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An overview on synthesis, stability, opportunities and challenges of nanofluids

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ABSTRACT

Nanofluids are the novel class of nanomaterials suspension in base fluids. A nanoscale colloidal dispersion which containing nanoparticles is called nanofluids. Nanofluids have shown enormously distinctive features, unique properties by offering the unexampled possibility for many applications. Nanofluids are a new generation of heat transfer fluids that have attracted researchers' attention from diverse fields due to their anomalous thermal behaviour and potential applications. Improved thermophysical properties of nanofluids including the thermal conductivity, viscosity, diffusivity, heat transfer coefficient are the most fundamental properties of nanofluids in the field of nanotechnology. Among all of the exciting properties of nanofluids, long-term stability is the first basic requirement in nanofluid research for maintaining their enhanced and outstanding thermophysical properties. This paper provides the ongoing advancement on the investigation of nanofluids including the preparation method, approaches to improve the stability, the assessment technique for the stability focusing challenges and opportunities of further improvement towards the performance of nanofluids.

1. Introduction

Cooling and lubrication is a vital requirement in modern manufacturing industries. Different types of oils are being extensively used by numerous researchers as coolant and lubricant [1–4]. The application of different types of oil reduces friction and heat from various movable and stationary parts in the system [5,6]. The thermal properties including the thermal conductivity, viscosity of oils influence significantly the heat transfer process [7]. For instance, fluids with higher thermal conductivity have better heat transfer properties [8–10] as thermal conductivity is an indicator of the efficiency of thermal convection [11]. Usually, the traditional liquids like water, ethylene glycol, different types of oils have low thermal conductivity [12] but the use of different types of nanoparticles into the base fluid increases heat transfer potential of fluids [8,13]. Thus, the emergence of nanofluid which is the suspension of nano-sized particles [14] has pulled the attention of researchers and the use of nanofluid can improve the rate of heat transfer of fluid. Choi, Eastman [15] discovered nanofluids which are the suspension of nano-sized particles into the base fluid like water, ethylene glycol, engine oil etc. Nanofluids also known as novel heat transfer fluids because of its potential characteristics and features in different fields such as machining [16–18], transportation [19,20], electronics [21,22], nuclear cooling system [23], solar energy collectors [24,25], biomedical fields [26,27] etc. How-ever, the occurrence of aggregation of nanoparticles with the elapsed time leads to sedimentation of particles which reduce stability including thermophysical properties of nanofluids [28,29] because to sustain the improved thermal conductivity is directly related to the stability [30,31]. To prepare the nanofluid with homogeneity and better stability is still one of the critical challenges in the field of nanofluid because of strong Van der Waals attraction among particles [12,32].

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Although research work in the field of nanofluid is still not much, synoptic reviews were presented in Refs. [7,12,31,33,34]. The main focus of this paper is to enhance stability which is one of the crucial properties of nanofluid because the thermophysical properties are directly related to it. However, this article is split into three parts: preparation methods of nanofluids are presented in first part, middle part is dedicated to stability and stability enhancement techniques of nanofluids and third part is for stability analysis techniques including some important challenges and possible opportunities in the field of nanofluid which need to be focused in the future research.

2. Preparation of nanofluids

The preparation method of nanofluid is one of the most primary steps in the field of nanofluids. Generally, there are two conventional methods for nanofluid preparation: one-step and two-step preparation process [12,34]. One-step method consists of synthesis of nanoparticles and dispersing the nanoparticles into the base liquids at the same time [35,36]. Shahsavar, Salimpour [37] used single-step method for making Fe_3O_4-CNT/distilled water nanofluid while Fe_3O_4 and CNT were coated with tetramethylammonium hydroxide (TMAH) and Gum Arabic (GA). Cu/Pd nanofluids are synthesized through single-step method [38]. One-step was also followed by Manimaran, Palaniradja [39] while producing CuO/distilled water nanofluid. Using one-step method diethylene glycol-based Cu nanofluids is prepared by Nikkam, Ghanbarpour [40]. While one-step method is employed, the uniformity of nanofluid can be in-creased by reducing agglomeration of nanoparticles and to achieve optimum stability is one the most significant issues for sustaining better thermal properties [34]. On the contrary, this method is not preferable for the industrial purpose [35] because of its higher production cost, aptness to base fluid with low vapour pressure only [41,42]. Simple schematic diagram of one-step process is represented in Fig. 1.

