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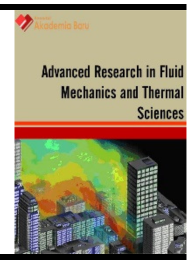

Review on Preparation Techniques, Properties and Performance of Hybrid Nanofluid in Recent Engineering Applications

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Hong Wei Xian[1], Nor Azwadi Che Sidik[1,*], Siti Rahmah Aid[1], Tan Lit Ken[1], Yutaka Asako[1]

[1] Malaysia – Japan International Institute of Technology (MJIIT), University Teknologi Malaysia Kuala Lumpur, Jalan Sultan Yahya Petra (Jalan Semarak), 54100 Kuala Lumpur, Malaysia

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ABSTRACT

Nanofluid has been drawing attention in various engineering applications in past decade due to its superior heat transfer characteristics than conventional working fluid. From past researchers, it is found that behavior of nanofluid can be greatly varied by various factors such as method of preparation, concentration/type of suspended nanoparticles and type of base fluid used. Due to the desire to possess nanofluid with more advantageous characteristics, dispersion of different nanoparticles into base fluid has led to a novel product which is called hybrid nanofluid. Different types of hybrid nanofluid were prepared and studied by former researchers in accordance with parameters required in their studies. Based on literature review, hybrid nanofluid shows greater heat transfer performance and rheological properties compared to base fluid and mono nanofluid. This paper reviews the preparation method, stability investigation method, thermophysical properties and heat transfer performance of hybrid nanofluid in various heat transfer applications. Apart from that, this review outlines challenges regarding hybrid nanofluid and some suggestions to improve future researches in this area.

1. Introduction

In heat transfer applications, nanofluid has gained attention as new and efficient heat transfer fluid due to its superior thermophysical properties compared to conventional working fluid such as water, ethylene glycol and oil. Nanofluid was first introduced by Choi and his team [1]. It was discovered by them that a solution with dispersed nanoparticles can improve heat transfer performance in cooling system. Since then, many researchers started to investigate

* *Corresponding author.*
E-mail address: azwadi@utm.my (Nor Azwadi Che Sidik)

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different types of nanoparticles (metal, non-metal, oxides, carbides) mixed into various solutions by either experiment, simulation or both approaches [2-8]. Nowadays, many fields which require effective working fluid are involved with this novel nanotechnology. With the higher demand of better performance in various heat transfer systems, nanofluids with single type of nanoparticles can be upgraded with addition of different nanoparticles into base fluid. Dispersion of two different types of nanoparticles into base fluid is called hybrid nanofluid, in which physical and chemical properties of dispersed nanoparticles are combined and presented in a homogenous phase. Past researchers showed that hybrid nanofluid has better thermal conductivity and heat transfer performance than both mono nanofluid and base fluid [9-11].

Since hybrid nanofluid shows favorable characteristics and performance, authors are inspired to review different aspects of hybrid nanofluids which include thermophysical properties, heat transfer performance, preparation method and stability investigation method. This paper tends to provide a clear review on hybrid nanofluids and thus most of the experimental works stated in this paper are reviewed thoroughly from the aspects aforementioned.

2. Thermophysical properties

Thermophysical properties of SiO_2-CuO/C nanoparticles dispersed in glycerol and ethylene glycol were studied by Akilu and his team [12]. They prepared both mono and hybrid nanofluids with concentration of 0.5 % to 2.0 % and thermophysical properties were measured from 30 ^oC to 80 ^oC. Result of thermal conductivity and specific heat capacity of SiO_2 nanofluid and SiO_2-CuO/C hybrid nanofluid against concentration are shown in Fig. 1.

