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ORIGINAL ARTICLE

# Preparation, stability and wettability of nanofluid: A review

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**ABSTRACT** – Nanofluids possess many advantages over conventional working fluid especially in physical, thermal and rheology properties. Nowadays, nanofluids have been applied extensively in many engineering applications in enhancing the overall performance. Preparation and characterization of nanofluids are vital as the nanomaterials have significant effects on the dispersion and stability of nanofluids. On the other hand, there is a trend to employ more than a single nanoparticle for preparing nanofluid. The hybrid nanofluid receives wide attention due to its capability in improving the thermal-physical properties of single phase nanofluids. In this paper, the flow of formulating nanofluid from preparation method, characterization, wettability analysis and stability techniques are discussed comprehensively. Furthermore, the challenges for obtaining stable suspension and wettability behaviour of nanofluids are discussed as well. The main objective when preparing the nanofluids is to obtain a well-dispersed nanoparticle into the base fluid. Based on the literature review, the impact of surfactant on the stability and the correlation between nanofluids wettability and thermal-physical properties of nanofluids have great potential to discover. There are some aspects that can be considered to expand the knowledge of nanofluids such as the composition ratio of hybrid nanofluid with regards to achieving the best stability and wettability study of hybrid nanofluid with and without surfactant in the suspension. Therefore, a lot of research should be conducted in order to explore the behaviour of nanofluid and the effect of various surfactants in terms of stability as well as its thermal and viscosity effect on the engineering applications.

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*Nanofluid; preparation; contact angle; stability; dispersibility*

## INTRODUCTION

Nanofluid is a new generation of working fluid that containing nanoparticles in base fluid. It has immense potential in thermal-related applications for increasing the efficiency of heat transfer. In recent years, many researchers around the world have explored the potential of nanofluid due to its superior physical, thermal and rheology properties [1-3]. Heat transfer enhancement could improved up to 40% for oxide nanoparticles [4]. Nevertheless, before it can be acceptable commercerliazed irrespective of any applications, the challenge of getting stable suspension especially in stationary condition should be overcome. The main challenge in preparing nanofluid is to get long-term homogeneous suspension where the particles tend to aggregate [5, 6]. According to J.Lin and H.Yang [7], the flow of instability of nanofluids resulting significant changes of thermal and mechanical effectiveness. Furthermore, the formation of large agglomeration has caused interruptions of the liquid flow in small space passage resulting inefficiency of heat transfer. On the other hand, instability of nanofluids also affect its thermophysical properties [8]. This is a significant problem especially for hybrid nanofluids which two or more particles are dispersed in the base fluid. Due to this reason, there is technical difficulty to get an optimum combination of nanoparticles, base fluid, and surfactant. The problem of getting stability condition of nanofluid is attributed to the surface charge (positive or negative) or Van der Waals forces in the base fluid [9, 10]. The lack of physical phenomena understanding for the anomalous behavior of nanofluids might be the reason why the nanoparticle suspensions easily get poor characterization [5]. Thus, proper nanofluid preparation technique is very important for obtaining a stable suspension for a long period. Consideration of type of nanoparticles, type of base fluid, surfactant and concentration in the formulation of nanofluid is also important to avoid unnecessary negative effects for practical engineering application. One aspect to consider wisely for nanofluids preparation is type of base fluid such as water, oil and ethylene glycol. The advantage of water-based nanofluid is that the nanofluid in a mist condition is easy to become as airborne in the air [11]. This is more environmental friendly in open air application which evaporation of water is considered safe for human beings.

Nanofluid wettability characteristics are vital parameter especially in lubricating friction expose surface like machining application and for metal coating using nanofluids. The presence of nanoparticles in base fluid can change the liquid contact angle either in hydrophilic (more wet) or hydrophobic (less wet). Pumping power is minimized remarkably when nanofluids behave hydrophobic as reported by Kang et al. [12]. However, lesser degree of contact angle can enhance heat transfer coefficient based on Phan et al. [13] findings. Volume concentration, exposure time, pressure and salinity

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percentage are the factors affecting the contact angle of nanofluid. Controlling contact angle of nanofluids is important due to it has effect on surface coverage, heat transfer capability, fluid viscosity and pumping power.

From the literature, the effect of various surfactant on the stability, wettability as well as the presence of stabilizer in suspension in influencing nanofluids thermal conductivity and viscosity have limited reaserch works. Moreover, no correlation developed for nanofluids wettability and its effect on nanofluids thermal-physical properties. This is another scope of research can be futher explored for better understanding of this unique working fluids that really encouraging in near future. Hence, to address this problem, a lot of studies should be made through details experimentation discovery. In this paper, nanofluids preparation are discusssed in details from the beginning of nanoparticles synthesis and preparation methods till the evaluation of nanofluid stability. This is important of research framework that need to be considered wisely when employing either single or hybrid nanofluids with the objective in achieving greater thermal-physical properties that can further improve cooling and lubricating aspects regardless of any engineering application. Therefore, this paper aims to discuss the recent formulation techniques for preparing nanofluids, the wettability of nanofluids and the methodology of nanofluid stability evaluation.