Compared with one-step method, two-step method is mostly used method in industries for producing at large scales of nanofluids [12,34]. Under two-step method after producing the nanoparticles through different synthetic techniques, the nanoparticles are dispersed into the base fluid [43]. Fig. 2 shows the schematic diagram of two-step preparation method of nanofluids. Most of the researchers used this method for preparing nanofluid [44–46]. Senthilraja et al. used two-step method during preparation of distilled water-based CuO and Al_2O_3 single nanofluid and also Al_2O_3-CuO hybrid nanofluids [47]. Sundar, et al. also used two-step method for CuO [48], Nanodiamond [49,50], Al_2O_3 [48] and Fe_3O_4 [51] nanofluids. Carbon nanotube containing nanofluids also has been synthesised using two-step method by many researchers [52–55]. Eastman, Choi [56] recommended two-step method for preparing oxide nanoparticles based nanofluids rather than metallic particles based nanofluids. In two-step method, it is difficult to avoid agglomeration of nanoparticles which is one of the most critical issues or challenges [34] whereas this method is associated with lower production cost [31] compared to one-step.

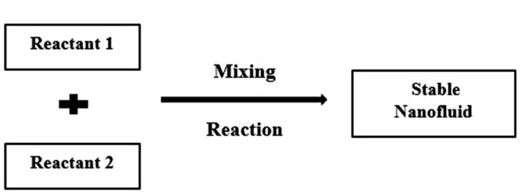

Fig. 1. One-step synthesis technique of nanofluids.

3. Stability of nanofluids

The investigation on the nanofluid's stability is an essential issue in the field of nanotechnology. The scientists observed stable nanofluids without apparent sedimentation for various time periods starting from hours to months. Stability of nanofluids has influential effects on the attributes of nanofluids. For instance, clogging of nanoparticles can leads to the degradation of thermal conductivity [12]. Hence, it is crucial to explore the parameters which influence the homogeneity of nanolfuids. This section will represent various stability improvement and analysis techniques in an organized manner.

3.1. Stability improvement process

Settlement of nanoparticles in the nanofluid can be happened because of losing stability. Besides, thermal properties can also be deteriorated for the agglomeration of nanoparticles. So, different kinds of stability improvement techniques will be briefly discussed in the following section of this article.

3.2. Ultrasonication

To enhance the stability of nanofluid it is essential to break down the agglomeration of nanoparticles. Ultrasonicator probes or baths (Fig. 3) help to disperse the nanoparticles physically [31]. Numerous researchers use probe and bath sonicator to disperse the nanoparticles uniformly [11,57,58]. Usually, ultrasonication is conducted at various power and frequency for various span of time. The time of sonication may be dependent on the type, size, shape, concentration, mixing ratio of nanoparticles and base fluid and also on the preparation method etc [34]. Yiamsawas, Mahian [59] used ultrasonic vibrator of 600 W power for two hours to get the stability of nanofluids (TiO_2/ethylene glycol- water and Al_2O_3/ethylene glycol- water). In this study, the range of temperature was 10° to 60 °C for 1, 2, 3 and 4% volume concentrations. Accordingly, the stability of nanofluid is observed to be generally excellent for a considerable length of time. Esfe, Afrand [44] used EG as base fluid for Al_2O_3 nanoparticles of 5 nm in the range of 0.2 to 5% volume concentrations. In this experiment, a magnetic stirrer is used to mix the nanoparticles in the base fluid for one hour and to get the steady and uniform suspension ultrasonication of 400 W power was done for 8–9 h through anticipating sedimentation of nanoparticles in the base fluid. Under two-step method, Al_2O_3 nanoparticle of 13 nm diameter showed totally uniform suspension until 3 days after preparation in the range of 0 to 1% volume concentration while sonication was done for 30 min [57]. In case of TiO_2: SiO_2 (20:80, 40:60, 50:50, 60:40 and 80:20) nanofluid 1 h magnetic stirring and 2 h sonication gives the stability for 14 days while a mixture of 60% water and 40% ethylene glycol (EG) is used as base fluid [46]. Hence, ultrasonication is an important method as its purpose is to break down clusters using sound energy of ultrasonicator at different levels of frequencies and period of time for various nanofluids. Moreover, Type, size, concentration, mixing ratio, preparation method of particles including type of base fluid determine the most suitable sonication conditions [31].

