) and 13.1% for mango bark/water nanofluid (1.0% concentration). This shows that hybrid non-bio nanoparticles have greatest thermal conductivity enhancement of base fluids compared to single non-bio nanoparticles and bio nanoparticles.

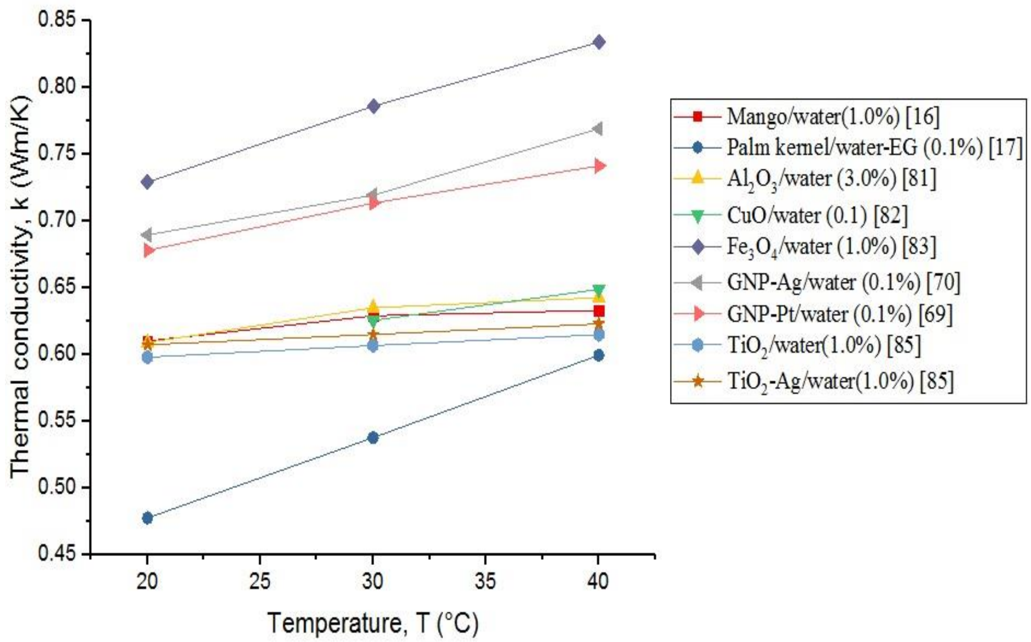

Figure 5. Variation of thermal conductivity as a function of temperature.

Specific heat capacity

Specific heat capacity is one of the important properties that affect the performance of nanofluids. However, there are few literatures related to the effect of nanoparticle on the specific heat capacity of nanofluids [62]. The function of specific heat capacity of a nanofluid is to dictate the variation of temperature that affect the heat transfer and flow performance [88]. By adding small amount of the nanoparticles, specific heat capacity values of nanofluids can be modified significantly [89]. The specific heat capacity of nanofluids can be measured from equations and also by a differential scanning calorimeter [90],[66].

$$C_{p,nf}\rho_{nf} = \emptyset\rho_{np}C_{p,np} + [1-\emptyset] \times \rho_{bf}C_{p,bf} \tag{4}$$

where $C_{p,nf}$ is specific heat capacity of nanofluid, ρ_{nf} is density of nanofluid, ρ_{np} is density of nanoparticle, $C_{p,np}$ is specific heat capacity of nanoparticle, ρ_{bf} is density of base fluid, $C_{p,bf}$ ks specific heat capacity of base fluid.