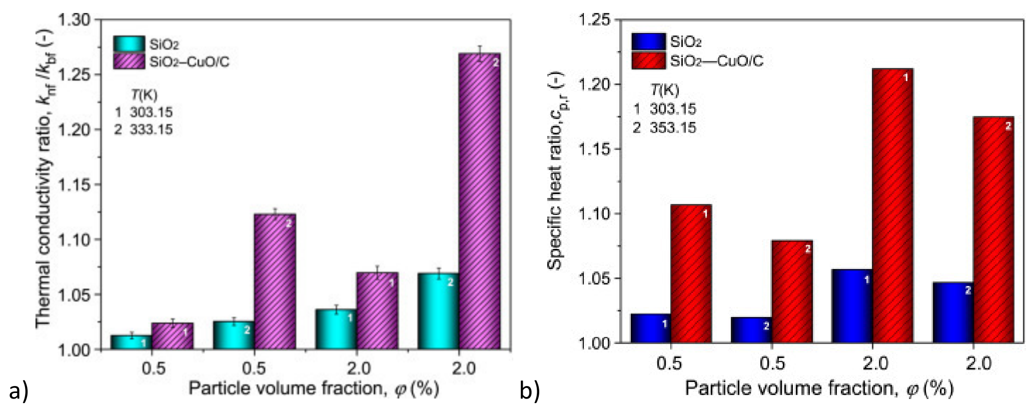

Fig. 1. (a)Thermal conductivity and (b)specific heat capacity of SiO_2-CuO/C hybrid nanofluid versus concentration

Their result revealed that thermal conductivity of hybrid nanofluid is higher than mono nanofluid regardless of temperature and concentration difference. On another perspective, specific heat capacity of hybrid nanofluid increases with increasing temperature and decreasing concentration. They suggested that deterioration of specific heat capacity with increment of nanoparticles concentration is due to the lower specific heat capacity of solids compared to liquids.

Esfe and his team [13] measured thermal conductivity of ZnO-double wall carbon nanotubes (DWCNT) nanoparticles which mixed with ethylene glycol. 24.9% of maximum thermal conductivity ratio (TCR) was obtained at 1.9 vol.% nanoparticles and 50 ^oC. In addition, the hybrid nanofluid was found to be better than ZnO and DWCNT mono nanofluid in terms of thermal conductivity enhancement and price. The same author [14] carried out measurement on similar hybrid nanofluid in which SiO_2 was used instead of ZnO. At 50 ^oC, 1.71 vol.% nanoparticles showed maximum TCR and 38% increment in thermal conductivity when compared to ethylene glycol. In another experimental study on SiO_2-multi-walled carbon nanotube (MWCNT)/EG hybrid nanofluid, thermal conductivity ratio increment of 20.1% was obtained at 50 ^oC and 0.86 vol.% nanoparticles when compared to base fluid [15].

Sharma *et al*., [16] investigated alumina-graphene hybrid lubricant as cutting fluid in turning operation. They suggested that due to its excellent thermophysical properties, Al-graphene (GnP) hybrid lubricant reduced nodal temperature of turning operation by 5.79% when compared to alumina lubricant. An approach on investigating thermal conductivity of Al_2O_3-Cu/EG hybrid nanofluid was carried out by Parsian and Akbari [17]. Thermal conductivity was measured using transient hot wire method. Their result revealed that 2.0 vol.% nanoparticles enhanced thermal conductivity for 28% at 50 ^oC when compared to base fluid. They also observed that thermal conductivity at low nanoparticles concentration (<0.5 vol.%) was slightly affected by temperature change.

Thermophysical properties of hybrid nano-lubricant was identified by Asadi and his co-workers [18]. It was found that $Mg(OH)_2$-MWCNT hybrid nano-lubricant enhanced the thermal conductivity by 50%. For combination of 0.05 wt% MWCNT and 3 wt% Ag dispersed in deionized water, thermal condutivity improvement was found to be 14.5% at 40 ^oC [19].