## PREPARATION OF NANOFLUIDS

There two techniques which the nanofluid can be synthesized either using (i) the one-step evaporation method with base fluid or (ii) the two-step method where nanoparticles are formed first in different condition and then the nanoparticles are dispersed in the base fluid.

### One-step method

In the one-step method, generally, the nanofluids can be synthesized using mechanical, biological, chemical and chemical approach. For example, there are many techniques can be used to synthesis the nanofluid such as mechanical milling, mechanical stirring, ball milling, pulse wire evaporation, plasma treatment, solvothermal, thermochemical, chemical vapor deposition, and catalytic chemical vapor deposition [14,15]. In the previous study done by B.Munkhbayar et al. [16], Ag and Ag-MWCNTs nanofluids were synthesized by applying the one-step method using pulsed wire evaporation (PWE). In this method, the thin and long wire was overheated when the voltage roughly 300V had supplied. Subsequently, due to heat-induced by the voltage supply, the wire began to evaporate just within a few milliseconds when the temperature was increased exponentially and later it turns into plasma. Eventually, the small particles are condensed when the high-temperature plasma get cooled by the mixed argon-oxygen gas. The overall process is strictly controlled in the reaction or condensation chamber. The similar method also employed by Lee et al. [17] for preparing ZnO in Ethylene Glycol (EG). In this pulse wire evaporation (PWE) method, the volume concentration of ZnO nanoparticles in the base fluid is strictly controlled via the wire explosion number. Aberoumand and Jafarimoghaddam [15] synthesized Cu nanofluid using Electrical Explosion Wire (EEW) which high voltage and current had supplied through a thin copper electrode that submerged in the engine oil. The physical Copper electrode can be transformed into Cu nanoparticles by inducing small explosion in the liquid media which also acts as a base fluid.

### Two-step method

In the two-step method, the nanoparticle is obtained separately and they are dispersed into a base fluid at a certain volume or weight concentration with or without surfactant. Yu Su et al. [19] synthesized graphite oil-based nanofluids by a two-step method which the nanoparticles that purchased from the supplier were dispersed in vegetable-based oil and ester oil as base fluids. S. Suresh et al. [20] studied the thermal conductivity and the viscosity of $Al_2O_3$-Cu hybrid nanofluids that prepared using the thermochemical method. The two methods was applied to synthesis the hybrid nanofluid powder and mixed these two materials in a ratio 90:10 (alumina: copper oxide). In general, a total four stages involved for preparing the nanosize powder that consists of; i) spray-drying at 180ºC to get precursor powder, ii) oxidation of precursor powder at 900ºC in air atmosphere for 60 minutes, iii) the CuO reduced to form metallic copper in hydrogen atmosphere and iv) homogenisation of $Al_2O_3$ nanocomposite powder by applying ball-milled method of the powder mixture at 400rpm for one hour. The summary of nanofluids preparation methods by the scholars that consists of one and two-step method is shown in Table 1. Two-step method is preferred rather than one-step method in preparing the nanofluids due to availability of nanoparticles in mass quantity for the research works.

**Table 1.** Summary of preparation method applied by the researchers for different nanoparticles and fractions

| Author | Nanoparticles | Concentration | Base Fluid | Type of Synthesis |
|---|---|---|---|---|
| Zhu et al. [21] | $CuSO.5H_2O$ | 0.15wt% | Water | One-step method |
| Hung et al. [22] | HCNF's | 0.02 wt% | Sodium dodecyl sulphate | One-step method |
| Gurav et al. [23] | Polyaniline | 0-1.2wt% | DI Water | Two-step method |
| Cacua et al. [24] | $Al_2O_3$ | 0.1-0.5 wt% | DI Water | Two-step method |

