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Preparation, Stability and Characterization of Nano fluids: A Review

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Abstract. As the name suggests, nanofluids are the latest in a long line of nanotechnology-based fluids that comprise nanometer-sized particles scattered throughout a liquid medium. Research on nanofluids has progressed rapidly in recent years due to numerous reports indicating a significant increase in their thermal conductivity. Although nanoparticle concentrations of less than 1% by volume have shown several fascinating features, they have also shown an expansive increase in the thermal conductivity, viscosity and other thermo-physical parameters in the base fluids. The thermo-physical properties of the nanoparticles are principally influenced by their composition, volume fraction, and size. Nanofluid fabrication methods, stability, and thermo-physical features such as heat conductivity and viscosity have been examined extensively in this article. The results show that adding nanoparticles improves the nanofluid's thermal characteristics. Nanofluids' future scope has also been sketched out.

Keywords: Nanofluids, thermal conductivity, viscosity, stability, characterization.

1. Introduction

Nanofluids are the nanotechnology-based fluids obtained by scattering nanometer-sized particles in the base fluids. Nanofluids possess improved thermal conductivity, thermal diffusivity and viscosity compared to that of base fluids [1]. Hence numerous analysts have focused towards nanofluids to profitable utilization of them. Particles utilised in nanofluids range in size from 1 to 100 nm. The fundamental objective of nanofluids is to achieve large enhancement in thermal conductivity relative to small volume fraction of nanoparticles [3].

Nanofluids have recently gained popularity as a result of their broad variety of uses and superior thermal characteristics. Choi and Eastman [4] presented the new class of nanofluids by applying the distinctive features of nanofluids. Cu nanoparticles dispersed in ethylene glycol at less than 1% volume fraction increased thermal conductivity by 40%, whereas carbon nanotubes in oil increased thermal conductivity by 150%. From then, numerous investigations were carried out both theoretically and experimentally by various specialists. Figure 1 shows more common nanoparticles and base fluids exploited in synthesis of nanofluids from the literature.

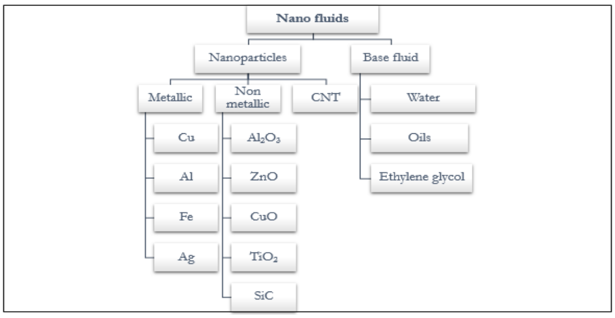

Fig. 1 Common nanoparticles and base fluids for synthesizing nanofluids.

Despite previous reviews [1–3], this paper seeks to cover the procedures for preparing nanofluids, stability study, and thorough discussions on characterization of thermal conductivity, viscosity of nanofluids. Various methods for evaluating heat conductivity and viscosity are discussed.

In sections 2, preparation methods for nanofluids were described. Stability of nanofluids and methods to evaluate the stability are discussed in the 3rd section. Section 4 gives the detailed discussion about the thermal conductivity and 5 dealt with viscosity of nanofluids. Factors affecting these mentioned parameters also presented in detailed manner. Conclusions are detailed in section 6. The final part of the paper discusses the current problems and future direction for the nanofluid research.

2. Nanofluid preparation methods

Preparation of nanofluids is the first stage towards their use. Preparation of nanofluids can be accomplished in two ways: one step and two steps. Following is an explanation on how these two approaches produce nanofluids.

2.1 Single-step method

In single step process, nanoparticles and nanofluids are generated parallelly. Physical Vapour Deposition or chemical processes are used to create the nanoparticles. Particles' agglomeration in the base fluid gets curtailed and stability of nanofluids enhances in this process since this process is carried out in single place. However, a disadvantage of this method is that it is appropriate to the fluids those with low vapor pressure. This factor restricted the application of this method [2].

Akoh et al. [5] invented the VEROS technology (Vacuum Evaporation onto a Running Oil Substrate). This procedure was intended to make dry nanoparticles, but it failed to separate the particles from the fluids. Later, a modified VEROS technique was proposed by Wagener et al. [6]. For the synthesis of nanofluids, they used high-pressure magnetron sputtering to suspend metallic nanoparticles like Fe and Ag. Eastman et al. [7] used one-step procedure to disperse copper nanoparticles into ethylene glycol nanofluids. They follows the same method that Akoh et al. [5] followed. Lo et al. [8] prepared Cu, CuO and Cu_2O based nanofluids with different dielectric fluids using single-step method. Liu et al. [9] prepared Cu/water nanofluids through chemical reduction method. As a result of Zhu et al. [10]'s work, copper nanofluids may be prepared in one step by dispersing copper nanoparticles in water with the help of a surfactant, which results in clogging-free and stable nanofluids. They came up with a conclusion that it a fast often efficient single-step chemical method for preparing Copper nanofluids. TiO_2 nanoparticles were dispersed in water using a single-step chemical approach by Chang et al. [11]. A high-pressure homogenizer is used to prepare the nanofluids. Sonage B.K and mohanan [12] synthesized Zinc Oxide nanoparticles by sol gel method and prepared nanofluid by one-step method. Figure 2 shows the Single-step preparation process of nanofluids.

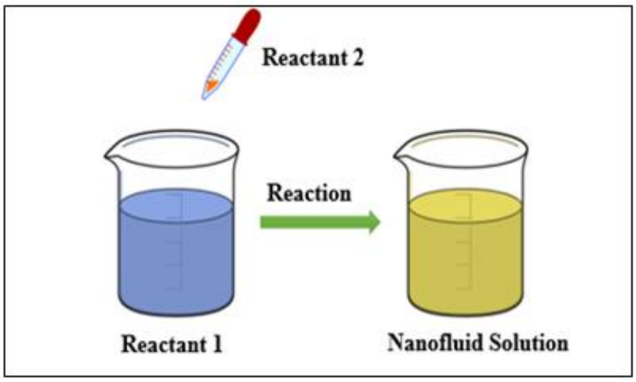

Fig. 2 Single-step preparation process of nanofluids [13]

2.2 Two-step method

For the preparation of nanofluids, this is the most used procedure. This procedure begins with the dry powder production of nanometer-sized particles, followed by the dispersion of such powders in a suitable base fluid. As a result of the nanoparticles' high surface area and surface activity, it is impossible to avoid aggregation and clustering in the process. Nanofluid dispersion stability can be improved by simple approaches such as ultrasonication or the addition of surfactant/activator to the nanofluids. This method is very attractive for industrial scale applications due to its ease of preparation. Two-step method works well for oxide nanoparticles [1]. However this method is not up to its mark for metallic particles [14].

Hong et al. [15] used a two-step procedure and prepared Fe/ethylene glycol nanofluids. Xuan and Li [16] used two step procedure to prepare nanofluids by dispersing copper nanoparticles in water and oil. Nanoparticle aggregation was prevented using surfactants and ultrasonic agitation. TiO_2 nanoparticles were dispersed in water created using a two-step technique by Murshed et al. [17]. Al_2O_3 nanoparticles were dispersed in water, ethylene glycol and pump oil using a two-step process by Xie [18]. Ultrasonication and magnetic stirring were used to prevent nanoparticle agglomeration. Liu [19], Choi [20] employed two-step method to produce carbon nanofluids. The two-step process was used by Li et al. [21] to create nanofluids containing water-dispersed copper nanoparticles. Mondragon et al. [22] prepared silica nanofluids by the two-step method. The representation of preparation of nanofluids by two-step method is shown in Figure 3. Table 1 summarizes the preparation methods of nanofluid systems by various researchers.