Leong and his co-workers [20] compared thermal conductivity of Cu-TiO_2 hybrid nanofluid, Cu nanofluid and TiO_2 nanofluid by varying concentration of nanoparticles, pH value, sonication time and type of surfactant. Their results showed that 0.8 wt% of Cu-TiO_2 hybrid nanofluid gave the highest thermal conductivity enhancement (9.8%) compared to water/ethylene glycol mixture when polyvinylpyrrolidone was used as surfactant. Surprisingly, TiO_2 showed higher thermal conductivity than hybrid nanofluid and Cu nanofluid when gum arabic (GA) and dodecylbenzenesulfonate (SDBS) were used.

3. Heat transfer performance

3.1 Experimental

Ho *et al*., [21] investigated the effect of hybrid suspension made up of Al_2O_3 nanoparticles and n-eicosane (phase change material) in a rectangular minichannel heat sink. They used ultra-pure Milli-Q water as base fluid and prepared 2 to 10 wt% mono-nanofluid, PCM suspension and hybrid suspension. Their results revealed that latent heat absorption of n-eicosane and high thermal conductivity of Al_2O_3 nanoparticles in hybrid suspension contribute to the improved heat transfer performance than both Al_2O_3 and PCM suspension alone. However, they found that Al_2O_3 nanofluid performed better than hybrid nanofluid at high Reynolds number due to significant difference in pressure drop.

Heat transfer and hydraulic performance of hybrid nanofluid flowing under turbulent condition in a tube was studied by Sundar *et al*., [22] experimentally. Compared to water, Nusselt number was increased by 24.66% and 35.43% when 0.1% and 0.3% of nanodiamond-nickel hybrid nanofluid were tested at Reynolds number of 22,000. As penalty, friction factor was increased by about 7% and 12% respectively when 0.1% and 0.3% hybrid nanofluid were used.

Arunachalam and Edwin [23] studied on hydrothermal performance of Al_2O_3 nanofluid and Cu-Al_2O_3 hybrid nanofluid in a straight tube under laminar flow. For 0.4 vol.% Al_2O_3-water nanofluid, heat transfer coefficient was 20.8% higher than water. When 0.01 vol.% of Cu nanoparticles was added to 0.4 vol.% Al_2O_3 nanofluid, the heat transfer coefficient was further increased by 5%. Other than that, pressure drop increased by 0.89 times when hybrid nanofluid was used instead of water.

Hamid and his team [24] investigated heat transfer performance of TiO_2-SiO_2 nanoparticles with various mixture ratios dispersed in water-ethylene glycol base fluid. It was found that 40:60 ratio (TiO_2-SiO_2) nanoparticles with total of 1 vol.% concentration gave the highest heat transfer enhancement, 35.32% at 70 ^oC. On the other side, the highest dynamic viscosity was obtained at 50:50 mixture ratio. The author also suggested that 20:80 mixture ratio is the most cost effective when size of TiO_2 nanoparticles are 2.27 times bigger than that of SiO_2.

Heat transfer and pressure drop of nanoplatelet/platinum hybrid nanofluid in square shaped microchannel were analyzed [25]. Turbulent flow and constant heat flux were considered along their experiment. With 0.1 wt% nanoparticles, convective heat transfer coefficient was found to increase by 30% at Reynolds number of 17,500. As demerit, about 10% of increment of pressure drop was found to be highest among all tested conditions.

3.2 Numerical Works on Hybrid Nanofluids

Two different types of hybrid nanofluid were compared by Gabriela and Angel [26] numerically by simulating the laminar flow in a flattened tube. From their results, it was found that MWCNT-Fe_3O_4/water showed higher heat transfer improvement when compared to ND-Fe_3O_4/water and base fluid at Reynolds number tested (from 250 to 2000). Bahiraei *et al.*, [27] simulated the hydrothermal performance of Fe_3O_4-CNT hybrid nanofluid in minichannel heat exchanger. For Reynolds number of 500 and 2000, heat transfer rate was increased by 53.8% and 28.6% respectively, when compared to water. In addition, they observed that Fe_3O_4 concentration has greater effect on heat transfer rate compared to CNT concentration. The demerit on increasing Reynolds number and nanoparticles is increased pressure drop and pumping power.