| | | | | |
|---|---|---|---|---|
| Wang et al. [25] | $Al_2O_3$ | 0.0-4.0 vol% | Palm oil | Two-step method |
| Sharma et al. [26] | MWCNTs | 2.0wt% | SAE20W40 oil | Two-step method |
| Mao et al. [27] | $Al_2O_3$, $MoS_2$ | 1.0-5.0 vol% | DI Water, Canola oil, Synthetic emulsion | Two-step method |
| Zhang et al. [28] | $Al_2O_3$/SiC | 2.0 vol% | Bluebe#LB-1 and plant oil | Two-step method |
| Elcioglu et al. [29] | $Al_2O_3$ | 1.0-2.0 vol% | Water | Two-step method |
| Baby et al. [30] | Silver/Graphene | 0.05 vol% | Ethylene Glycol / DI Water | Two-step method |
| Suresh et al. [31] | $Al_2O_3$/Cu | 0.1 vol% | Sodium-lauryl sulphate | Two-step method |
| Wei et al. [32] | SiC/$TiO_2$ | 1.0 vol% | Diathermic Oil | Two-step method |
| Setti et al. [33] | $Al_2O_3$,CuO | 0.05-1.0 vol% | Water | Two-step method |
| Amrita et al. [34] | Nanographite | 0.3 wt% | Water | Two-step method |
| Muthusamy et al. [35] | $TiO_2$ | 0.1 – 1.5vol% | Ethylene Glycol | Two-step method |
| Agarwal et al. [36] | CuO | 0.0-2.0vol% | DI Water, Ethylene Glycol (EG), Engine Oil | Two-step method |

## DISPERSION OF NANOPARTICLES

A proper mixing between based fluids and nanoparticles is essential for nanofluid preparation. Nanomaterials volume concentration must be defined clearly using Eq. (1) before the materials are added into based-oil [37]. The nanofluids can be prepared either by weight percentage or volume fraction relative to the amount of the base oil. From the studies, researchers have a high tendency to mix the nanomaterials between 0.1 and 2.0 weight percentage (wt %) or between 0.5 and 5 % of volume fraction (vol %). The required amount of nanoparticle for nanofluid weight concentration can be calculated as shown below in Eq. (2), [38]. In addition, the density of hybrid nanoparticles and nanofluid can be determined by Eq. (3) and Eq. (4) respectively. The conversion between weight percentage and volume fraction of nanoparticles in preparing nanofluids can be referred in Eq. (5). These equations are helpful when preparing either single phase or hybrid nanofluids.

$$\emptyset = \frac{[\frac{m_{np}}{\rho_{np}}]}{[\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}]} \tag{1}$$

where m is the mass and $\rho$ is the density. While np and bf are referred to nanoparticle and base fluid respectively.

% of weight concentration=(weight of nanoparticle)/(weight of nanoparticle+weight of base fluid) (2)

The density of hybrid nanoparticle can be calculated using Eq. (3) [39],

$$\rho_{np} = \frac{\emptyset_1\rho_1 + \emptyset_2\rho_2}{\emptyset} \tag{3}$$

where Ø is volume concentration, $\rho_1$ is the density of nanoparticle '1' and $\rho_2$ is the density of nanoparticle '2'.

The density of nanofluid can be determined using equation which given as [40, 41],

$$\rho_{nf} = (1-\emptyset)\rho_{bf} + \emptyset\rho_{np} \tag{4}$$

where $\rho_{nf}$ is the density of nanofluid ( $g/cm^3$), $\rho_f$ is the density of the base fluid, $\rho_s$ is the density of solid particles and Ø is volume concentration.

In order to covert the weight percentage into volume concentration, Eq. (5) can be applied for this purpose [42].

$$\varphi = \frac{\omega\rho_{bf}}{(^{\omega}/_{100})\rho_{bf}+(^{1-\omega}/_{100})\rho_{np}} \tag{5}$$

where ω is the weight percentage of nanoparticles, $\rho_{bf}$ is the density of the base fluid and $\rho_{np}$ is the density of nanoparticle

For instance, Najiha et al. [42] prepared 0.5, 2.5 and 4.5 % of the volume fraction of $TiO_2$ nanolubricants in the experiment. On the other hand, Huang et al. [43] experimented with 0.5 wt% multi-walled carbon nanotube (MWCNT) and also without (MWCNT) using MQL system. Another example is that Yu Su et al. [19] mixed 0.1 wt% and 0.5 wt% of graphite nanoparticles with vegetable-based oil. M. Asyraf et al. [44] prepared the samples by employing an ultrasonic liquid processor at 100W for output power, 25% amplitude and within 18ºC and 23ºC for 4-hour duration. Generally, a mixer can be used for blending nanofluids upon added with the nanoparticles volume fraction. Wang [45] employed a supersonic homogenizer for preparing $Al_2O_3$ nanofluid at maximum power of 250 Watt and 23 kHz frequency. Besides, an ultrasonic dismembrator or ultrasonic vibrator also can be used for the same purpose. The mixing process normally takes about 8 hours to 10 hours just to ensure the particles are properly mixed with the based fluids.