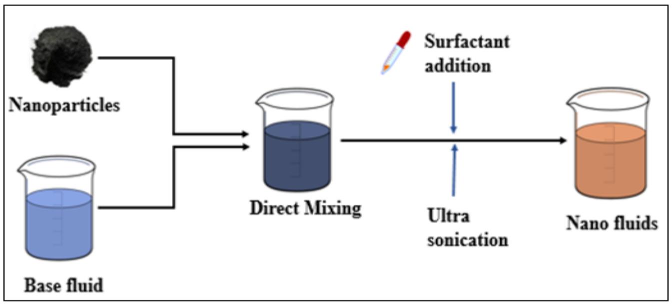

Fig. 3 Two-step method for preparing nanofluids [13]

Table 1. Nanofluids preparation methods reported in the literature.

Sl. no.	Nanoparticle	Particle size (nm)	Base fluid	Preparation method: Single-step	Preparation method: Two-step	Reference
1	Cu	10	EG	√		[7]
2	Cu	75 -100	H_2O	√		[9]
3	Fe	10	EG	√		[15]
4	Cu	100	H_2O		√	[16]
5	Fe_3O_4	10	H_2O	√		[25]
6	TiO_2	15	H_2O		√	[17]
7	Al_2O_3	20	H_2O		√	[18]
8	Al_2O_3	60	EG		√	[18]
9	CNTs	25 -50	Engine oil		√	[19]
10	CNTs	25 nm×50 µm	poly oil		√	[20]
11	Ag	35	Silicon oil		√	[24]
12	CB	40	DI		√	[24]
13	Fe_3O_4	10	H_2O	√		[25]
14	CuO	33	H_2O		√	[26]
15	CNTs	15×30 µm	EG		√	[27]
16	CNTs	15×30 µm	H_2O		√	[27]
17	CNTs	15×30 µm	Decene		√	[27]

3. The stability of the nanofluids

Nanofluids which can lose their significance in its applicable areas due to their sensitive to aggregation. Therefore, a detailed knowledge on stability is a necessary thing. It is also imperative to know the factors influence the stability because alteration of thermos-physical properties is mainly dependent on stability. This section deals with the stability evolution methods with addition of processes that are used for enhancement of stability of nanofluids.

3.1 Methods for Stability Evaluation of nanofluids

Number of literatures studies on the stability of nanofluids often which, some researchers considered different methods for evaluation of stability of nanofluids. Below mentioned methods are the different methods utilized in the evaluation of stability by various researchers.

- Sedimentation Methods
- Centrifugation methods
- Zeta-potential analysis
- UV-vis spectrophotometer
- TEM and SEM

3.1.1 Sedimentation Methods

Photo capturing is one of the common method to know the sedimentation of nanofluids. Sedimentation of nanofluids can be find out by capturing the photos of nanofluid which is kept separately in a test tube at certain time intervals [1]. For assessing particle size and fluid concentration above sediment, Li et al. [2] employed special apparatus. A stable suspension indicates no change in the particle size or concentration. Zhu et al. [28] produced graphite nanofluids and utilised a sedimentation balance method to test the stability of graphite suspension. The weight of the sediment nanoparticles at the bottom is the indication of the stability.

3.1.2 Centrifugation Method

Centrifugation method is developed for stability evaluation since the sedimentation method is time taking method. The centrifugation approach was used by Singh et al. [29] to investigate the stability of Ag/water nanofluids. Nanofluids have been proven to be stable under centrifugation and in a stationary condition for more than 30 days without sedimentation. The centrifugation method was also used by Li [30] to determine the stability of polyaniline colloidal solutions.

3.1.3 Zeta-potential analysis

It's a crucial factor in determining how particles suspend in a fluid. Zeta potentials with high values indicate that electrostatic repulsions between particles increase, resulting in better nanofluid stability [28]. When the attracting energy between nanoparticles exceeds the repelling energy, agglomeration may occur. To avoid aggregation, the repulsive energy should be increased. Thus, nanofluids with higher zeta potential values indicate more stable fluids, while lower zeta potential nanofluids tend to settle [22]. Zhu et al. [31] find the stability of Al_2O_3/water nanofluids by zeta potential method. On knowing that they add surfactant/activator for enhancing the stability. Kim et al. [32] dispersed Au nanoparticles in water. The prepared nanofluid shown the large zeta potential value. The nanofluid shows stability for more than 30 days without sedimentation. Stable nanofluids are often those with a zeta-potential >30 mV [1]. Table 2 depicts Zeta potential and corresponding stability state.

Table 2. Zeta potential and its corresponding state of stability [1].

Zeta potential value(mV)	Stability
15	Particles lightly settled
30	Medium stability
0	Little or no stability
45	Good stability
60	Excellent stability

3.1.4 UV-Vis spectrophotometer

Spectral analysis via UV-vis spectrophotometer is one of the way for stability evaluation of nanofluids. Its applicability for all base fluids is the most special feature to attract towards it. It gives the results with respect to the particle concentration [1]. To evaluate the dispersion stability of Cu and Al_2O_3 nanofluids Huang et al. [33] used the spectrophotometer. A UV–vis spectrophotometer was employed to investigate the stability of nanofluids including carbon nanotubes, silicon dioxide, and copper oxide, as well as water, ethylene glycol, and oil as their base fluids. Li et al. [21] used copper nanofluids for their study and they have gone for sedimentation methods along with zeta potential analysis for stability evaluation of nanofluids.

3.1.5 Transmission Electron Microscopy (TEM) and Scanning Electron Microscope (SEM)

Transmission Electron Microscopy (TEM) and Scanning Electron Microscope (SEM) are two popular tools used for finding the size, morphology of the nanoparticles. Aggregation of nanoparticles in the nanofluids can be directly monitored by TEM and SEM [35]. Figure 4 shows TEM and SEM Photographs of different nanofluids.

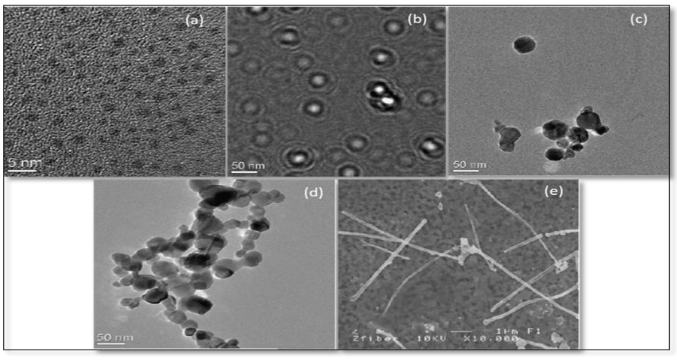

Fig. 4 (a)TEM Photograph of Au. (b), Al_2O_3 (c) TiO_2, (d) CuO, (e) Carbon nanotubes [50]

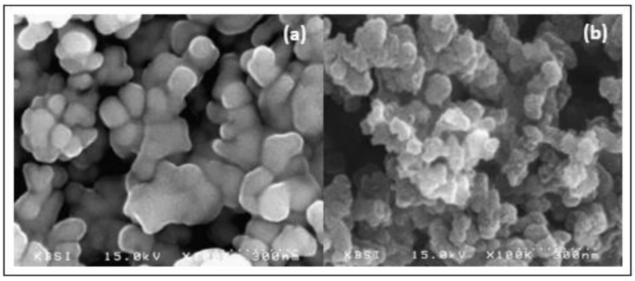

Fig. 5 (a)SEM Photograph of Ag nanoparticles. (b) CB nanoparticles [24]

3.2 Enhancing the stability of nanofluids

A few researches point out some ways for enhancement of stability of nanofluid. The following section highlighted some methods for enhancement.