Elahmer and his team [28] compared Ag-CNT/EG hybrid nanofluid and CNT/EG nanofluid in a horizontal tube. They found that cylindrical shaped nanoparticles have higher thermal conductivity than spherical nanoparticles. Also, heat transfer coefficient of the hybrid nanofluid was found to be highest followed by mono nanofluid and then base fluid.

A numerical study on hybrid nanofluid in microchannel under forced convection laminar flow was carried out by Nimmagadda and Venkatasubbaiah [29]. Mono nanofluids with 3% volume concentration (Al, Cu and SWCNT) nanoparticles were reported to improve Nusselt number by 21.09%, 32.46% and 71.25% respectively at Reynolds number of 600 when compared to water. On the other side, Cu-Al/water hybrid nanofluids with different hybridization ratio (20:80 and 50:50 Cu-Al) showed higher average Nusselt number than Al mono nanofluid under same Reynolds number.

Five different types of alumina-water based hybrid nanocoolant were compared in term of thermal performance [11]. CuO, Fe_2O_3, Ag, Cu and TiO_2 nanoparticles were considered in the study. It was found that silver-alumina combination showed highest heat transfer rate (3%), effectiveness (0.8%) and pressure drop (5.6%) among all other hybrid nanofluids, when compared to water.

4. Preparation Methods of Hybrid Nanofluids

There are two common methods to prepare nanofluid, which is one-step method and two-step method. Until now, mono nanofluids and hybrid nanofluids produced by past researchers are based on these two methods, or similar procedures with some modifications. Preparation method plays vital role in producing nanofluid with low agglomeration and even distribution of nanoparticles for long duration so that thermal conductivity of nanofluid produced can be remained steady [30].

4.1 One-Step Method

Preparing nanofluid using one-step method is the combination of both production and dispersion of nanoparticles into base fluid at the same time, hence few processes are avoided to reduce agglomeration of nanoparticles. Anyhow, only fluids with low vapor pressure are compatible with this method. One of the earliest approach was done for developing mono nanofluid which involved evaporating metal by electron beam heating [31]. Evaporated metal atoms then were deposited (condensation process) on running oil surface and hence running oil with ultrafine particles was obtained.

For hybrid nanofluid, Hung and his co-workers [32] used acetylene flame synthesis system to produce hybrid carbon nanofluid (HCNF). C_2H_2 flame (carbon source) was used to produce smoke and carbons in smoke were condensed into water mist inside the synthesizer. In this way, HCNF was produced without involving secondary processes. The schematic diagram of the combustion system is shown in Fig. 2 below.

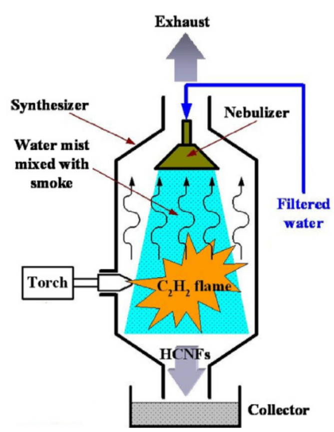

Fig. 2. Schematic diagram of acetylene flame synthesis system

Munkhbayar *et al.*, [19] synthesized Ag-MWCNT/water hybrid nanofluid by first preparing MWCNT/water nanofluid using wet grinding method. During the process, MWCNT nanoparticles were purified by nitric acid and sulfuric acid using ultrasonic cleaner. Polarization by chemical treatment was done to make sure good dispersion capability of MWCNT. On the other side, pulse wire evaporation (PWE) method was used to prepare Ag nanoparticles. 90 mm of feeding wire into reaction chamber and 300 V of voltage pulse were used. Then, the MWCNT nanofluid prepared earlier was poured into an exploding bottle which placed in PWE instrument. The Ag nanoparticles was made direct contact with MWCNT nanofluid inside chamber wall and hence the end product obtained was Ag-MWCNT hybrid nanofluid. Different concentrations of Ag nanoparticles were varied by adjusting number of wire explosion while concentration of MWCNT was fixed.