## CHARACTERIZATION OF NANOFLUIDS

The main objective of characterizing nanofluid is to ensure that nanoparticles are presented in a base fluid and no agglomeration among particles occurs in the fluid. Moreover, the shape and size of the nanoparticles that dispersed can be verified. Thus, a very high-resolution microscope such as transmission electron microscope (TEM), X-Ray diffraction pattern and scanning electron image (SEM) image of nanofluid should be obtained so that the average grain size of nanoparticles, *Dp* can be calculated using the Scherrer formula [20, 46] as given below,

$$D_p = \frac{0.94\lambda}{\beta cos\theta} \tag{6}$$

where, $\lambda$ the X-ray wavelength, $\beta$ is the line broadening at half the maximum intensity (FWHM) and $\theta$ is the angle of incidence.

Besides, Al-Ansari et al. [47] used dynamic light scattering (DLS) for measuring $SiO_2$ nanoparticles in the suspension. A diffractometer is an instrument which can rely upon to get the XRD spectra. Bruker AXS D8 Advance X-ray diffractometer is one of the measurement instruments available in the market. It is very useful to identify crystalline compounds either organic and inorganic in the solution. Meanwhile, a scanning electron microscope with the range of magnification between 10,000x to 20,000x can be used to meet the objectives of nanofluid characterization. Typically, a Jeol JSM microscope model is used to get the SEM image. In addition, both TEM and SEM can be applied for measuring a single nanoparticle and aggregation condition in the base fluid. Saravankumar et al. [48] investigated the presence of silver nanoparticle by measuring Ultraviolet-vis absorption spectra over wavelength. The peak of absorbance found at 400nm wavelength with associated with surface plasmon excitation which also indicated the formation of silver nanoparticles in the sample.

### Wettability of Nanofluids

The wettability of nanofluid is referred to a degree of the wetting surface. It has a strong correlation between the nanofluid viscosity and surface tension. The heat transfer performance of nanofluid is greater with the lower of surface tension [49]. Moreover, it can be determined by measuring the contact angle or the wetting angle of a droplet. This angle is referred to a certain degree angle between cutting tool surface and the tangent line at the interface of a droplet as shown in Figure 1. Several factors such as concentration, nanoparticle size and solid surface tension have remarkable influence on the wettability [50]. Interesting findings by Kim et al. [51] that nanoparticles improved on surface wetting, however no enhancement recorded in terms of critical heat flux (CHF). In addition, according to Feini et al. [52], during the nanofluid boiling nanoparticle deposition (NBND) process, surface wettability can be engineered by controlling the nanoparticle concentration.

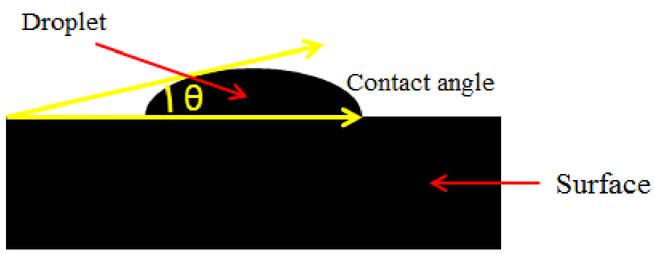


**Figure 1.** A nanofluid droplet contact angle

In general, the lower the contact angle is better for the cutting fluid wettability to the workpiece and the cutting tool surface as reported by Andhare et al. [53] . They observed that the lowest contact angle was 18° for a droplet of MWCNT nanofluid of 0.3 vol%. Anssari et al. [54] investigated the relationship of the contact angle of nanofluids based on volume concentration and exposure time. It revealed that strong surface wettability found at higher concentration and longer exposure time. K.Park et al. [55] found that an Oil-based nanofluid showed a lower contact angle compared to water-based nanofluid. Furthermore, the contact angle can be measured using a DSA 100 droplet measurement which the sessile drop technique is applied [19].

## STABILITY OF NANOFLUIDS

The stability of nanofluids is crucial when preparing nanofluid because it has a significant effect on thermal conductivity. There is a strong correlation between the stability of nanofluid and its thermal conductivity. In other words, the stability has corresponded to the dispersion of nanoparticles in the base fluid were the better of nanoparticles dispersibility, the higher thermal conductivity of nanofluid [56]. In order to evaluate the stability of nanofluids, there are many methods and measurement instruments that can be used such as mixer, homogenizer, and sonicator. The homogenizer is a mixer which has high rotating speed up to 12,000 rpm. Alper [57] used homogenizer at 500 rpm to mix and stabilize nanographene in vegetable oil. According to Lee et al. [58], the stability of solution can be achieved when sonication time for the nanofluid is more than 5 hours.