Cabaleiro et al. investigated the specific heat capacities of Mg/EG, ZnO/EG ZrO_2/EG, ZnO/water-EG and ZrO_2/water-EG using differential scanning calorimeter, DSC, Q2000 (TA Instruments, New Castle) equipped with a refrigerated cooling system RSC90 [91]. The results showed that specific heat capacity of all the nanofluids increased with temperature. O'Hanley et al. (2012) investigated the specific heat capacities of SiO_2/water, Al_2O_3/water, and CuO/water nanofluids using differential scanning calorimeter and showed that the specific heat capacity of the nanofluids decreased with nanoparticle concentration [92]. Vajjha et al. (2009) investigated the specific heat capacity of three nanofluids containing aluminium oxide, zinc oxide, and silicon dioxide nanoparticles in a base fluid of 60:40 EG/ over a temperature range of 315–363 K. The result shown that specific heat capacity of the nanofluids decreased with nanoparticles concentration and increased with temperature [93]. Vajjha et al. (2012) investigated specific heat capacity of nanofluids using Al_2O_3, CuO and SiO_2 with base fluid of 60:40 EG/W with variations of nanoparticle volume concentration and temperature. The specific heat capacity of these nanofluids decreased with nanoparticle volume concentration because the nanoparticles have lower specific heat compared to the base fluid. Meanwhile, the specific heat capacity increased with temperature showing nanofluids possess slightly better thermal capacity at higher temperature [94]. Hussein et al. (2013) investigated specific heat capacity of Al_2O_3, TiO_2 and SiO_2 water based nanofluids in volume concentrations ranging between 1 and 2.5% at different temperature. The results shown that SiO_2 has highest specific heat capacity following by Al_2O_3 and TiO_2 [95].

In the present study, the variation of specific heat capacity as a function of temperature for nanofluids that investigated by different researchers were as shown in Figure 6. Specific heat capacity of non-bio nanofluids increase with temperature shows that nanofluids possess slightly better thermal capacity at higher temperature. Specific heat capacity of nanofluid is important to analyze energy and energy performance of a system. For instance, nanofluid with lower specific heat capacity will be applied in a system that required quick temperature change. Specific heat capacity of nanofluids is depended on the specific heat capacity of nanoparticles dispersed into base fluids. In order to get required specific heat capacity of nanofluids, it is important to know the properties of nanoparticles and base fluids first.

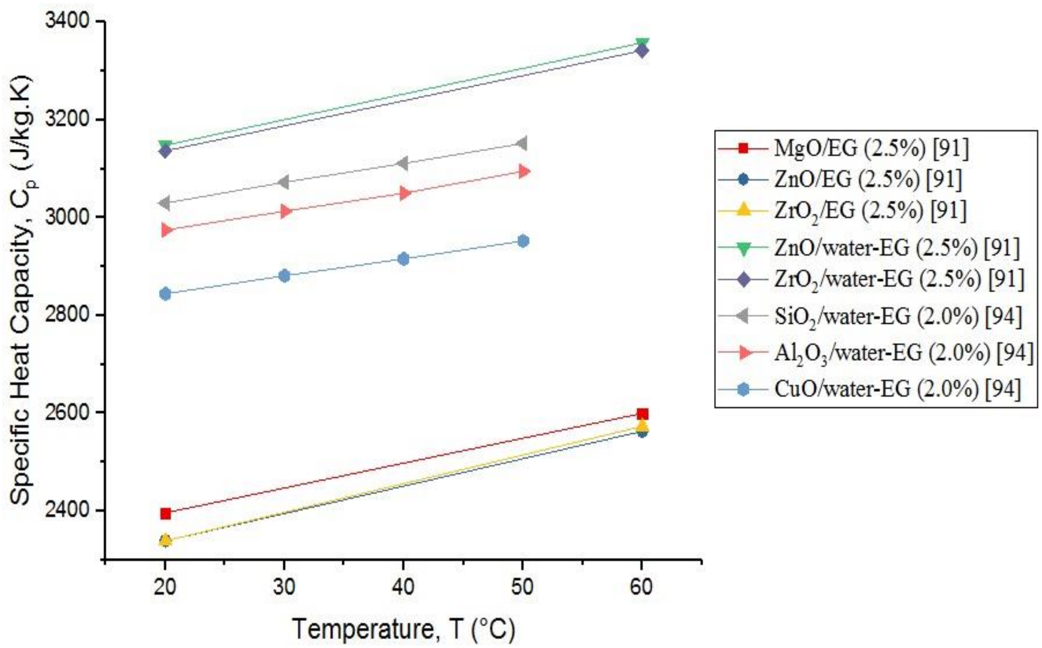

Figure 6. Variation of specific heat capacity with temperature.