3.2.1 Surfactant or activator adding

Nanofluids are typically stabilised by the use of surfactants. Surfactants sometimes called as activators or dispersants. Surfactants affect the surface characteristics of the nanofluid system. When the surfactant is added to the nanofluid system it introduces a bond between the nanoparticles and the base fluids. Selection of suitable surfactant is a tough challenge. Water-soluble surfactants should be used for solvents that are polar, while oil-soluble surfactants should be used for solvents that are non-polar [3]. The other way to choose the suitable surfactant is based on the hydrophilic/lipophilic balance (HLB) value. Every surfactant having its own HLB value and for each base fluid there should be a provision on the surfactant HLB value range. Various types of surfactants have been used in studies for various sorts of nanofluids. Ghadimi et al. [1] listed some important surfactants which are mentioned below.

- Sodium dodecyl sulfate (SDS)
- Poly vinyl pyrrolidone (PVP)
- Salt and oleic acid
- Dodecyl trimethyl ammonium bromide (DTAB)
- Hexadecyl trimethyl ammonium bromide (HCTAB)
- Sodium octanoate (SOCT)
- Gum Arabic

Though the addition of surfactant is an effective way to enhance the stability of nanoparticles, there are some problems associated with surfactants. For example, addition of surfactant changes the pH of the nanofluid which influences several factors. The molecules of surfactant that adhere to the nanoparticle surface may also increase the heat resistance amongst the particles and the base fluid. This diminishes the thermal conductivity enhancement [3].

3.2.2 PH control of nanofluids

Strong repulsive forces in nanofluids can make them more stable if the PH is controlled. Xie et al. [27] prepared CNT/water nanofluids and acid treatment is done for stability enhancement. This leads to good stability of CNT nanofluids. Lee et al. [39] experimented on different pH of nanofluids with Al_2O_3 nanoparticles. The observations shown that was an increment or decrement of agglomeration on changing the pH. It's worth noting that the optimal pH value is base fluid dependent and it is not same for all base fluids. The optimal pH values for graphite, alumina, and copper distributed in water are 2, 8, and 9.5, according to Wang and Li's [36] studies.

3.2.3 Ultrasonic Agitation

Sonication is the process of agitating particles in a nanofluid system by use of sound energy. This process is used to avoid sedimentation and agglomeration of nanoparticles. Agglomerations can be broken down with the use of Ultrasonic bath, processor, and homogenizer. Compared to other equipment like the magnetic and high shear stirrer, these are more effective [1]. Numerous investigations used this and succeeded. The experimental results for stability by different sonication process were consolidated in Table 3.

Table 3. Literature summary of ultrasonic procedures.

Nanoparticle	Basefluid	Stability process	Duration	Investigator
Al_2O_3	DW	Ultrasonication	6 h	[37]
MWCNT	DW+SDS	Ultrasonic disruptor	2 h	[38]
Graphite (nm)	DW + PVP	Ultrasonic vibration	30 mins	[40]
Al_2O_3	DW, EG	Ultrasonic cleaner	15 h	[42]
TiO_2	DW	Ultrasonication	2 h	[44]
Fe_3O_4	Kerosene + oleic Acid	Ultrasonication	0-80 min	[46]
CuO	DW+SDBS	Ultrasonic vibrator	1 h	[47]
Al_2O_3	DW	Ultrasonication	11 h	[51]
ZnO	Ammonium poly	Horn ultrasonic	0-60 min	[57]
Fe	EG	Ultrasonic cell disruptor	10-70 mins	[63]

4. Experimental learnings on thermal conductivity

Recently, much research has been done on the thermo-physical behaviour of nanofluids. In all studies, small volume fractions of nanoparticles increased heat conductivity significantly. In the present article, the existed studies on nanoparticles with enhanced thermal conductivity were inspected. From the studies it was known that plenty of parameters effects the thermal conductivity and a detailed discussion of effect of each parameter that is compelling on thermal conductivity is talked about.

The basic requirement for improving thermal conductivity is the measurement of thermal conductivity. There are numerous methods for measuring thermal conductivity. The literature classifies thermal conductivity measurement techniques into transient and steady state methods. Transient hot wire method, temperature oscillation method, hot strip method and 3ω methods are frequently used transient measurement techniques. Steady-state measurement includes parallel plate and cylindrical cell method. Figure 6 shows the methods available for the thermal conductivity.

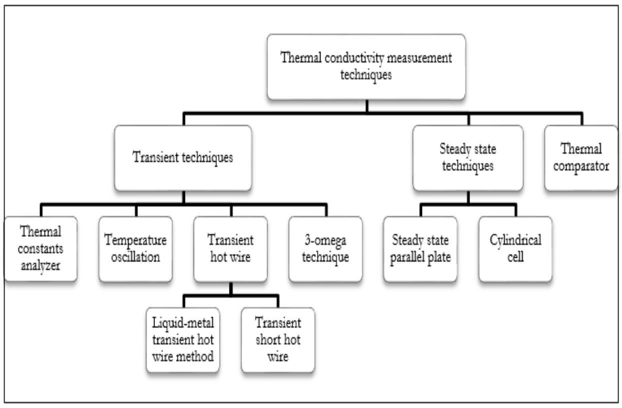

Fig. 6 Different techniques for thermal conductivity measurement [41]

From all the available methods, transient hot wire (THW) method is the most efficient technique for measuring nanofluids thermal conductivity [43]. THW method is very fast in working when compared to the other techniques and it is simple in its design over the other methods [45]. The transient hot-wire method used by Duangthongsuk and Wongwises [48] is showed schematically in Figure 7. Table 4 summarizes the measurement techniques used in various researches.