**Table 2.** Summary of the nanofluid stability method and its important parameters

| Author | Nanoparticles | Concentration | Stability Method | kHz | Watt | Time |
|---|---|---|---|---|---|---|
| Sayuti et al. [59] | Carbon Onion | 0.0,0.5,1.0 & 1.5 wt% | Sonification | 40 | 500 | 30 minutes |
| Ebrahim et al. [60] | $Al_2O_3$-MWCNTs | 0.0265 – 1.0 vol% | Ultrasonic processor | 24 | 400 | 6 hours |
| Verma et al. [61] | Aluminum oxide ($Al_2O_3$) Titanium oxide ($TiO_2$) Silicon oxide ($SiO_2$) Copper oxide (CuO) Graphene Multiwalled carbon nanotubes (MWCNTs) | 0.25 – 2.0 vol% | Ultrasonic Vibrator | 36±3 | 100 | 10 hours |
| Sayuti et al. [62] | $SiO_2$ | 0 – 1.0wt% | Sonification | 40 | 500 | 48 hours |
| Chandrasekar et al. [63] | $Al_2O_3$ | 0.33-5.0 vol% | Ultrasonic Vibrator | 36±3 | 100 | 6 hours |
| Zhu et al. [64] | $Al_2O_3$ | 0.02 – 0.2 wt% | Ultrasonic Vibrator | 40 | 100 | 1 hour |
| Suresh et al. [20] | $Al_2O_3$-Cu | 0.1 – 2.0 vol% | Ultrasonic Vibrator | 40 | 180 | 6 hours |

## SURFACTANT AS A STABILIZER

It has been reported that a common problem in preparing nanofluids is coagulated of nanosized particles in suspension. The issue of agglomerate in nanofluid, especially in hybrid nanofluid, is due to strong Van der Waals interactions [65]. This is the most challenging parts in controlling the stability of nanofluids [66]. Due to the surface and interfacial tensions in nanocoolant that may contribute to agglomerate and immiscible fluids issues, researchers have proposed a surfactant or dispersant which may solve the problem. The surfactant used in the suspension can slow down the accumulation of the nanoparticles. A surfactant is addictive which can be added to lower down the surface tension and to uniformly disperse the particles as well as to stabilize the dispersion. There are many examples of surfactants which also known as 'surface acting agent' used by the researchers in their nanofluids such as gum Arabic (GA), oleic acid, sodium dodecyl sulfate (SDS) [67–69], sodium dodecylbenzene sulfonate (SDBS) [64] and cetyltrimethylammonium bromide (CTAB) [70]. K.Y Leong et al. [71] claimed that nanofluids with surfactants are more stable compare with nanofluids without surfactants. In the experiments, gum arabica (GA), polyvinylpyrrolidone (PVP) and cetyl trimethylammonium bromide (CTAB) were used as surfactants. The thermal conductivity exhibited 26% enhancement for nanofluids containing surfactants. Besides, the thermal conductivity, solubility, mobility, and fluid viscosity also can be improved when surfactant was added into nanofluids [72]. However, Zhu et al. [64] found that the thermal conductivity ratio is decreased when SDBS surfactant increases in the solution. From the study, the maximum thermal conductivity ratio of the nanofluid is 1.10 at 0.02 wt% of SDBS.

Furthermore, the presence of surfactants has changed liquid properties in terms of surface bonding among molecules in improving the dispersibility of nanoparticles in nanocoolants. The electrostatic repulsive forces among nano-sized particles and the hydrophobic surface forces that causing adsorption in suspension have a high tendency to breakdown the agglomeration of nanoparticles in based-fluid [73]. This can significantly increase the dispersibility of nanofluids. According to S.M.S. Murshed et al. [73], CTAB is better and effective rather than oleic acid in breaking down the particles conglomerate in suspension. Similar findings by Al-Waeli et al. [74] revealed that CTAB and tannic acid + ammonia solution found the highest stability of nanofluids with more than 80 days rather than SDS and SDBS surfactants. However, the increase of surfactant more than 0.5ml cause the decreasing of thermal conductivity of nanofluids [74]. According to Wei Yu et al. [75] the presence of surfactants may provide additional thermal resistance and subsequently may reduce the effectiveness of nanofluids thermal conductivity. It has been reported by Baghbanzadeh el al. [76], that there was a negative effect of surfactant, especially on nanofluid thermal properties. In contrast, the presence of surfactant or dispersant in suspension can increase the nanofluid thermal conductivity [77]. For instance, in the experiments done by K.Y Leong et al. [71], gum arabica (GA), polyvinylpyrrolidone (PVP) and cetyl trimethylammonium bromide (CTAB) were used as surfactants. The thermal conductivity exhibited 26% enhancement for nanofluids containing surfactants. However, a very low percentage should be used to avoid any effect on heat transfer single-phase and thermal-properties performance.