Factor affecting thermo-physical properties

The effects of different parameters such as material type, concentration, temperature, and base fluid on the thermophysical properties of nanofluids should be understood well [96]. Based on the investigations by various researchers, increment of particle concentration enhances thermal conductivity and viscosity of nanofluids. In addition, increasing the working temperature enhances the thermal conductivity of nanofluids while reducing viscosity [27].

Effect of material type

Generally, the density of nanofluids is depended on the density of nanoparticles dispersed into base fluids. For instance, high density of nanofluid can be achieved by adding nanoparticles with high density in the base fluid and vice versa. However, the increment of density of nanofluids is very insignificant or even negligible. Effect of material type on density of different nanofluid have shown in Table 2.

Table 2. Summary of the effect of material type on density of different nanofluid.

Nanofluids	φ, %	T, °C	ρ_{nf}, g/cm^3	References
Al_2O_3/water	2.0	30	1.012	[68]
CuO/water	2.0	30	1.015	
ZnO/water	2.0	30	1.013	
SiO_2/water	2.0	25	1.021	[97]
TiO_2/water	2.0	25	1.059	[65]

Generally, metallic, non-metallic and advanced structural materials that can achieve high thermal conductivity enhancement of base fluids usually have drawback of significantly increased viscosity of base fluid. For instance, carbon nanotube based water nanofluids is one of the best solar absorbing fluids showed higher viscosity enhancement with very low nanoparticles weight percentage [98]. However, bio-nanofluids and hybrid nanofluids have low viscosity compared to metallic, non-metallic and advanced structural materials nanofluids. Effect of material type on viscosity of different nanofluid have shown in Table 3.

Table 3. Summary of the effect of material type on viscosity of different nanofluid.

Nanofluids	***T*, °C**	***φ*, %**	μ_{nf}**, *cP***	**References**
Banana/water	30	1.5	1.070	[74]
Mango bark/ water	30	0.5	0.810	[16]
Al_2O_3/water	40	1.0	66.40	[68]
MgO/water	40	1.0	70.50	
CuO/water	40	1.0	68.00	
ZnO/water	40	1.0	65.80	
SiO_2/water	30	0.05	1.029	[97]
TiO_2/water	30	0.05	1.105	[65]
GNP-Ag/water	30	0.1	1.036	[70]
GNP-Pt/water	30	0.1	1.044	[99]

One of the important factors that affect the thermal conductivity of the nanofluids is particle material type [100]. Most of the reports proved that higher thermal conductivity of suspended nanoparticles have higher enhancement of nanofluids' thermal conductivity. Grapheme and CNTs are some advanced structural materials which achieve the significant high increment on the thermal conductivity of the nanofluids. Au, Ag, Cu and Fe are few kind of metallic simple with high thermal conductivity that achieves noticeable strengthening property. Then, CuO, Al_2O_3, TiO_2, ZnO, SiC and SiO_2 are some of the metal or non-metallic compound with different thermal conductivity [15]. However, material with high thermal conductivity is not a decisive factor to improve the flow and thermal performance of the nanofluid [101]. Effect of material type on thermal conductivity of different nanofluid have shown in Table 4.

Table 4. Summary of the effect of material type on thermal conductivity of different nanofluid.

Nanofluids	***φ*, %**	***T*, °C**	**k_{nf}, W/mK**	**Effect, %**	**References**
Mango bark/ water	1.0	20	0.610		[16]
Al_2O_3/water	1.0	20	0.609		[102]
CuO/water	1.0	20	0.637		
ZnO/water	1.0	20	0.621		
TiO_2/water	1.0	20	0.598		[85]
GNP-Ag/water	0.1	20	0.690		[70]
GNP-Pt/water	0.1	20	0.678		[99]
MgO/EG	5.0	30		40.6	[103]
TiO_2/EG	5.0	30		27.2	
ZnO/EG	5.0	30		26.8	
Al_2O_3/EG	5.0	30		28.2	
SiO_2/EG	5.0	30		25.3	

Generally, the specific heat capacity of nanofluids is depended on the specific heat capacity of nanoparticles dispersed into base fluids. For instance, high specific heat capacitive nanofluid can be achieved by adding nanoparticles with high specific heat capacity in the base fluid and vice versa. Effect of material type on specific heat capacity of different nanofluid have shown in Table 5.