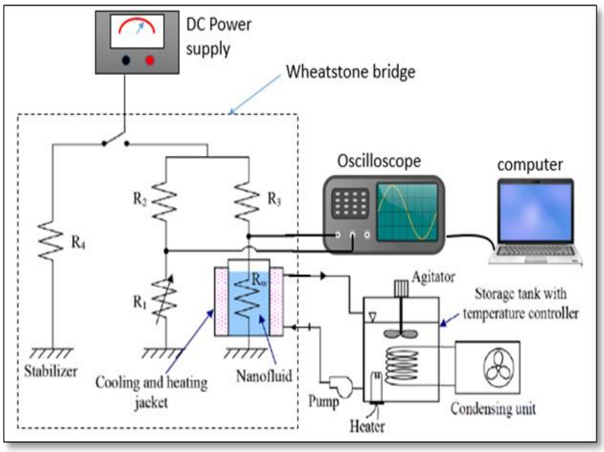

Fig. 7 Transient hot wire method schematic diagram [48]

Table 4. Measurement techniques used and thermal conductivity enhancement for some literature

Nanoparticle (size in nm)	Particle size (nm)	Base fluid	Measurement technique	Thermal conductivity enhancement	Researcher
Cu	-	EG	THW method	1.12 times for 2 vol%	[49]
Au	4	Ethanol	Optical beam deflection Technique	Around 1.3% for 0.018 vol%	[23]
Cu CuO	<10 35	EG EG	THW method	40% for 0.3 vol% 22% for 4 vol%	[7]
Fe	10	EG	THW method	18% for 0.55 vol%	[15]
Fe_3O_4	10	Water	THW method	38% for 4 vol%	[25]
Cu	10	Water	THW method	70% for 3 vol%	[103]
TiO_2 Al	15 80	EG EG	THW method	18% for 5 vol% 45% for 5 vol%	[99]
Al_2O_3 CuO	28 23	Water/EG Water/EG	Steady-state Method	Al_2O_3/water 12% for 3 vol% Al_2O_3/EG 26% for 5 vol%	[62]
CuO Al_2O_3	29 36	Water	Steady-state method	52% for 6 vol% 30% for 10 vol%	[54]
Al_2O_3	29	EG	Steady-state parallel plate method	18% for 4 vol%	[105]
Al_2O_3 CuO Cu	33 36 35	Water Water Oil	THW method	29% for 5 vol% 60% for 5 vol% 44% for 0.052 vol%	[60]
TiO_2	34	water	THW method	6% for 0.66 vol%	[107]
CuO	35.4	EG/water	THW method	9% for 1 vol%	[38]
Cu	35.4	water	THW method	24% for 2 vol%	[106]
Al_2O_3	38	Water/EG	THW method	CuO/EG: 22% for 4 vol%	[61]
Al_2O_3 CuO	38.4 28.6	Water	Temperature oscillation technique	2% for 1 vol% 10.8% for 1 vol%	[51]
TiO_2	10×40	Deionized water	THW method	30% for 5 vol% 33% for 5 vol%	[70]
CuO	50	DIW	Quasi-steady state	17% for 0.4 vol%	[108]
Al_2O_3	60.4	EG/water	THW method	30% for 5 vol%	[18]
Al_2O_3	80	DIW	THW method	24% for 5 vol%	[104]

4.1 Factors influencing the thermal conductivity

Literature states that there are distinct features influencing thermal conductivity of nanofluids. Those are shown schematically in below Figure 8.

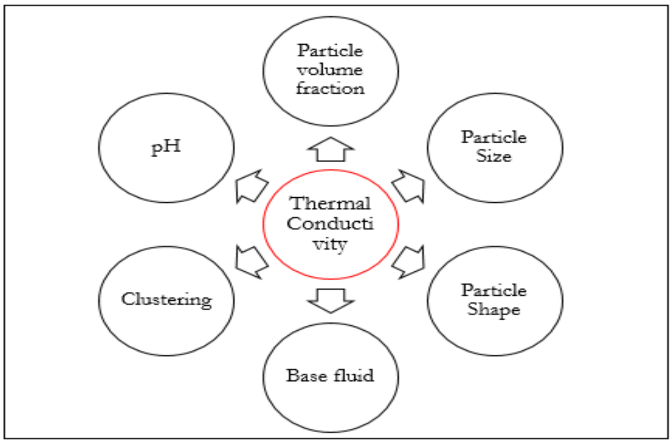

Fig. 8 Thermal conductivity influencing factors

Thermal conductivity is influenced by many parameters. In the following section, detailed description was given about each parameters and its effect on thermal conductivity.

4.1.1. Temperature effect on thermal conductivity

Thermal conductivity can be improved significantly by raising the fluid temperature. Many researchers have investigated the thermal conductivity of nanofluids. Al_2O_3 and CuO nanoparticles were dispersed in water by Das et al. [51]. They carried out experiments to see how temperature affected thermal conductivity. For measuring thermal conductivity, a temperature oscillation technique was used. There is an increase in thermal conductivity in the temperature range of 21°C-51°C, and this increase is greater for CuO/water based nanofluids than for Al_2O_3/water based nanofluids. Chon and Kihm [52] investigated the effect of fluid temperature on nanofluids thermal conductivity for Al_2O_3/water nanofluids. Considerable enhancement in the thermal conductivity was obtained as temperature changes. Mohammad Hossein et al. [53] studied the effect of temperature on thermal conductivity for SiO_2 nanoparticles dispersed in ethanol. The aftereffects of investigations demonstrated that the thermal conductivity of nanofluid system is increases with the increase of fluid temperature. Li and Peterson [54] directed an exploratory examination to analyze the effect of temperature on CuO/water, Al_2O_3/water nanofluids thermal conductivity. Outcomes shows that the fluid temperature have significant effects on nanofluid thermal conductivity. Figure 9 shows how the temperature effects the thermal conductivity of Al_2O_3/water, CuO/water nanofluids.

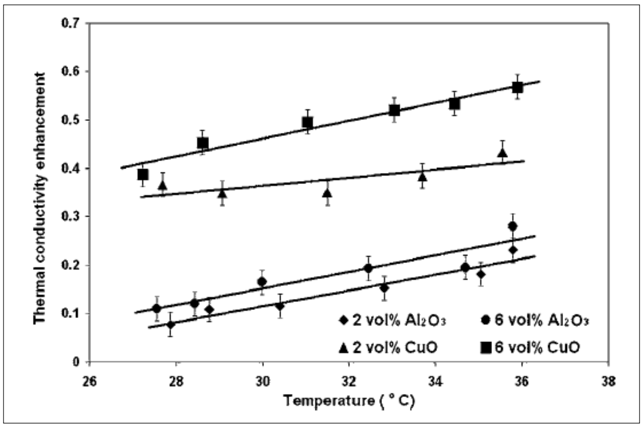

Fig. 9 temperature effect of Al_2O_3/water and CuO/water nanoparticle suspensions. [54]

Experimental studies were made by Ding et al. [55] on MWCNT/water nanofluid to understand the relation of temperature and thermal conductivity. Estimations were made at temperatures in the range of 20°C - 30°C (20°C, 25°C and 30°C) and nanoparticle concentration also varied between 0.1 and 1%. It was inferred that as temperature increases thermal conductivity ratio also increases. Thermal conductivity increases with particle concentration from 0 - 0.5 percent at 20 and 25°C, but then plateaus at 0.5 %. And at 30°C, it increased by 0.5 percent. Zeinab Hajjar et al. [56] prepared graphene oxide (GO) water nanofluid. It was found that GO fixation and temperature affect thermal conductivity. Thermal conductivity measurements show that nanofluids have better thermal conductivities than basefluids. The increase in thermal conductivity depends on GO content. When the particle concentration is 0.25 wt%, the increase in thermal conductivity is 33.9 percent at 20°C and 47.5 percent at 40°C.