Khalil et al. [72] used 3 wt% of sodium dodecylbenzene sulfonate (SDBS) in alleviating the accumulation of nanoparticles in the mixture. M. Asyraf et al. [44] suspended different volume fractions of $Al_2O_3$ nanoparticles into soluble cutting oil with 1 wt% of SDBS. S.Suresh et al. [20] used sodium lauryl sulfate (SLS) as a dispersant in preparing $Al_2O_3$-Cu hybrid nanofluids sample. R.A. Raju et al. [78] added 0.5% volume of sodium dodecyl sulfate (SDS) into the mixture of 0.2% volume of MWCNT and distilled water for preparing the nanofluid sample. B.Zareh-Desari et al. [79] added oleic acid as surfactant into soybean oil and Rapeseed oil at 0.3wt% and 1.0wt% respectively. The relative volume concentration decreased over an hour regardless of the sample preparation. The suspension should be utilized after sonication time. Ueki et al. [80] dissolve 0.5wt% polyvinylpyrrolidone (PVP) as a surfactant in the solution to control the pH value at 9 which the solution found stable. On the other hand, the main problem is how to select suitable surfactant based on nanoparticles concentration and type of based-oil. The water-soluble surfactant is suitable with polar solvent based-fluid, whereas oil-soluble surfactant is more suitable with non-polar solvent based-fluid [75]. However, certain researchers are against the application of surfactant in preparing nanofluids to avoid contamination issue [43] and for preventing foams that my presence [16]. Due to these reasons, B.Munkhbayar et al. [16] used surfactant-free in preparing MWCNT-Ag hybrid nanofluids. Researchers claimed that nanofluids must be stable and can be dispersed for a long period when nanofluids are prepared without surfactant.

## STABILITY EVALUATION OF NANOFLUIDS

After nanofluids preparation, the stability test should be conducted using both qualitative and quantitative method in order to ensure no sedimentation occur in the suspension. Observation on the nanoparticle sedimentation is an example of qualitative method. UV light absorbance rate, pH value and zeta potential values are quantitative measurement that can be applied to evaluate the dispersibility. However, zeta potential value measurement is more reliable compared to other methods due to the data obtained is more precise and accurate. This section discusses different methods of nanofluids stability evaluation with regards to obtain a stable suspension regardless different type of nanomaterials, base fluids and sonication time. The sonication time can be increased when instability of nanofluid is obtained. Reduction of nanoparticles weight concentration may help in improving nanofluid stability. Moreover, application of surfactant in the suspension may enhance nanofluid stability in the long duration. Meanwhile, Stoke Law suggests that sedimentation time of a nanoparticle can be prolonged when smaller nanoparticle and higher viscosity of the based fluid use in preparing the nanofluid.

### Observation Method

A very simple measurement of nanofluid stability is by observing the nanofluid in the test tubes in a stationary condition within a certain period as shown in Figure 2. This method is inexpensive and rely based on qualitative approach by daily observation. The exact time when the nanoparticles are deposited can be arguable. The test tubes must be transparent to observe any changes of nanofluids in terms of color, the formation of different layers and agglomeration. The particles should have not settling on the bottom side of the test tubes. Besides, the color of the nanofluid should be in uniform and shouldn't have different layers with the period study. These criteria should be observed in daily basis with the regards of maximum duration of nanofluids stability.