3.3. Use of surfactant

Use of surfactant is another method to stabilize the nanofluid which can play an important by reducing the surface tension of liquid [60]. Surfactant is added to nanoparticles to reduce the surface energy and to enhance the dispersibility of particles. Several studies mentioned the use of surfactant to minimize quick settle down

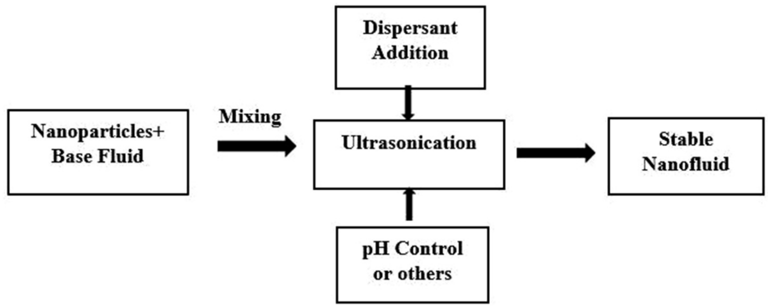

Fig. 2. Two-step synthesis technique of nanofluids.

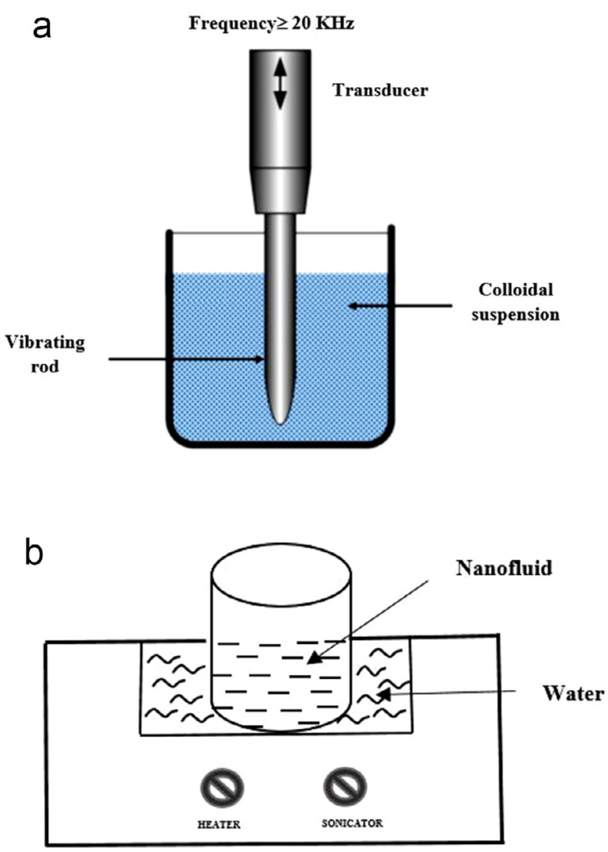

Fig. 3. Schematic diagram of probe and bath sonication.