According to the most of existing studies, temperature and thermal conductivity have a linear connection, meaning that as temperature rises, the thermal conductivity of nanofluid rises as well. However, there are some conflicting outcomes were also said in many researches. For instance, Masuda et al. [58] measured the thermal conductivity for Al_2O_3/water, SiO_2/water, and TiO_2/water nanofluids at various temperatures. Their outcomes showed that the temperature rises the thermal conductivity ratio is diminished, which is conflicting result to that of numerous discoveries in the literature. Thermal conductivity of TiO_2/deionized water nanofluid was measured by Turgut et al. [59] and measurements were made at various temperatures with powder quantity 0.2-3 vol%. The thermal conductivity ratio did not change appreciably as the temperature changed.

4.1.2. Thermal conductivity variation upon particle's volume fraction

Thermal conductivity of nanofluids is greatly influenced by particle volume fraction. So it would be viewed as the most significant component in perspective of this. Generally, it is expected that addition of nanoparticles would increase thermal conductivity of nanofluids. So many investigatons in the literature mentioned about how the thermal conductivity of nanofluids influenced by particle volume fraction. Nanofluids comprising Al_2O_3/water, TiO_2/water and SiO_2/water, were tested for thermal conductivity by Masuda et al. [58]. For 4.3 vol% nanoparticles at room temperature the enhancement in the thermal conductivity was observed to be 32.4%. The enhancement shows linear relationship with particle volume fraction. Eastman et al. [60] measured the thermal conductivity of nanofluids with Al_2O_3, CuO and Cu as nanoparticles and water, HE-200 oil as base fluids. A large enhancement in the thermal conductivity was accomplished for only 5 vol% of nanoparticles. Choi et al. [20] prepared MWCNT/oil nanofluids and experiments were carried out for thermal conductivity at various particle volume concentrations. A nonlinear relationship was observed between them. Nanofluids containing CuO and Al_2O_3 nanoparticles distributed in water and ethylene glycol (EG) were created by Lee et al. [61]. At very small particle volume concentrations a straight relationship was seen between the volume fraction and effective thermal conductivity. Nanofluids with Al_2O_3, CuO nanoparticles and water/ethylene glycol base fluids was prepared by Wang et al. [62] and analyzed the dependency of thermal conductivity on volume fraction. The author concluded that as particle volume fraction increases the thermal conductivity ratio also increases. Eastman et al. [7] used Copper nanoparticles (<10nm) dispersed in ethylene glycol. For volume fraction of only 0.3% there is a 40% enhancement in the thermal conductivity. Hong and Yang [15] prepared nanofluid with Fe nanoparticles (10nm) and ethylene glycol and observed that Fe nanofluids showed enhancement of thermal conductivity and follows a non-linear relationship with the particle volume fraction. Xuan and Li [16] also worked out on the influence of volume fraction on thermal conductivity and shown the enhancement is very large than base fluids at different particle volume fractions. The figure below shows enhancement in thermal conductivity with respect to particle loading.

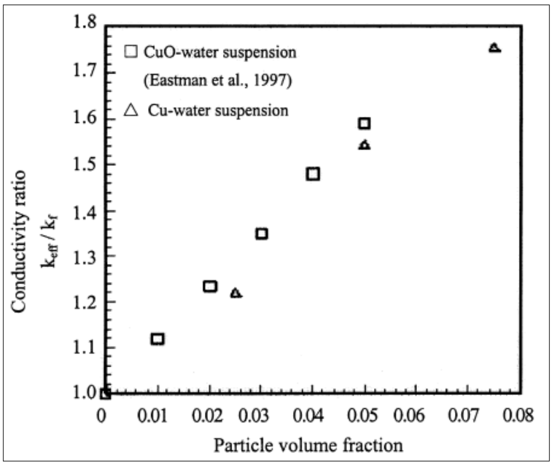

Fig. 10 Dependency of thermal conductivity on particle volume fraction for the Cu/water nanofluids [16]

Xie et al. [64] prepared SiC nanoparticles dispersed in DW/EG and measured the thermal conductivities by transient hot-wire method. They found that for same volume fraction of nanoparticles in any base fluids shows same enhancement in their thermal conductivities.

4.1.3. Effect of Particle Size

Particle size plays vital role in influencing the thermal conductivity of nanofluids. Lee et al. [61] prepared CuO nanoparticles of size 23.6 nm and dispersed in ethylene glycol. They got the enhancement of 20% for only 4 vol% of CuO nanoparticles. Afterward, Eastman et al. [7] studied Cu nanoparticles (10 nm) dispersed in ethylene glycol. The author inferred that nanoparticle size is an important parameter on which the enhancement in the thermal conductivity depends. Chopkar et al. [66] prepared $Al_{70}Cu_{30}$/ethylene glycol nanofluids by taking the same nanoparticles but different in size. They found an inverse relation of thermal conductivity enhancement and the particle size. For a fixed volume concentration as the particle size increased from 9 to 83 nm, enhancement in the thermal conductivity reduced from 38% to 3%. The below figure shown by [66] that as crystallite size decreases the enhancement in the thermal conductivity increases.

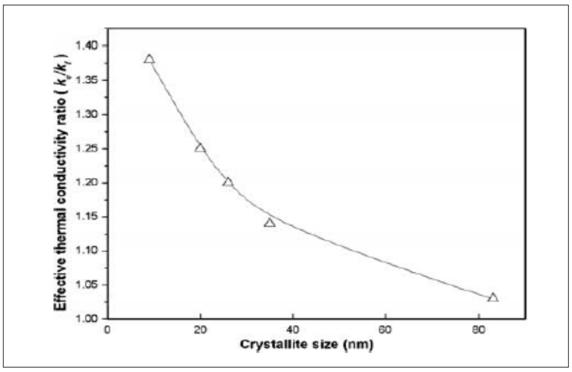

Fig. 11 Crystallite size effect on thermal conductivity for ethylene glycol based nanofluid. [66]

Chopkar et al. [67] produced nanofluids containing Al2Cu and Ag2Al nanoparticles in water, ethylene glycol, and studied the thermal conductivity enhancement variation with particle size in another work. It was observed that as the particle size decreases there is an enhancement in the thermal conductivity. Mintsa et al. [68] prepared Al_2O_3/water nanofluids and the nanoparticles of size 36 and 47 nm were utilized as a part of the investigation. Both the particle volume concentration and temperature were varied over certain range. It was witnessed that at room temperature the augmentation in thermal conductivity is same for 36 nm and 47 nm nanoparticles but at higher temperatures nanofluids with 36 nm size nanoparticles indicates large enhancement compared to 47 nm nanoparticles. Murshed et al. [70] did their investigations by dispersing TiO_2 nanoparticles in water. The two different sizes of nanoparticles with 10 × 40μm and 15nm taken for the preparation. For 10 × 40μm they observed nearly 33% enhancement in the thermal conductivity and for15nm particles it was found to be 30%. Teng et al. [69] studied the effect of nanoparticle size on the thermal conductivity for alumina-water based nanofluids. Thermal conductivity of nanofluids was measured at different temperatures for different particle sizes. The results clarifies that there is an enhancement in the thermal conductivity for small nanoparticle size and higher temperature. The thermal conductivity of Al_2O_3/water and Al_2O_3/ethylene glycol nanofluids with nanoparticles ranging from 8 to 282 nm was studied by Beck et al. [71]. The thermal conductivity of nanofluids decreases as the particle size decreases, according to their tests.