4.2 Two-Step Method

Two step method consists of two main procedures: production of nanopowder and dispersion of nanopowder into base fluid. Firstly, nanopowder is produced through chemical or mechanical process such as inert gas condensation, chemical vapor deposition or mechanical alloying. Then, the nanopowder produced is added into base fluid through mixing process and ultrasonic agitation. This method is widely used among past researchers due to simpler steps and low production cost thus it is suitable for mass production, with its demerit that agglomeration would occur more easily due to high surface activity. Anyhow, agglomeration of nanoparticles can be reduced by adding surfactant with suitable quantity and temperature.

Equal amount of Fe_3O_4 and MWCNT nanoparticles were dispersed into ethylene glycol, stirred for 150 minutes and homogenized for six and a half hours using Hielscher ultrasonic homogenizer with 24 kHz ultrasonic waves [33]. Then, 0.1 to 1.8 vol.% hybrid nanofluid was produced and the total volume fraction is calculated using Eq (1).

$$\varphi = \left[\frac{(\frac{m}{\rho})_{Fe_3O_4} + (\frac{m}{\rho})_{MWCNT}}{(\frac{m}{\rho})_{Fe_3O_4} + (\frac{m}{\rho})_{MWCNT} + (\frac{m}{\rho})_{EG}}\right] \times 100 \tag{1}$$

Al_2O_3-Cu hybrid nanofluid was prepared by first mixing Al_2O_3 and Cu nanoparticles with deionized water [23]. Sodium lauryl sulfate was then added as dispersant when the hybrid nanofluid was exposed to ultrasonic homogenizer with 180 W power and 40 kHz ultrasonic waves for six hours. Kannaiyan and his team [34] produced Al_2O_3/CuO nanofluid by synthesizing CuO and Al_2O_3 nanoparticles separately, then dispersed both type of nanoparticles into water/ethylene glycol mixture.

Hamid *et al.*, [24] diluted both TiO_2 and SiO_2 nanoparticles which were initially in suspended condition up to 1 vol.% concentration. Then, hybrid nanofluid was prepared by mixing TiO_2 nanofluid and SiO_2 nanofluid using different mixture ratios. TiO_2-CuO/C nanocomposite was prepared by Akilu *et al.*, [35] using wet mixing approach. Firstly, CuO/C nanocomposite was synthesized using modified former researchers' method [36]. Then TiO_2 and CuO/C powder were mixed with ratio of 80:20 in 20 mL of hexane. The mixture was exposed to ultrasound of 20 kHz for 30 minutes using sonicator and followed by centrifugation process using scanspeed centrifuge (2000 rpm, 25 ^{o}C, 10 minutes). The supernatant was dried in oven to obtain TiO_2-CuO/C powder.

Leong *et al*., [20] prepared Cu-TiO_2 hybrid nanofluid in several steps. First, ascorbic acid, hydrogen peroxide (reducing agent) and distilled water were mixed and stirred for 5 minutes. The mixture was heated up to 90 ^{o}C and Cu alloy was then immersed in. In results, precipitation of copper ascorbate was obtained and it was dried for 6 hours at 90 ^{o}C. After that, the dried copper ascorbate precipitates were crushed into smaller size and mixed into TiO_2-distilled water solution using magnetic stirrer for two hours. Then, Cu-TiO_2 precipitates were filtered and dried in oven for six hours and crushed into smaller size. Lastly, Cu-TiO_2 hybrid nanofluid was prepared using two step method.