of particles [11,61,62]. Sodium dodecyl sulfate (SDS) [11,62,63], Sodium Dodecyl Benzene Sulphonate (SDBS) [61], salt [64], oleic acid [65], dodecyltrimethylammonium bromide (DTAB) [66], hexadecyltrimethylammoniumbromide (HCTAB) [67], polyvinylpyrrolidone (PVP) [38,62], gum arabic [68] are commonly used surfactants in the field of nanofluids. Xia, Jiang [62] compared the performance of sodium dodecyl sulphate (SDS) and polyvinylpyrrolidone (PVP) to show the dispersibility and stability of Al_2O_3 nanoparticles in deionized water. In this study, PVP shows better dispersibility by enhancing stability than SDS while the concentration of surfactants were 0.5, 1 and 2%. The author mentioned that the comparatively lengthy alkyl chain of nonionic PVP is one of the reasons for its better performance. Moreover, the proneness to foam production due to using SDS is another abettor for worsening through rapid sedimentation. PVP surfactant was also used for stabilizing the Cu/Pd aqueous based nanofluid for different molar ratios at 80 °C [38].

The use of surfactant plays an important role to make a uniform and more durable solution. The quantity of surfactant influences substantially over the uniformity of suspension [61]. Mansour and Elsaeed [61] compared the performance of various quantities (0.1 and 1% wt.) of sodium dodecyl benzene sulfonate (SDBS) surfactant over Al_2O_3/transfer oil nanofluid. A little weight percentage of surfactant with appropriate concentration of nanoparticles is progressively viable for both stability and heat transfer. This study also reveals that the average size of particle enhances with increasing surfactant and also nanoparticles concentration. 0.1% wt. of SDBS shows better durability and dispersibility than 1% wt. of SDBS. The authors represented that the formation of double chain surrounding the nanoparticles for applying a larger amount of surfactant as the reason for deteriorating the performance of surfactant.

Kakati, Mandal [69] incorporated 0.03% SDS during preparation of Al2O3/deionized water nanofluid for 0.1 to 0.8% volume concentration under 10 to 50 °C. Hence, the nanofluid shows 4–5 days stability whereas without surfactant nanoparticles tend to be sedimented within just 1 h of preparation. In another research, 0.1, 0.3% oleic acid is used as surfactant along with 30 min sonication to stabilize hBN: Al_2O_3 (hexagonal boron nitride: alumina) nanofluid while SAE 15 W40 diesel engine oil works as a base liquid [65]. Addition of SDS surfactant with appropriate sonication time Al_2O_3/distilled water shows stability with almost ± 30 mV [63]. However, it is a critical issue to measure the quantity of surfactant for different types of nanofluids. Improper use of surfactant may create a negative impact on the properties of nanofluids by diminishing the interaction between surfactant and nanoparticles. Yu and Xie [34] stated that thermal resistance between particles and base fluids can be enhanced by using surfactant. Especially, for high-temperature applications, the use of surfactant is not recommended [70–72]. Ghadimi, Saidur [73] reported that the proper-ties of surfactant deteriorate largely at temperatures more than 60 °C.

3.4. Surface modification technique

Under surface modification technique the nanoparticles are dispersed into the base fluid after functionalizing the nanoparticles' surface by various techniques. Copper nanoparticles were used for modification of the surface of SiO_2 nanoparticles [74]. In this process, Stober method is used for synthesization of SiO_2 nanoparticles through hydrolysis and precipitation of TEOS (tetraethyl orthosilicate) in water/EG mixture for 2 h. Then deionized water was added with the derived products along with ammonia and $CuCl_2$ for 6 h at room temperature. Hence, the Cu- SiO_2 nanocomposite was found after some necessary steps like filtration, washing with ethanol and drying at ambient temperature. Actually, this surface modification technique is totally surfactant-free stability enhancement method. Yang and Liu [75] found 6 months stability of SiO_2 nanofluids because of using surface functionalized SiO_2 nanoparticles by grafting silanes to the surface of nanoparticles. For this treated nanoparticles no sedimentation layer is found even at boiling temperature. For the purpose of preparing surfactant-free nanofluids, a wet mechanochemical reaction was employed on single-walled and double-walled CNTs containing nanofluids [76]. This study reveals that the hydroxyl group has been incorporated on the surfaces of CNT through infrared spectrum analysis. Yu, Kim [77] followed plasma treatment for surface functionalization of diamond nanoparticles. Polymethacrylic acid (PMAA) was applied in an aqueous solution of ZnO nanoparticles to adjust the attributes of the surface of ZnO [78]. Thus, the dispersibility of ZnO nanoparticles had improved by forming zinc methacrylate on the surface of ZnO without changing the crystalline structure of particles.