Table 5. Summary of the effect of material type on specific heat capacity of different nanofluid.

Nanofluids	***φ*, %**	***T*, °C**	**$C_{p,nf}$, J/kg.K**	**References**
Al_2O_3/water-EG	2.0	20	2975	[94]
SiO_2/water-EG	2.0	20	3032	
CuO/water-EG	2.0	20	2845	
MgO/EG	2.5	20	2217	[91]
ZnO/EG	2.5	20	2339	
MWCNT/ water-EG	0.3	10	3625	[96]
Al_2O_3/water-EG	2.0	20	2975	[94]
SiO_2/water-EG	2.0	20	3032	
CuO/water-EG	2.0	20	2845	

It can be concluded from the above review that the thermo-physical properties of nanofluids are strongly depends on material type. In order to get the required thermo-physical properties of nanofluids, it is recommended to know the properties of the base fluids and nanoparticles.

Effect of temperature

Most literature reviews showed that density of nanofluids would decrease with temperature. However, the effect of temperature on density is very small and even negligible. The behaviour of the fluids that increased in volume at higher temperature is the reason that density of nanofluids decreased with temperature [97]. Effect of temperature on density of different nanofluid have shown in Table 6.

Table 6. Summary of the effect of temperature on density of different nanofluid.

Nanofluids	**φ, %**	***T*, °C**	**ρ_{nf}, g/cm³**	**Effect, %**	**References**
Al_2O_3/water	2.0	30-40	1.012	- 0.4	[68]
MgO/water	2.0	30-40	1.015	- 0.7	
CuO/water	2.0	30-40	1.015	- 0.5	
ZnO/water	2.0	30-40	1.013	- 0.4	
SiO_2/water	2.0	25-40	1.021	- 0.5	[97]
TiO_2/water	2.0	25-40	1.059	- 0.6	[65]
GNP-Ag/water	0.1	20-40	0.999	- 0.6	[70]
GNP-Pt/water	0.1	20-40	0.999	- 0.6	[99]
ACG/EG	0.06	20-40	1.112	- 1.3	[104]

Most of the findings from researchers prove that the decreasing nature of viscosity of nanofluids with increasing temperature such as graphite nanofluids [105][65]. Similarly, water based Al_2O_3 and CuO nanofluids also shows the same trend when the temperature is raised from 21 °C to 75 °C [106]. This is because a weakening of inter-molecular forces and inter-particle forces between the molecules at higher temperature [77]. Effect of temperature on viscosity of different nanofluid have shown in Table 7.

Table 7. Summary of the effect of temperature on viscosity of different nanofluid.

Nanofluids	**φ, %**	***T*, °C**	**μ_{nf}, *cP***	**Effect, %**	**References**
Banana/water	1.5	20-40	1.250	- 28.6	[74]
Coconut/water-EG	1.0	20-40	9.836	- 51.4	[107]
Mango bark/ water	1.0	20-40	1.048	- 29.3	[16]
Al_2O_3/water	2.0	40-60	667.0	- 26.6	[68]
MgO/water	2.0	40-60	742.4	- 31.2	
CuO/water	2.0	40-60	694.0	- 28.8	
ZnO/water	2.0	40-60	659.7	- 27.6	
SiO_2/water	0.1	25-40	1.161	- 16.5	[97]
TiO_2/water	0.1	25-40	1.366	- 21.7	[65]
GNP-Ag/water	0.1	20-40	1.276	- 27.8	[70]
GNP-Pt/water	0.1	20-40	1.288	- 26.7	[99]

Thermal conductivity enhancement of nanofluids can be affected by temperature due to clustering effect and Brownian motion. The higher the thermal conductivity of nanofluids, the more drastic Brownian motion. Meanwhile, clustering effect is negative for Brownian motion. The temperature affects the thermal conductivity of nanofluids differently because of the unpredictable roles of temperature on the particle Brownian motion, particle clustering and dispersion stability of nanofluids. Hence, higher temperature will not always increase thermal conductivity of nanofluids, and some results are reversed [15]. Effect of temperature on thermal conductivity of different nanofluid have shown in Table 8.

Table 8. Summary of the effect of temperature on thermal conductivity of different nanofluid.