4.1.4. Effect of Particle shape

Particles of spherical shape and particles of cylindrical shape are the two shapes predominantly used in the field of nanofluids. Thermal conductivity of SiC/distilled water and SiC/ethylene glycol nanofluids were explored by Xie et al. [64]. Nanoparticles of spherical shape with 26 nm size and cylindrical shape with 600 nm size were chosen for the study. Almost for same volume fraction, the nanoparticles with cylindrical shape shown higher enhancement compared to the nanoparticles with spherical shape. Thermal conductivity of TiO_2/deionized water nanofluids was measured by Murshed et al. [70] for particles of spherical shape (15 nm) and rod-shape (10 x 40 nm). At the fixed volume concentration, the rod shaped nanoparticles recorded more enhancement than spherical shaped nanoparticles. Liu et al. [9] carried out trials with needle and square shaped Cu nanoparticles size of 50 to 250 nm dispersed in water. Needle shaped nanoparticles showed greater enhancement in thermal conductivity. So, it is clearly evident from the studies that the thermal conductivity enhancement is more in case of particles of cylindrical shape than spherical shaped particles. However, when compared to spherical shaped nanoparticles, cylindrical shape particles have significantly larger viscosities and due to this, more pumping power is required and this reduces the achievable utilization of nanofluids with cylindrical shape particles [72]

4.1.5. Base fluid effect on thermal conductivity

Thermal conductivity is also sensitive to base fluid type. Wang et al. [62] prepared Al_2O_3 and CuO nanoparticles and dispersed them in different base fluids such as ethylene glycol, water, engine oil and vacuum pump fluid. Out of all base fluids with Al_2O_3 nanoparticles, ethylene glycol shown the large enhancement in thermal conductivity. At some fixed volume fraction these two nanofluids showed almost same enhancement in the thermal conductivity. Following figure gives clarity on the above context.

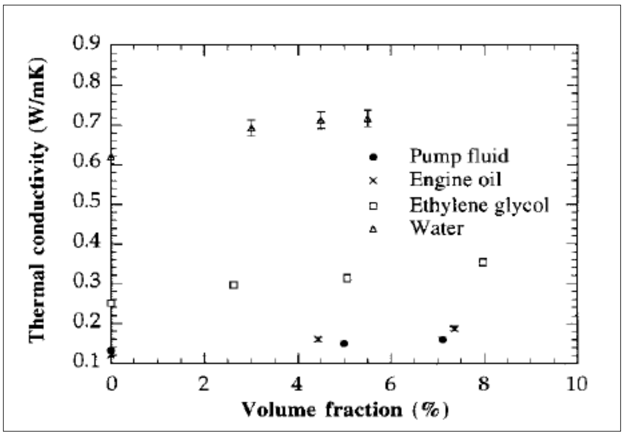

Fig. 12 Thermal conductivity dependency on base fluids for Al_2O_3 nanoparticles [62]

Timofeeva et al. [65] used ethylene glycol/H_2O and H_2O basefluids to investigate the base fluid effect on heat transfer characteristics of SiC nanoparticles. It is demonstrated that enhancement with ethylene glycol/H_2O basefluid is more than that of SiC/water nanofluids. Xie et al. [73] prepared nanofluids with Al_2O_3 nanoparticles dispersed in different base fluids like ethylene glycol, water, pump oil and glycerol. They analyzed the effect of the base fluid on the thermal conductivity. For each nanofluid, enhancement in thermal conductivity over the thermal conductivity of base fluid was observed. Chopkar et al. [67] used Al_2Cu and Ag_2Al nanoparticles dispersed in water and ethylene glycol. Water-based nanofluids showed a higher enhancement in thermal conductivity compared to ethylene glycol based nanofluids. Liu et al. [19] investigated thermal conductivity of MWCNT's blended ethylene glycol or synthetic engine oil. MWCNT with ethylene glycol nanofluids showed lower enhancement than MWCNT with synthetic engine oil nanofluid.

4.1.6. Clustering impact

This phenomenon is always there in nanofluids and also one of the parameters that influences thermal conductivity nanofluid system. Hong et al. [63] prepared nanofluids with Fe nanoparticles and investigated how clustering influences nanofluids thermal conductivity. Investigations dig out that clustering is directly relates to thermal conductivity of nanofluids. Karthikeyan et al. [75] dispersed CuO nanoparticles (8 nm) in water and ethylene glycol to study thermal properties of the nanofluids. They measured the thermal conductivity of nanofluid as a function of time and their results shows that the thermal conductivity decreases with time increases due to clustering of nanoparticles. Hence, they concluded that the cluster size of particles have significantly effects the thermal conductivity. Zhu et al. [25] investigated the effects of Fe_3O_4 nanoparticles clustering on thermal conductivity by consolidated results with [70], [61], [58] for same volume fractions of TiO_2, CuO, Al_2O_3 and concluded that the stacking and grouping of nanoparticles was the primary cause of nonlinear thermal conductivity in nanofluids. Evans et al. [56] carried out their experiments on how clustering of the nanoparticles in the nanofluid system effect on the nanofluids thermal conductivity.

4.1.7. Effect of pH

A review of the literature finds that there are few studies looking into the effect of base fluid pH on nanofluid thermal conductivity. Xie et al. [18] investigated the pH effect on thermal conductivity for Al_2O_3 nanoparticles dispersed in base fluids like ethylene glycol, water and pump oil. Experiments demonstrated that thermal conductivity of nanofluids decreased significantly with increasing pH values. For the same volume fraction, when pH value equal to 2.0, the enhancement in thermal conductivity of Al_2O_3/water nanofluid is about 23% and it is reduced by 4% when pH value is equal to 11.5. Wang et al. [77] prepared Cu/water and Al_2O_3/water nanofluids and investigated the effect of pH on thermal conductivity. Maximum enhancement in thermal conductivity for Cu/water nanofluids is obtained when pH value is 8 and for Al_2O_3/water nanofluids the optimum pH value is 9.5. They also discovered that base fluid thermal conductivity not strongly depend on its pH value. Murshed et al. [78] looked at the influence of pH on TiO2/water nanofluid thermal conductivity. They discovered that increasing the pH value lowers heat conductivity. However, this reduction is typically insignificant; for example, when the pH value was altered from 3.4 to 9, they only saw a 2% drop. It is known that to obtain the good stability nanofluids some additives, so called the surfactants are used. But this surfactant also changes the pH value of the nanofluids. According to most studies, researchers didn't include information on the samples' pH levels in their findings. This suggests that pH may be a major contributor to the variability in thermal conductivity of nanofluids [72].

Apart from the mentioned parameters sonication time and surfactant addition also influences the thermal properties of the nanofluids. However, the conducted survey is very limited. Noroozi et al. [74] prepared Nanofluids containing Al_2O_3 nanoparticles dispersed in distilled water. The effect of the ultrasonic system on the stability and thermal diffusivity of the nanofluids was investigated. It is known that thermal diffusivity is in direct relation with thermal conductivity. Thermal conductivity and viscosity were studied varying particle volume concentration, temperature, and pH value by Zhou et al. [76] using various typical surfactant solutions.