3.5. Changing the pH value

Modification of pH value of the solution is another way to make the nanofluid more stable. The isoelectric point (IEP) of solution represents the particles' surface charge and zeta potential as zero value. So the pH value far from IEP shows better durability by strengthening repulsive forces among particles and enhancing zeta potential [79,80]. Wen, Lin [72] applied simple acid treatment for CNT nanofluid and found moderate stability of the suspension. Acid treatment of GNP nanoparticles was conducted by suspending the nanoparticles into the mixture of HNO_3 and H_2SO_4 (1:3) [76]. Then the products are washed using DI water and dried using an oven. Finally, the GNP solution is mixed with Ag (NO_3) OH solution which showed durability until 60 days. Choudhary, Khurana [63] reported that making the nanofluids little bit acidic or basic by adding HCL or NaOH shows standard durability with the improved value of zeta potential. Sometimes, it is difficult to measure the IEP point of the solution and the suitable value of pH is not same for all kinds of samples. For example, the optimum value of pH is 9.5 for water-based copper solution and 2 for graphite containing solution [81]. Most importantly, to keep the value of pH of solution in the optimum range is an urgent need as maintenance of acidic and basic solution is not safe for workers and work environment. Besides, corrosion of surfaces may occur by using this kind of alkaline and acidic solution in industries [82]. Finally, Table 1 summarizes various preparation and stability enhancing methods including stability periods for different kinds of nanofluids.

One can notice from Table 1 that most of the researchers utilized two-step method for the synthesization of nanofluids and the highest stability period was 6 months which was obtained through surface functionalization technique in case of silica nanofluid. Many researchers used sonication, dispersant addition process for achieving stability, some followed surface functionalization, pH adjustment technique also.

However, most of the investigations' focus is on the short term stability which can be a barrier during applying in the real life applications and also in commercialization. So, additional studies are in demand to evaluate the effects of various parameters to achieve long term stability.

3.6. Stability analysis of nanofluids

Agglomeration of nanoparticles in the nanofluids is a common characteristic which affects the thermal properties of nanofluids. So the analysis of stability and also influential factors to the stability of colloidal suspension is an unavoidable issue. There is no specific method to study and analysis the stability. Researchers used different methods for measuring the stability such as sedimentation method [46,71,83], zeta potential measurement method [73,84], ultraviolet–visible (UV–vis) spectroscopy [11,58,82], DLS test [45], TEM technique [58,85] etc.

3.7. Sedimentation method

Sedimentation is the simplest and widely utilized strategy to examine the stability of nanofluids [83]. Although it needs a long time to observe the sedimentation of particles, it is the only method from which the stability period can be derived by visual inspection. In this process, the nanofluid can be called stable for that specific time period when the concentration of fluid stays consistent with time. Numerous researchers used this method for testing the durability of nanofluids [46,71]. For instance, the stability period of water/EG based TiO_2-SiO_2 nanofluid was more than one month which was visualised through sedimentation method [58]. Ouikhalfan, Labihi [11] found the stability period of CTAB and SDS treated TiO_2 nanofluid by following sediment photograph technique. Hence, the capturing image of sedimentation has demonstrated to be an appropriate guide to view the stability of nanofluid.