Nanofluids	***φ*, %**	***T*, °C**	**k_{nf}, W/mK**	**Effect, %**	**References**
Palm Kernel/ water-EG	0.1	10-50	0.416	50.2	[17]
Mango bark/ water	1.0	20-40	0.610	3.8	[16]
Al_2O_3/water	1.0	20-40	0.609	12.2	[102]
CuO/water	1.0	20-40	0.637	22.1	
ZnO/water	1.0	20-50	0.621	9.5	
TiO_2/water	1.0	20-40	0.598	2.8	[85]
GNP-Ag/water	0.1	20-40	0.690	14	[70]
GNP-Pt/water	0.1	20-40	0.678	9.3	[99]

The specific heat capacity increased with temperature showing nanofluids possess slightly better thermal capacity at higher temperature. For instance, Cabaleiro reported that MgO/EG nanofluid, ZnO/EG nanofluid and ZrO2/EG nanofluid shown an increasing specific heat capacity with increasing temperature [91]. Effect of temperature on specific heat capacity of different nanofluid have shown in Table 9.

Table 9. Summary of the effect of temperature on specific heat capacity of different nanofluid.

Nanofluids	***φ*, %**	***T*, °C**	**$C_{p,nf}$, J/kg.K**	**Effect, %**	**References**
Al_2O_3/water-EG	2.0	20-60	2975	5.3	[94]
SiO_2/water-EG	2.0	20-60	3032	5.3	
CuO/water-EG	2.0	20-60	2845	5.1	
MgO/EG	2.5	20-60	2217	17.3	[91]
ZnO/EG	2.5	20-60	2339	9.6	
ZnO/EG	2.5	20-60	2339	9.6	

It can be concluded from the above review that density and viscosity of nanofluids decreased with increasing temperature. Meanwhile, thermal conductivity and specific heat capacity of nanofluids increased with increasing temperature. This is because of the behaviour of the fluids at higher temperature. The fluids have higher volume with similar mass at higher temperature causes density of nanofluids decreases. The viscosity of nanofluids decreased as the intermolecular interactions between the molecules become feeble. The thermal conductivity of nanofluids increased as more kinetic energy carried by particles and increases rate of collision between particles at higher temperature.

Effect of concentration

Density of nanofluids increased with nanoparticles concentration because the nanoparticles are lie between the layers of base fluid. This will increase the mass of the base fluid without changing its volume [64]. Effect of concentration on density of different nanofluid have shown in Table 10.

Table 10. Summary of the effect of concentration on density of different nanofluid.

Nanofluids	T, °C	φ, %	ρ_{nf}, g/cm³	Effect, %	References
Al_2O_3/water	30	1.0-2.0	1.005	0.7	[68]
MgO/water	30	1.0-2.0	1.004	1.1	
CuO/water	30	1.0-2.0	1.006	0.9	
ZnO/water	30	1.0-2.0	1.005	0.8	
SiO_2/water	30	1.0-2.0	1.006	1.3	[97]
TiO_2/water	30	1.0-2.0	1.029	2.8	[65]
GNP-Ag/water	30	0.0-0.1	0.995	0.1	[70]
GNP-Pt/water	30	0.0-0.1	0.995	0.1	[99]

Most researches proved that the viscosity of nanofluid is a function of concentration. Thus, the higher nanoparticles concentration, the higher viscosity of nanofluids. For instance, viscosity of Al_2O_3/water nanofluid is relative to the concentration and behaves like a Newtonian fluid with volume concentrations less than 4% [108][109]. Effect of concentration on viscosity of different nanofluid have shown in Table 11.

Table 11. Summary of the effect of concentration on viscosity of different nanofluid.