Synthesis of Fe_3O_4/GnP hybrid nanoparticles was done by Askari *et al*., [37]. Firstly, mixture of graphite powder and sulfuric acid was stirred for 10 minutes and potassium permanganate was added. Mixture of ferrous chloride, ferric chloride and deionized water was stirred and graphene oxide obtained earlier was added at room temperature. Then, ammonia solution was added to change light brown colour of the mixture to black colour. Heating of 80 ^{o}C for 60 minutes was applied to the mixture and followed by room temperature cooling process. Solid material in the mixture was separated using magnet and washed by deionized water until pH value of 7 was obtained. The end product obtained was Fe_3O_4/GnP nanoparticles. Preparation method of hybrid nanofluids stated in this paper is summarized in Table 1 below.

5. Stability Enhancement and Investigation Method

It is important to determine stability of nanofluid after mixing and sonication process. This is to ensure nanoparticles are not agglomerating and form settlement in the suspension due to gravity. In fact, nanoparticles tend to agglomerate due to high surface activity and van der Waals force. The increased size of agglomerates would lead to instability of nanofluids and followed by variation of thermophysical properties and deterioration of heat transfer performance. To resolve this problem, surfactant is usually added into nanofluid to disperse nanoparticles. Table 1 above shows few surfactants used in hybrid nanofluids by former researchers. However, high working temperature may cause surfactants to produce foam during experiment. In addition to that, surfactant molecules may increase thermal resistance between nanoparticles and base fluid as the surfactant molecules may attach to the surface of nanoparticles, in which heat transfer rate will be limited [30]. Another method to enhance stability is the use of functionalized or surface modified nanoparticles, which is surfactant-free method. There are past researchers used functionalized MWCNT nanoparticles to synthesis hybrid nanofluids without the use of surfactant [44]. Besides that, past researchers usually performed ultrasonic homogenizing process on nanofluids which produced from two-step method. This process can help to reduce the size of agglomerates and provide even dispersion of nanoparticles to enhance stability of a suspension [45].

There are many methods done by former researchers to determine stability of nanofluid, such as zeta potential analysis, sedimentation method, centrifugation method, electron microscopy, spectral analysis and light scattering method [46].

Table 1
Preparation method of hybrid nanofluids

Author	Nanoparticles	Base fluid	Surfactant
One step method			
[19]	MWCNT (20 nm)-Ag	Deionized water	-
[32]	Amorphous carbon, graphene oxide, and graphite-2H	Distilled water	Sodium dodecyl sulfate
Two step method			
[12]	SiO_2-CuO/C (80:20)	Glycerol/EG (60:40)	-
[13]	ZnO-DWCNT (90:10)	EG	-
[14]	SiO_2 (30 nm) DWCNT (1-3 nm, 2-4 nm)	EG	-
[15]	SiO_2-MWCNT (70:30)	EG	-
[17]	Al_2O_3 (5 nm)-Cu (50 nm) (50:50)	EG	-
[18]	$Mg(OH)_2$ (10nm)-MWCNT (30 nm) (85:15)	Engine oil (5W50)	-
[20]	Cu-TiO_2	Water /EG (50:50)	Polyvinylpyrrolidone
[21]	Al_2O_3-(n-eicosane)	Ultra pure Milli-Q water	-
[22]	ND-Ni	Double distilled water	NanoSperse AQ
[23]	Al_2O_3-Cu	Deionized water	Sodium lauryl sulfate
[24]	TiO_2-SiO_2	Water/EG(60:40)	-
[33]	Fe_3O_4-MWCNT (50:50)	EG	-
[34]	Al_2O_3-CuO	Water/EG	-
[35]	TiO_2-CuO/C	Ethylene glycol	-
[37]	Fe_3O_4-GnP	Deionized water	-
[38]	MWCNT(3-5 nm, 5 -15 nm) MgO (40 nm) (20–80%)	Water/EG	-
[39]	ZnO (10-30 nm) TiO_2 (21 nm)	Water/EG	-
[40]	Al_2O_3-Cu	Deionized water	Sodium dodecyl sulfate
[41]	ND-Co_3O_4	Water/ EG	-
[42]	Al_2O_3-Cu	Water	Sodium lauryl sulfate
[43]	CNT, Cu, Au, CNT-Au and CNT-Cu	Water	Laurate salt
[44]	GnP-MWCNT	Deionized water	-