3.8. Zeta potential test

Zeta potential test is another method for the assessment of the stability of colloidal dispersions [12,34]. The electrostatic repulsion between the surface of particles and the stationary layer of fluid is termed as zeta potential. So the importance of the value of zeta potential is directly related to the stability of nanofluids. A high positive or negative value of zeta potential for nanofluids indicates the stabilized condition while the low value of zeta potential suggested the unstable condition [73,86]. The zeta potential is legitimately also an indicator of the period of stability of nanofluids [63]. The zeta potential with the value of 0 mV, 15 mV, 30 mV, 45 mV, 60 mV depicts the unstable, little bit stable with quick settlement of particles, moderately stable, good stability and excellent stability conditions respectively [87,88]. For instance, water-based Al_2O_3 nanofluid showed the value of zeta potential -30 mV to 26 mV while SDS surfactant is added to increase dispersibility but it showed 14mv to 2 mV in case of surfactant-free nanofluid [63]. As zeta potential is a key indicator for measuring the durability of colloidal suspension, many other researchers used this test during investigation [42,84,89,90].

3.9. UV–vis spectral analysis

Absorbency ratio of nanoparticles is proportionately related to the concentration nanofluid. Spectral absorbency analysis is one the authentic method to evaluate the durability of nanofluids [91,92]. Ouikhalfan, Labihi [11] followed UV–vis analysis to derive the stability of TiO_2 suspension quantitatively. From this study, it is found that for the same wavelength absorbance ratio was declined with respect to sediment time. Yu and Xie [34] specified the wavelength range as 190–1100 nm for getting the most reliable result from spectral analysis method. Numerous researchers also suggested about spectral analysis method for the assessment of colloidal stability [93–95]. Li, Zhu [96] used UV–vis method along with other two methods of sedimentation photographs, zeta

Table 1
Summary of preparation method, stability improvement method and stability period with relevant information for various kinds of nanofluids.