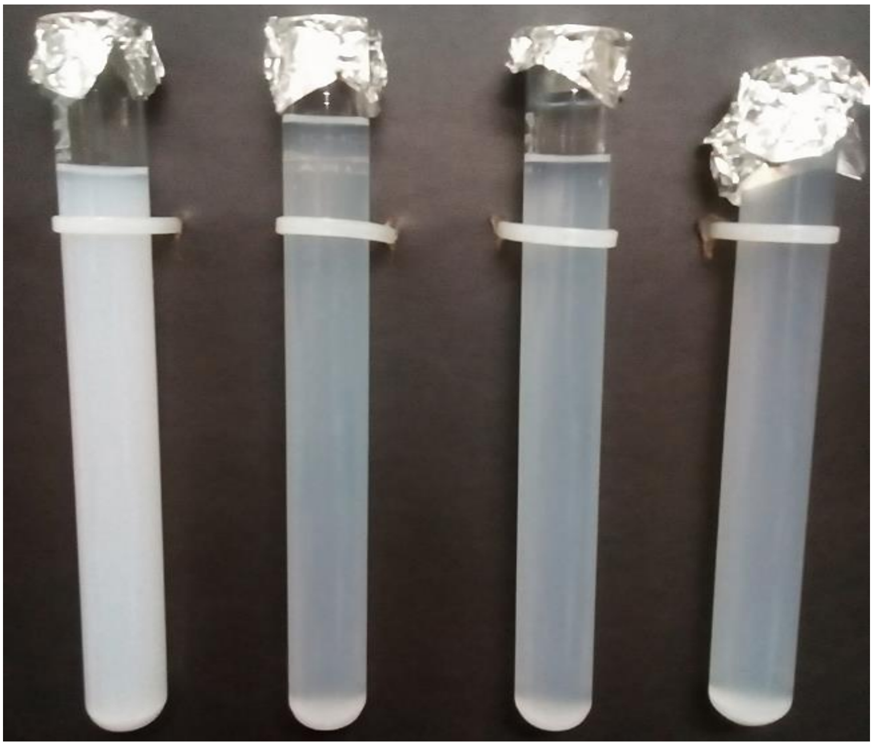

**Figure 2.** Observation method of nanofluids stability in the test tubes

### Ultra Violet (UV) Light Absorbance Rate Measurement

The measurement of UV light absorption is essential in nanofluid characterization prior to validate nanoparticles dispersibility in the base fluid as it gives quantitative results. Hence, the sedimentation trend of the nanoparticles can be monitored closely based on daily basis. However, the UV light absorbance by the nanoparticles is penetrated at the specific point which in turn does not reflect the stability condition of the nanofluids. In general, the value of a higher absorbance rate is directly proportional to the higher nanoparticle dispersibility. A UV spectrometer is an apparatus that can be used to measure nanofluid UV light absorption. The working principle of UV spectrometer is based on Beer-Lambert's Law [81]. In this law, the amount of absorption light is to be influenced by the number of solid particles in the medium. In other words, the more suspended particles in the fluid, the more the light absorption. Normally, the wavelength is ranging from 200 nm to 800 nm. B. Munkhbayar et al. [16] measured UV light absorption using UV Spectrometer (X-ma 3000 series) for the different weight percentage of MWCNT- Ag hybrid nanofluids. The results showed that the maximum absorbance of Ag-MWCNT composite nanofluid was 2.506 abs at 264 nm and the UV spectra absorbance of MWCNT-Ag nanofluid was greater over 400 nm wavelength. This finding is also comparable with Ag nanoparticles that possess high UV spectra absorbance ranging from 400mm to 800mm wavelength. Yang et al. [82] studied the absorbance rate of halloysite (Hal) nanotubes nanofluid at 0.8% volume concentration with different solvents. The suspension stability found better in water compared to other solvents. The stability of nanofluid can rely on the consistency of overlapped absorption spectra [83]. For instance, Wang et al. [84] investigated the nanofluid dispersion stability by applying spectrophotometer for 24 hours. Form the study, Chinese ink absorbance didn't change over time compared to other samples tested. That's mean Chinese ink has shown greater dispersion stability.

### pH Value Measurement

The measurement of pH value is one of the common and simple methods for measuring nanofluid stability. Moreover, the stability of nanofluid can be increased by controlling pH value due to strong repulsive forces [85]. The nanofluid is considered stable when its PH value is far from Isoelectric point (IEP). Chandrasekar et al. [63]found that the $Al_2O_3$ nanofluid pH value around 5 which has a big difference to $Al_2O_3$ Isoelectric point at 9.2 [86]. Hence, the samples nanofluid are stable. R.Kamatchi et al. [87] measured rGO PH level for 0.01, 0.1 and 0.3g/l within five days upon nanofluid preparation and found that the PH value is between 7.56 and 8.69. These PH values are far away from the IEP value ~4.7. Therefore, the nanofluid is considered stable when comparing these two PH values. The pH value is deferred from one sample to another. For example, a good pH value for graphite, alumina, and copper that dispersed in water is 2, 8 and 9.5 respectively [88]. Qi et al. [89] prepared 4 samples $Al_2O_3$-water and $TiO_2$-Water at 7,8,9 and 10 pH value. Then, the nanofluid transmittance was measured across the samples. The study was to investigate the effect of pH value on the nanofluid stability. From the investigation, the suspension at pH=8 was shown better stability compared to other suspensions as it had the lowest transmittance over time.

### Zeta Potential Value Measurement

The zeta sizer nano (mavern nano Z) also can be used to verify the stability status of nanofluid. This is the most reliable method compared to others in evaluating dispersion condition of nanofluids. This method requires zeta potential analyzer which is state-of-art laboratory equipment that can be handled by the competent person. Zeta potential value represents the electric potential difference between the stationary medium or the base fluid and the dispersion medium in nanofluids. In order words, high zeta potential value is associated with strong repulsive forces which indicate high stability whereas the low value of zeta potential means the particles have high tendency to flocculate. The nanofluid is considered stable when the value of zeta potential is higher than 30mV or below than -30mV over the nanofluid volume concentration percentage[90,91] or over a pH value [92]. Leong et al. [71] revealed the results of zeta potential (mV) of different nanofluids at different concentrations. It can be concluded in the study that the mixture of 0.01 wt% CNT, based-oil and CTAB as surfactant possess high zeta potential value. Liu et al. [93] investigated zeta potential value of nanofluids at different volume concentrations before and after being kept at 180°C for one month. The stability of modified Graphe (MGE) decreased to 29mV which slightly below 30mV, hence indicated the suspension still stable even after one month.