Nanofluids	T, °C	φ, %	μ_{nf}, cP	Effect, %	References
Banana/water	30	0.0-1.5	0.814	31.6	[74]
Coconut/ water-EG	30	0.04-1.0	4.329	54.1	[107]
Mango bark/ water	30	0.5-1.0	0.810	7.4	[16]
Al_2O_3/water	40	1.0-2.0	66.40	0.6	[68]
SiO_2/water	30	0.05-0.5	1.029	5.3	[97]
TiO_2/water	30	0.05-0.5	1.105	30.0	[65]
GNP-Ag/water	30	0.0-0.1	0.861	20.4	[70]
GNP-Pt/water	30	0.0-0.1	0.862	21.1	[99]

Effect of concentration to nanofluids is a significantly studied factor as it could influence thermal conductivity enhancement. Various types of nanoparticles such as Cu, Ag, Au, Al, Fe, CuO, TiO_2, Al_2O_3, MWCNTs and SWCNTs used to study the effect of concentration. Normally, small amount of valuable metal or advanced material nanoparticles could make huge contributions to the thermal conductivity enhancement of nanofluids [15]. Effect of concentration on thermal conductivity of different nanofluid have shown in Table 12.

Table 12. Summary of the effect of concentration on thermal conductivity of different nanofluid.

Nanofluids	*T*, °C	*φ*, %	k_{nf}, W/mK	Effect, %	References
Palm Kernel/ water-EG	30	0.0-0.5	0.494	20.9	[17]
Mango bark/ water	30	0.5-1.0	0.623	1.1	[16]
Al_2O_3/EG	30	1.0-2.0	0.266	10.5	[102]
MgO/EG	30	1.0-2.0	0.315	2.5	
ZnO/EG	30	1.0-2.0	0.274	4.0	
CuO/EG	30	1.5-3.0	0.265	5.3	
TiO_2/water	30	0.0-1.0	0.601	0.8	[85]
TiO_2-Ag/water	30	0.0-1.0	0.601	0.7	[85]
GNP-Ag/water	30	0.0-0.1	0.610	18.0	[70]
GNP-Pt/water	30	0.0-0.1	0.610	17.0	[99]

Most of the literature reviews stated that the specific heat capacity of the common nanofluids decreased with concentration. For instance, Moldoveanu et al shows that specific heat capacity of Al_2O_3, TiO_2 and SiO_2 nanofluids decreases with the increase of nanoparticles concentration [110]. However, there are some inconsistent results about the effect of specific heat capacity of nanofluids with nanoparticles concentrations [111]. Effect of concentration on specific heat capacity of different nanofluid have shown in Table 13.

Table 13. Summary of the effect of concentration on specific heat capacity of different nanofluid.

Nanofluids	*T*, °C	*φ*, %	$C_{p,nf}$, J/kg.K	Effect, %	References
Al_2O_3/water-EG	50	2.0-4.0	2942	- 2.7	[93]
SiO_2/water-EG	50	2.0-4.0	3953	- 2.4	
CuO/water-EG	50	1.0-3.0	3179	- 6.1	
MgO/EG	20	2.5-5.0	2400	- 1.4	[91]
ZnO/EG	20	2.5-5.0	2339	- 1.6	
ACG/EG	30	0.00-0.06	2520	2.0	[104]

It can be concluded from the above review that density, viscosity and thermal conductivity of nanofluids increased with increasing nanoparticles concentration. This is because nanoparticles is the reason that thermo-physical properties of base fluids enhanced. Meanwhile, specific heat capacity of nanofluids usually decreases with the increase of concentration. However, there are few inconsistent results about the effect of specific heat of nanofluids with concentrations.

CONCLUSION

In the present paper, the lowest viscosity value of nanofluids in literature was mango bark water-based nanofluid (0.81 cP). The maximum thermal conductivity value of nanofluids in the literature was GNP-Ag water-based nanofluid (0.69 W/mK). Non-bio nanofluids were widely applied in heat transfer application due to its high thermal conductivity enhancement. Meanwhile, bio nanofluids were generally investigated for drag reduction application due to its natural characteristics that might lower viscosity of the nanofluids. The density and specific heat capacity are strongly depends on the material type. Meanwhile, the viscosity and thermal conductivity are hugely affected by temperature and concentration. The most influential parameters on thermo-physical properties of nanofluids are material type following by and temperature. Most of the literatures confirmed bio nanofluids have low viscosity value and hybrid non-bio have high thermal conductivity value. However, there have no literature on hybrid bio and non-bio nanofluids. In order to obtain ideal thermo-physical of nanofluids for applications, more research and study need to be conducted in future. Hence, the hybrid bio/non-bio nanofluids can be investigated to improve current state of nanofluid applications in engineering systems.

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