5. Measurement of Viscosity

Since viscosity is as significance as that of thermal conductivity for all fluid heat transfer applications, there are various examinations have been led on the viscosity of the nanofluid. A device called 'viscometer' is used to find the viscosity of the fluids. The researchers used different viscometers for finding the viscosity of the nanofluids. Kulkarni et al. [79] researched rheological behavior of CuO/deionized water nanofluid and they found the viscosity by Brookfield viscometer. Li et al. [80] prepared nanofluid by suspended Copper Oxide (CuO) nanoparticle in water and viscosity of the prepared nanofluid was measured using a capillary viscometer. They additionally said how the capillary tube diameter impacts the viscosity. He et al. [81] measured TiO_2-distilled water nanofluid viscosity for various concentrations and for three distinctive particle sizes by utilizing Ubbeholder capillary viscometer. The author expressed that viscosity increments on increasing both particle size and particle concentration. Chevalier et al. [82] considered SiO_2/water and SiO_2/EG viscosity for various particle sizes and different concentration range by micro machined capillary viscometer. Duangthongsuk and Wongwises [48] prepared TiO_2 nanoparticles dispersed in water and Bohlin rotational rheometer (Malvern Instrument) was used for measuring the viscosity of nanofluids.

5.1. Factors effecting viscosity

According to researcher's investigation, there are different critical parameters influencing the viscosity of the nanofluids. These factors are shown schematically in the following figure

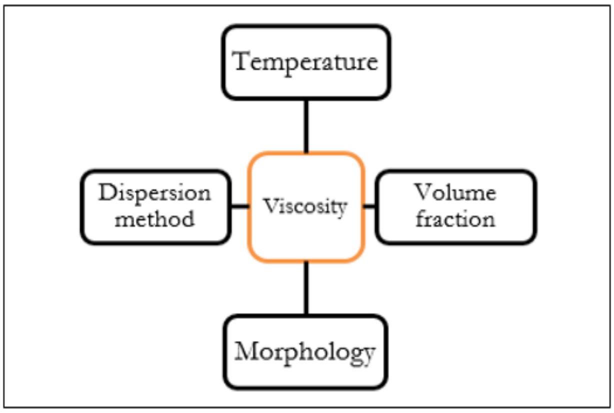

Fig. 9 Viscosity influencing factors

Mahbubul et al. [83] checked the most recent advancements in the viscosity with all the influencing parameters. Pak and Cho [84] worked out the experiments with Al_2O_3/water nanofluid. A few viscosity influencing parameters were outline in his study. In the following section, the effect of each individual parameter on viscosity was discussed.

5.1.1. Effect of Temperature

Temperature is the basic parameter which can alter the nanofluid properties. In the section 4 the effect of temperature on thermal conductivity was studied. However it also effects the viscosity of the nanofluids. Duangthongsuk et al. [48] measured the viscosity for TiO_2 based nanofluids. They collected the data at different temperatures ranging from 15°C to 35°C. Results shown that as temperature and particle concentration increases, the viscosity also increases. Figure 10 shown below explain the temperature dependency on viscosity.

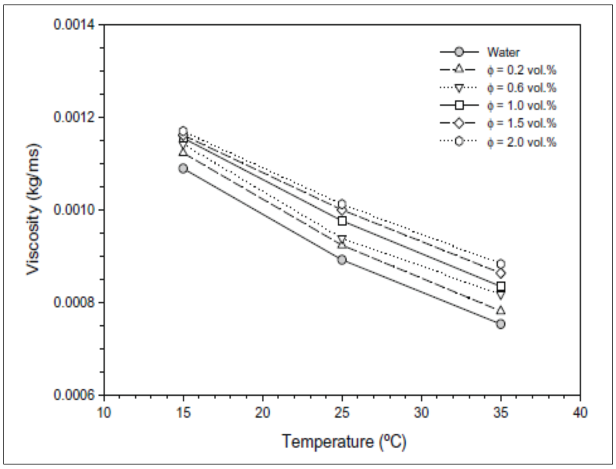

Fig. 13 Effect of temperature on viscosity of TiO_2-water nanofluids. [48]

Yang et al. [85] prepared four graphite nanofluid solutions and experimentally measured the effect of temperature on viscosity at four different temperatures. The results stated that the viscosity of nanofluids decreases as temperature increases. Chen et al. [86] investigated temperature effect on MWCNT/water nanofluid over some temperature range for viscosity behavior. They got to the conclusion that increasing the temperature to 55 degrees Celsius had essentially little effect on the viscosity of nanofluid. A sudden increment of viscosity was identified when the temperature changed from 55°C to 70°C. Namburu et al. [87] examined the viscosity of H_2O and $C_2H_6O_2$ based nanofluids containing SiO_2 nanoparticles in the temperature range 35°C to 50°C. The output showed that viscosity decreases exponentially with the increasing temperature. In another investigation with CuO nanoparticles and water, EG base fluids Namburu et al. [88] showed that viscosity was exponentially decreased with the increment in temperature.

Nguyen et al. [89] prepared Al_2O_3, CuO water-based nanofluids and examined the impact of temperature on nanofluids viscosity. The results showed that viscosity is dependent factor on temperature and as the temperature increases it is decreases. Ding et al. [55] through an experiment, demonstrated that the CNT viscosity in various volume concentration diminishes by temperature. Anoop et al. [90] measured the viscosity of prepared Al_2O_3-EG, CuO-EG and Al_2O_3-water nanofluids by dispersing nanoparticles in volume concentrations of 0.5, 1, 2, 4 and 6 % at different temperatures between 20° C to 50° C. They found that the viscosity is lessens with an expansion in the temperature. Duangthongsuk and Wongwises [48] completed their investigations with TiO_2 nanoparticles and water between the temperatures 15°C to 50°C. The authors found that viscosity of nanofluids declines with the expansion of temperatures. Turgut et al. [59] examined Al_2O_3/water nanofluids for temperature range of 20°C to 50°C and results showed that viscosity lessens with an expansion in temperature. Pastoriza-Gallego et al. [91] measured the impact of temperature on viscosity for CuO/water nanofluids over the temperatures of 283.15 K - 323.15 K. From their analyses, they observed that viscosity diminishes by expanding the temperature. Lee et al. [92] prepared nanofluids by dispersing SiC nanoparticles in distilled water and measured the viscosity over certain temperatures between 28°C to 72°C. The outcomes expressed that viscosity decreased by maintaining the higher temperatures within the range. Kulkarni et al. [93] experimented on nanofluids prepared by CuO, Al_2O_3 and SiO_2 nanoparticles dispersed in EG/water for viscosity behavior on temperature over certain range. They reported that as temperatures increases, viscosity decreases exponentially. Naik et al. [94] carried out experimentations on CuO/PG/water nanofluids and showed how the viscosity is dependent factor on temperature. Within the temperature range of of 258 K–335 K as the temperature increases the viscosity of the nanofluids decreases exponentially.

However, a few researches displayed quite conflicting outcomes on the viscosity. Prasher et al. [95] have shown that nanofluid viscosity is not a strong function on temperature. Chen et al. [96] experimental results indicating that viscosity of nanofluid is not a dependent factor on temperature. Further, in another research, Nanofluids with TiO_2 nanoparticles distributed in ethylene glycol were created by Chen et al. [97]. Viscosity of the nanofluid system was measured over certain temperature range (20–60°C). The results gives that the viscosity of nanofluid is independent of temperature.