There are many methods done by former researchers to determine stability of nanofluid, such as zeta potential analysis, sedimentation method, centrifugation method, electron microscopy, spectral analysis and light scattering method [46].

Sedimentation is one of the simplest methods to investigate stability. Usually, camera is used to capture photographs of nanofluids stored in visible container. Nanofluids can be considered stable when supernatant particles size or concentration is fixed. However, long period of time (up to months) is needed in order to observe the presence of sediments by naked eyes. Centrifugation is another method similar to sedimentation method, just that the sediments and supernatant are separated by exerting centrifugal force, instead of relying on gravity force which consume more time. Esfe *et al.*, [38] observed the presence of sediment of nanofluids with various concentration for 7 days, as shown in Fig. 3.

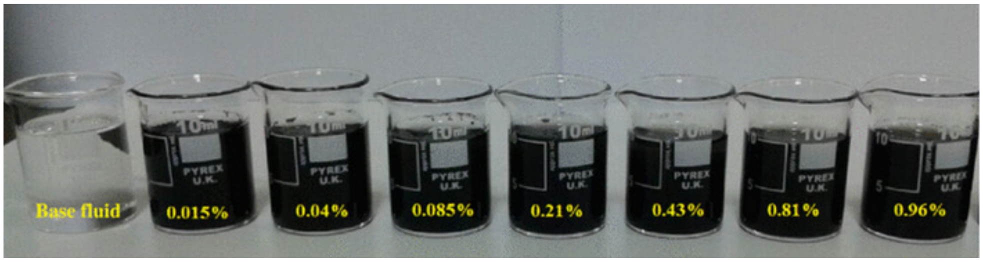

Fig. 3. Sedimentation method to observe stability of nanofluids

Zeta potential is a measure of electrostatic repulsion force between nanoparticles and base fluid. High repulsion force indicates high stability of nanofluid, which |30 mV| is generally considered as benchmark for a stable nanofluid and excellent stability nanofluid may exceed |60 mV|. For pH value of nanofluids, iso-electric point is the reference value to check the stability of suspension. When zeta potential value is around zero, pH value of nanofluids at that point is called iso-electric point and a stable suspension should have more than ±2 pH value from this point. Leong et al. [20] used acetic acid and ammonia hydroxide for adjusting the pH value of Cu-TiO_2 hybrid nanofluid. Stability of alumina-copper hybrid nanofluid was determined by Suresh *et al*., [42] using these two methods. The hybrid nanofluid was found to have pH value of around 6, which is in good stability. Other than that, they observed that the hybrid nanofluid has poor stability when concentration of nanocomposites is increased. In this case, they tested the stability using zeta potential analysis and found that zeta potential of the hybrid nanofluid decreased from +46 mV to +30.1 mV when the concentration was altered from 0.1% to 2%. This shows that stability of nanofluid is dependent on concentration of nanoparticles. Similar trend was obtained for SiO_2-CuO/C hybrid nanofluid, in which -48 mV and -33 mV were recorded for 0.5 vol.% and 2.0 vol.% nanoparticles respectively [12].

UV-vis-NIR spectrophotometer can be used to obtain concentration variation of nanofluids with sediment time by measuring absorbance of nanofluids, in which the linear relationship between these two variables was expressed as Beer-Lambert law. High value of absorbency means well distribution of nanoparticles in nanofluid. Former researchers [43] found that concentration of CuNP nanofluid dropped by 15% within half an hour, which indicates poor stability. Then, CNT nanoparticles were added to CuNP nanofluid to increase absorbance, due to the high exposed area and absorption coefficient of CNT nanoparticles. Their result showed that concentration of AuNP-CNT and CuNP-CNT nanofluids decreased by only 0.008% and 0.016% respectively within the same duration, which improved a lot compared to initial sample.