Particle Name/Base fluid	Shape-Size	Synthesis Technique	Magnetic stirring	Satbilization method	pH/Temperature, Concentration	Stability Period	Authors
TiO_2/EG-Water (20:80), Al2O3/EG-Water(20:80)	TiO_2- 21 nm, Al_2O_3- 120 nm	Two-step		2-hours sonication	$1 < ø \le 4\%$ $10\,°C \le T \le 60\,°C$	Months	Yiamsawas, Mahian [59]
Al_2O_3/EG	5 nm	Two-step	1 h	8–9 h	$0.2 < ø \le 5\%$ $24\,°C \le T \le 50\,°C$		Esfe, Afrand [44]
Al_2O_3/Water-EG	13 nm	Two-step		30 min	$0 < ø \le 1\%$ $10\,°C \le T \le 50\,°C$	3 days	Elias, Mahbubul [57]
Al_2O_3/Deionized water				Addition of 0.03% (wt) SDS	$0.1 < ø \le 0.8\%$ $10\,°C \le T \le 50\,°C$	4–5 days	Kakati, Mandal [69]
TiO_2:SiO_2 (20:80, 40:60, 50:50, 60:40 and 80:20)/ Water:EG (60:40)		Two-step	1 h	2 h ultrasonication	$ø = 1\%$ $30\,°C \le T \le 70\,°C$	14 days	Hamid, Azmi [46]
hBN: Al_2O_3/SAE 15 W40	70 nm			0.1 and 0.3% oleic acid addition, ultrasonic homogenizer	$0 < ø \le 0.5\%$		Abdullah, Abdollah [65]
Al_2O_3/Distilled water	20 nm		10 min by hand	60, 120 and 180 min of sonication; addition of SDS; addition of HCL and NaOH	$0.01 < ø \le 0.1\%$; addition of 0.1% HCL or NaOH	16 days	Choudhary, Khurana [63]
Al_2O_3/de-ionized water	13 nm	Two-step		addition of 0.5, 1 and 2% sodium dodecyl sulphate (SDS) and polyvinylpyrrolidone (PVP)			Xia, Jiang [62]
Al_2O_3/transformer oil	50 nm	Two-step	30 min	0.1 and 1% (wt) Sodium dodecyl benzene sulfonate (SDBS); 2 h ultrasonication			Mansour and Elsaeed [61]
Fe_3O_4-CNT/distilled water	13 nm – 10–30 nm × 10 µm	One-step +two-step		Gum arabic for CNTs and TMAH for Fe3O4 + 5 min sonication (20 kHz, 130 W)	$25\,°C \le T \le 35\,°C$		Shahsavar, Salimpour [37]
Cu/Pd 20:1 M ratio	Spherical	One-step		PVP	80 °C		Jaiswal, Wan [38]
CuO/deionized water	20 nm-spherical	One-step		4 h ultrasonication			Manimaran, Palaniradja [39]
Cu/diethylene glycol	5–100 nm, spherical	One-step		Sonication	20 °C	Several weeks	Nikkam, Ghanbarpour [40]
CuO/ distilled water	27 nm	Two-step	1 h	4 h ultrasonication	50 °C	Several hours	Senthilraja, Vijayakumar [47]
Al_2O_3/distilled water	50 nm	Two-step	1 h	4 h ultrasonication	60 °C	Several hours	Senthilraja, Vijayakumar [47]
Al_2O_3 – CuO hybrid/ distilled water two-step	Al_2O_3- 50 nm, CuO- 27 nm	Two-step	1 h	4 h ultrasonication	60 °C	Several hours	Senthilraja, Vijayakumar [47]
CuO/Ethylene glycol–water (50:50 wt%)	27 nm	Two-step		2 h ultrasonication	$0.2 < ø \le 0.8\%$ $15\,°C \le T \le 50\,°C$	stable: ZPVb – 20 mV	Sundar, Farooky [48]
Particle Name/ Base fluid	Shape-Size	Synthesis Technique	Magnetic stirring	Satbilization method	pH/ Temperature, Concentration	Stability Period	Authors
Nanodiamond/ ethylene glycol–water	19 nm, cubic	Two-step		Surface modification and 2 h bath sonication	60 °C	ZPV = -30 mV	Sundar, Hortiguela [49]
Nanodiamond/distilled water	11.4 nm, cubic	Two-step		Surface modification and 2 h bath sonication	$ø = 1\%$; $T = 59.85\,°C$	30 days	Sundar, Hortiguela [49]
Fe_3O_4/ distilled water	13 nm, cubic	Two-step		2 h sonication with CTAB (CTAB to NPs mass ratio- 1:10)		60 days	Sundar, Singh [51]
Al_2O_3/ Ethylene glycol–water	36.5 nm	Two-step		2 h ultrasonication	$0.2 < ø \le 0.8\%$ $15\,°C \le T \le 50\,°C$	stable: ZPVb – 20 mV	Sundar, Farooky [48]
SWCNT/water	0.951 nm						Jabbari, Rajabpour [53]
SiO_2/water, SiO_2/EG, SiO_2-Cu/water, SiO_2-Cu/EG	SiO_2 – 50–80 nm, Cu- 10 nm		3 h	Surface modification by Cu and 2 h ultrasonication	$0.002 < ø \le 0.01\%$ $20\,°C \le T \le 40\,°C$	Two weeks	Amiri, Movahedirad [74]
SiO_2	30 nm			Grafting silanes		6 months	Yang and Liu [75]
TiO_2/distilled water			15 min	addition of CTAB, SDS; 1-hour sonication	$ø=1.25\%$	Two weeks	Ouikhalfan, Labihi [11]

potential for aqueous copper dispersion. Similarly, Nabil, Azmi [58] found the absorbency ratio by UV–vis spectrometry method and sedimentation photograph for deriving the stability period of TiO_2: SiO_2 nanofluids. Hence, the combination of several methods can strengthen the result of the investigation.

3.10. Other methods

There are some other methods which are also being using in different researches, Such as electron microscopy, centrifugation method etc. For instance, centrifugation method was used to assess the durability of Ag nanofluid in which PVP was used as a dispersant for its steric effect [97]. Particles aggregation can also be observed by electron microscopy and light scattering technique. For this purpose TEM and SEM are usually used to take micrographs of nanoparticles [58,85,98]. Transmission electron micrograph of nanoparticles are used for TiO_2:SiO_2 hybrid nanofluids and found the size of particles are the same as before hybridization which is provided by supplier [46,58].