5.1.2 Effect of volume fraction

Volume concentration is another important parameter which impacts the viscosity and thermal conductivity of nanofluids. Many studies have looked into the effect of nanoparticle weight percent on viscosity. The result practically proves that the higher the wt percent, the higher the viscosity of the nanofluid. It's crucial to keep an eye on the relationship between a material's heat conductivity and rheological lubricity. According to Prasher et al [95] and Li et al [80], the volume fraction of nanofluids can have a significant impact on their viscosity. Lee et al. [92] researched on volume fixation and reported that the viscosity increments by volume. Ding et al. [55] measured the viscosity of CNT/water nanofluids. The viscosity of the nanofluid system is found to be increased as nanoparticles concentration increases. Chen et al. [86] measured the viscosity for MWCNTs at various volume fractions and they observed that the addition of volume concentration is directed to higher viscosity for MWCNTs. Das et al. [98] prepared Aluminum Oxide/water nanofluids and measured the viscosity of the nanofluid. Viscosity of the nanofluids is found to be higher for the the fluids with higher volume concentration. Using water as a solvent, Murshed et al. [99] evaluated the viscosity of Al_2O_3 and TiO_2 nanoparticles and found that 5 vol% Al_2O_3 and 5 vol% TiO_2 increased viscosity by roughly 82% and 86%, respectively. He et al. [81] measured the viscosity for TiO_2/water nanofluid at various concentrations and for different particle sizes and expressed that viscosity increments with the expansion of volume concentrations.

However, there are some opposing outcomes were displayed as like that of temperature. Chevalier et al [82], Gallego et al. [91] and Namburu et al. [87] communicated an opposing outcome that the viscosity decreased when increasing the volume of nanopowder .

5.1.3. Morphology (Particle shape and size) effect on viscosity

Nanoparticle shape and size together termed as morphology. The effect of morphology on nanofluid viscosity is considering factor. Therefore, an investigation on nanoparticles morphology is very much essential towards more effective and economical use of nanofluids. Viscosity difference between 36 and 47 nm of Al_2O_3 is greater than 4 percent when the volume concentration is greater than 4 percent [89]. However, the value of viscosity is almost same with volume concentrations below 4%. He et al. [81] prepared TiO_2/water nanofliuds and measured the effect of viscosity for different nanoparticle sizes and for different concentrations. They discovered that when particle size increases, so does viscosity.

However, some results are contradictory. Prasher et al. [95] after experimenting Al_2O_3 with 50, 40, and 27 nm in propylene glycol have articulated that viscosity is not dependent on particle size. Anoop et al. [90] also expressed similar result with Al_2O_3. Chevalier et al. [82] measured viscosity of SiO_2/water and SiO_2/EG blended with 190, 94, & 35nm and found an increase in viscosity. Namburu et al. [87] also determined 100, 50 & 20nm SiO_2 based nanofluids viscosity and reported the same. Gallego et al. [91] experimented with 37 and 27nm CuO blended in water and observed the same.

5.1.4. Dispersion method, PH adjustment, stabilizers

Wang et al. [62] investigated the viscosity of deionized water-based Al_2O_3 with 5 vol% and particle size of 28 nm by dispersing Al_2O_3 nanoparticles by a new dispersion method. They analyzed the viscosity behavior and reported a tremendous increment in viscosity for this dispersion methods. Pak and Cho [84] measured water-based Al_2O_3, TiO_2 nanoparticles. They found variation of viscosity between base fluid and nanofluid. PH was adjusted and nanoparticles were dispersed via repulsion. Wen et al. [100] introduced stabilizers to the nanofluids. The authors believe that the stabilizers are also important when measuring viscosity of nanofluids. However, sonication time can also a factor that affect the viscosity of nanofluids. Very limited research is conducted on this particular aspect. Enhancement in viscosity for various nanofluids existed in literature are depicted in Table 5.

Table 5. Enhancement in viscosity for various nanofluids existed in literature.

Nano-particle	Base fluid	Particle size (nm)	Volume fraction (%)	Enhan-cement in viscosity (%)	Reference
$CaCO_3$	DW	20-50	0.12-4.11	1-69	[102]
SiO_2	Ethanol	3	1.2-5	15-95	[82]
TiO_2	Deionized water	15	1-5	82 at 4%	[17]
TiO_2	Water	21	0.2-2	4-15	[48]
TiO_2	EG/water	25	0.1-1.8	20 at 1.8%	[9]
TiO_2	water	25	0.25-1.2	3-11	[101]
TiO_2	Water	27	1-4.3	11-60	[58]
Al_2O_3	PG	27	0.5-3	7-29	[95]
Al_2O_3	DW	28	1-6	9-86	[62]
Al_2O_3	EG	28	1.2-3.5	7-39	[62]
Al_2O_3	Deionized water	30 ± 5	0.01-0.3	0.08- 2.9	[18]
Al_2O_3	Water	36	2.1-13	10-210	[89]
Al_2O_3	PG	40	0.5-3	6-36	[95]
Al_2O_3	Water	47	1-13	12-430	[89]
Al_2O_3	PG	50	0.5-3	5.5-24	[95]
Al_2O_3	Deionized water	80	1-5	82 at 5%	[17]
SiO_2	Ethanol	94	1.4-7	12-85	[82]
Al_2O_3	Water	95	0.5-6	3-77	[90]
Al_2O_3	EG	100	0.5-6	5.5-30	[90]
Al_2O_3	Water	100	0.5-6	3-57	[90]
SiC	DW	<100	0.001-3	1-102	[92]
CuO	EG	152	0.5-6	8-32	[90]
SiO_2	Ethanol	190	1-5.6	5-44	[82]

6. Conclusions

In this paper an effort has been made to explain the preparation methods for nanofluid and stability evaluation methods for nanofluids. From the majority of researches, it is evident that two-step preparation method is accepted as it is simple and inexpensive. Further a detailed description is provided for enhancing the stability of nanofluids. More importantly, a genuine attempt was made to characterize the thermal conductivity along with viscosity of nanofluids.

7. Current problems and Future scope

Thermal conductivity has got the most significance in the application of nanofluids, however several groups have explored other heat transfer properties. The viscosity of nanofluids was also a major focus of the tests, as this is an important metric, like thermal conductivity. The fundamentals of thermal conductivity and viscosity are only just beginning to be understood quantitatively. The thermo-physical characteristics of nanoparticles are affected by a variety of parameters, including their size, shape, concentration, dispersion method, base fluid material, surfactant type and concentration, and many more, thus thorough knowledge of these parameters is necessary.

Developing new tools to characterize and comprehend nanofluids should be a primary goal of the next research. Moreover, the research turns its attention towards the computational models for straightforwardness of understanding and for better precision. The future research should receive greater attention on the below mentioned points.

- There are certain parameters greatly influenced by particle shape and size of nanoparticles. Therefore new methods for nanofluid preparation with controllable microstructure will be a fascinating research area.
- As mentioned that the stability is very important parameter, the research should paid attention on long term stability nanofluids in all the places where its application is involved.
- Choosing the suitable surfactant for base fluid is another issue. So development of the suitable activator/surfactant for enhance the stability is the topic on which the focus is much needed.
- Attention should be focused on pH value of the fluid since variations in pH influences the properties of nanofluid system which is evident from the survey.
- All results shown enhancement in the thermal conductivity with addition of nanoparticles. However, attention should be focus on the reverse engineering process i.e for required thermal conductivity what amount of nanoparticles should be added.

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