Electron microscopy and light scattering method are widely-used methods to observe the size of nanoparticles and agglomerates. In order to obtain high resolution of image, transmission electron microscopy (TEM) and scanning electron microscope (SEM) are used to provide detailed information on nanoparticles characteristics. Nanocomposite SiO_2-CuO/C was observed to have average 25 nm diameter using SEM [12]. Table 2 below shows stability investigation methods used by past researchers on hybrid nanofluids.

Table 2
Stability investigation methods on hybrid nanofluids

Author	Method	Nanoparticles	Base fluid
[20]	pH value	Cu-TiO_2	Water
[23]	pH value	Al_2O_3-Cu	Deionized water
[40]	pH value	Al_2O_3-Cu	Deionized water
[33]	Sedimentation	Fe_3O_4-MWCNT (50:50)	EG
[24]	Spectral absorbance analysis	TiO_2-SiO_2	Water/EG (60:40)
[43]	Spectral absorbance analysis	CNT, Cu, Au, CNT-Au and CNT-Cu	Water
[44]	Spectral absorbance analysis	GnP-MWCNT	Deionized water
[19]	Spectral absorbance analysis	MWCNT-Ag	Deionized water
[18]	Zeta potential	$Mg(OH)_2$-MWCNT	Engine oil (5W50)
[32]	Zeta potential	Amorphous carbon, graphene oxide, and graphite-2H	Distilled water
[37]	Zeta potential	Fe_3O_4-GnP	Deionized water
[41]	Zeta potential	ND-Co_3O_4	Water/EG
[12]	Zeta potential, pH value	SiO_2-CuO/C	EG/glycerol
[37]	Zeta potential, pH value	Fe_3O_4-GnP	Deionized water
[42]	Zeta potential, pH value	Al_2O_3-Cu	Water
[47]	Zeta potential, pH value	Ag-Fe	Deionized water

6. Conclusion

This paper reviewed different aspects of hybrid nanofluids. It was found that hybrid nanofluids show better thermal conductivity and heat transfer performance compared to mono nanofluids and base fluids at most of the time. Similar to mono nanofluids, hybrid nanofluids deteriorate heat transfer performance when concentration of nanoparticles is higher than its upper limit.

For preparation method, one step method is more complicated but hybrid nanofluids produced are more stable than that of two-step method. On the other side, two-step method is widely used by former researchers due to simple steps and suitable for mass production. To enhance stability of nanofluids produced, surfactants are used in order to disperse nanoparticles. Different type of surfactants added into nanofluids may produce different results [20]. However, surfactant may degrade thermophysical properties of nanofluids when excessive amount is added [48]. Few methods have been adopted to check the stability of hybrid nanofluids and each method has respective pros and cons.

Based on authors' review, experimental work on comparing heat transfer performance between hybrid and mono nanofluids is short in number. For future work, comparison should be done on same basis, such as preparation method, similar size of nanoparticles and stabilizing method to obtain more accurate results. One of the existing weaknesses is that although various properties of nanofluids are evaluated and compared, factors mentioned earlier are always omitted by past researchers and lead to inconsistency of results among them. In addition, more types of hybrid nanofluids are needed to study the effect of various nanoparticles combinations on thermophysical properties, as mono nanofluid was found to have higher thermal conductivity than hybrid nanofluid in previous studies [43, 49]. In short, more experimental works should be done on hybrid nanofluids as it contains great potential as an effective heat transfer fluid in various engineering fields. Since there are not many models and correlations available for hybrid nanofluids, experimental works with multiple parameters are needed to provide future researchers or industry reliable references.

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