4. Challenges and opportunities

Researchers revealed numerous potential characteristics of nanofluids in the past decades. Still, some issues may work as obstacles in the commercialization of nanofluids. So the scientist should pay more emphasis to resolve these issues. From the literature, it is found that most of the findings investigated nanofluids with having insufficient stability period [47,57,69]. Most studies focus on the thermophysical characteristics such as thermal conductivity [99–102], viscosity [9,53,103], density [46,58], heat transfer coefficient [46,58,104] etc. which is noteworthy. Besides, stability, which is a crucial issue for making the research findings more reliable and especially for real-life applications, should be given more priority. In the available literature, lack number of investigations which is focusing on the characteristics and performance of nanofluids in very low and high temperatures [59,74,105]. Research on the nanofluids at high and low temperatures may add value to understand the mechanism of performance of nanofluids at high and low temperature. It is found that high temperature can deteriorate the effects of dispersants by creating foam [34,104]. As the durability of nanofluid is directly related to the properties of additives. Future study should prioritize on the issue of additives selection, measurement and performance of different types of surfactants for various nanofluids. Sometimes temperature of suspension increased during long time ultrasonication using either probe or bath sonicator which may change the concentration of nanofluids through vaporization of few amounts of fluids. Thus, properties can also be affected. So this issue should be kept in consideration carefully during preparing nanofluids. Moreover, investigations should also be done on the corrosion and erosion behaviour of surfactant as well as nanofluids as there is no study focusing on this topic. Most importantly, there is no finding on the overall costing of different types of nanofluids. Traditional fluids are being replaced by different types of nanofluids for their novel properties. In case of replacement of a large amount of conventional fluids by nanofluids may reduce cost because of using comparatively simpler and smaller size equipment for heat transfer. Meanwhile, the price of different types of nanoparticles is very high due to their preparation method, properties etc [34,105]. So overall economic of different types of nanofluids with the necessary equipment in various practical applications may be an interesting topic which can be addressed in the future work.

5. Conclusion

Through this review paper, an endeavour has made to present most of the significant investigations focusing stability of nanofluids including preparation methods. From several kinds of literature, it is evident that the two-stage method is acknowledged and recommended by most of the scientists because it is an economic process with industrial level synthesis system. On the contrary, it is easier to avoid agglomeration using one-step method compared to two-step method but is associated with higher production cost. In the heat transfer applications of nanofluids, one of the most technical challenges is stability. Hence, some important stabilization methods are represented along with stability analysis techniques. Properties of nanoparticles and preparation methods of nanofluids have an influential impact on the stability of suspension. Most importantly, this paramount factor, stability also influences the thermophysical attributes of nanofluids. Ultrasonication, addition of dispersant, adjustment of pH, surface modification are the methods for augmenting stability. Following these techniques for achieving stability, the characteristics of nanofluids can also be modified. For instance, thermal conductivity can be varied by the alteration of sonication duration and this property can be improved up to suitable sonication time and conditions. In case of adjustment of pH, it is most important to keep the pH value in the safe region both for workers and workplace. Moreover, special attention should be given for selecting the type and quantity of surfactant to avoid uncertain abnormal status of stability as improper surfactant can degrade the colloidal durability substantially. However, this article also covers different stability analysis techniques e.g. sedimentation method, UV–vis spectrograph, zeta potential test, TEM, SEM etc. Additionally, from the reviewed studies, maximum 6 months stability is observed but most of the investigations found the stability just for the period of their experiments and in some cases little bit more time. Moreover, most of the studies represented the exciting potential of nanofluid, an increasing number of researches should be conducted concerning about long term stability, proper selection and use of surfactants, the discrepancy of results among different researchers and importantly costing of different kinds of nanofluids with necessary apparatus in the practical field.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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