### Other Methods

Surface modification technique also can be used to stabilize the suspension. However, it is costly and requires technical knowledge to perform surface modification on the nanoparticles. The nanoparticles surface is coated with the help of chemical reaction mainly from acid and oxygen. Amrita et al. [94] employed this technique where the nanographite dispersed and taking place in water easily. On the other hand, the diameter of dispersed nanoparticles can be measured using dynamic light scattering (DLS) method where S. H. Seyedmahmoudi et al. [95] measured the zinc oxide (ZnO) and titanium oxide ($TiO_2$) nanofluid stability using ZetaSizer Nano ZS DLS device (Malvern Instruments, Westborough, MA). From the measurement over 2 hours, 7 hours and 1 month, the reduction of the size of the nanoparticles was small which less than 2.99% that indicates the suspension was stable. The apparatus and instruments used by the researchers have been listed and shown in Table 3.

**Table 3.** Key instruments for measuring characteristics of nanofluids

| Measurement | Objective | Instrumentation | Model / Manufacturer | References |
|---|---|---|---|---|
| Contact Angle | To analyze the wettability of nanofluid | Contact Angle Analyzer | Phoenix 300 (Suwon, Korea) | [78] |
| | | | DSA 100 (KRUSS, Germany) | [19] |
| | | | Goniometer (DSA25 Kruss' GmbH) | [96] |
| Surface Tension | | Surface Tension Meter | Shanghai Precision Instrument Co., Ltd. | [19] |
| Nanofluid Stability | To mix and stir between nanoparticles and base fluid. Therefore, homogenous suspension can be obtained. | Ultrasonic Dismembrator, Ultrasonic Dispersion, Ultrasonicator | ATP 750 Anthena | [73,97 ,98] |
| | | Ultrasonic Vibrator | Digital Pro JP040-S | [20,99] |
| | | Ultrasonic processor | (Hielscher Company, Germany) | [100- 102] |
| | | Homogenizer | (IKA T25, Ultra-Turrax, Germany) | [98] |
| | | Sonicator | Q700 | [19] |
| | | Magnetic Stirrer | Stuart CB162 | [103,104] |
| | | Spectrophotometer | Unico SQ2800 | [105- 107] |

| | | | | |
|---|---|---|---|---|
| | To evaluate suspension stability based on wavelength measurement | Zeta Potential | Zetasizer (Malvren)<br><br>Nano Particle Analyzer SZ-100 (Horiba, Japan) | [20,108] |
| SEM image | To study the microstructure, physical size of a nanoparticle. | Scanning electron microscope<br>3D Confocal Microscope | (Carl Zeiss, Germany)<br>KEYENCE, Japan | [20,44,97]<br><br>[109] |
| TEM Image | To monitor nanoparticles dispersion in suspension and to obtain images of nanofluids in various concentrations. TEM is in higher resolution compare to SEM. | Transmission electron microscope | JEOL1011/ 2200FS | [73,110,111] |
| pH value | To verify pH value of nanofluid | pH meter | (Deep Vision : Model 111/101) | [20,111] |

## CONCLUSION

Due to the advantages of nanofluids in enhancing thermal-physical properties of the base fluids, nanofluids in recent years have been applied extensively in many critical areas such as cooling, lubricating and renewable energy. However, the preparation process for obtaining the long-term stability of nanofluid is a key challenge. The problem can be overcome by selecting suitable size and density of nanoparticle materials, composition ratio of hybrid nanoparticles, higher viscosity of the base fluids and the right combination with or without surfactant which regards to get the optimum condition of nanofluids in terms of desired physical, thermal and rheological properties. Based on literature, 95% of researchers employed two-step method in preparing nanofluids due to simple as it not required sophisticated apparatus. Average sonication time was recorded between three and ten hours to obtain better dispersion of nanoparticles. The understanding of a variety of base fluid such as oil-based and aqueous-based and application of surfactants in terms of suitability and solubility with nanoparticles is important before nanofluids can be prepared. The technique in obtaining the right composition ratio between hybrid nanoparticles in hybrid nanofluids preparation should be highlighted for the knowledge sharing. There is limited study on the effects of surfactants towards thermal-physical properties as well as in engineering application performance. As newly developed fluid, the thermal-physical properties and dynamic viscosity behavior have been influenced by the concentration and wettability condition of nanofluids. However, from literature review, there is no correlation developed between nanofluids wettability and thermal-physical properties of nanofluids for single and hybrid nanofluids. In a nutshell, hybrid nanofluids have an immense potential and can be manifested to be engineered as a replacement for conventional fluid which should be explored intensively in the future.

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