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A comparative study on stability and thermal properties of various nanofluids

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ABSTRACT

The attention of researchers in convective heat transfer by suspended nanoparticles in base fluids has grown lately to promote uncommon techniques for enhancing the thermal performance of fluids. In this study, the stability period and thermal properties of aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), and Al_2O_3–SiO_2 hybrid were investigated at volume concentration 0.1vol.% dispersed in Distilled Water (DW) as a base fluid. For the hybrid nanofluid, the samples consisted of (0.025 vol.%Al_2O_3+0.075vol.%SiO_2), (0.05vol.%Al_2O_3+0.05vol.%SiO_2), and (0.075vol.%Al_2O_3+0.025vol.%SiO_2). The two-step method was adopted to prepare the nanofluid samples by using an Ultrasonic device. Three different ultrasonication times were fitted for preparing the samples (1hr,2 hr, and 3 hr). The properties of single and hybrid nanofluids were evaluated at various temperatures (from 30 °C to 70 °C). The obtained results demonstrated that the dispersion of nanoparticles was homogeneous and more stable for a longer period for all samples that were prepared at 3 hr of ultrasonication process. Among all samples of nanofluids, SiO_2/DW was found to be the most stable coolant**.** For all nanofluids, with an increase in temperature, the thermal conductivity and specific heat were increased significantly while density and viscosity were decreased.

1. Introduction

Improving warmth move rates by using nanofluids has drawn huge consideration from analysts around the globe. Ordinary strong nanoparticles, size of 1-100 nm with high warm conductivities, are suspended in the base liquids that have low warm conductivities. The nanofluids have demonstrated an upgrade in viable warm conductivities and the convective warmth move coefficients of the first base fluid[1]. Nano-fluid, a collection of nanomaterials in a continuous and saturated liquid, has been known to be capable of achieving significantly higher thermal conductivity than the associated base liquid, causing an enhancement in heat transfer coefficients [2].Hybrid nanofluid as an expansion of nanofluid is obtained by scattering composite nano-powder or two diverse nanoparticles in the base liquid. It is accepted that half-breed nanofluid will offer great warm qualities when contrasted with the base liquid and nanofluid containing single nanoparticles because of synergistic impacts[3]. A blend of nanofluids happens only by utilizing remarkable techniques like one-stage and two-advance strategies. Steady and quality nanofluids are integrated utilizing these strategies to use them for any warmth move and exploratory purposes. According to various authors, the physical properties of nanofluids are influenced by several factors. Temperature is the most important factor which plays a significant role in the nanofluid thermal performance.

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Nomenclature

DW	Distillate water	np	nanoparticles
k	thermal conductivity (W m^{-1} K^{-1})	w	the weight(Kg)
C	specific heat (J kg^{-1} K^{-1})	μ	viscosity in mpa.s
bf	base fluid	ρ	the density of the nanoparticles (Kg . m^{-3})
nf	nanofluid	φ	Volume concentration

[4] claimed that nano-fluids could be better than traditional working fluids like Ethylene Glycol (EG) and water due to the more beneficial and encouraging heat transfer properties of nano-fluids. [5] used Al_2O_3 nanoparticles with 4.3 vol.% and noted an increase in the warm conductivity of water under fixed conditions by 32.4%. [6] thought about the warm conductivity between Cu-EG nanofluid and unadulterated EG. The outcome showed that 40% expansion in warm conductivity of Cu-EG nanofluid at a volume portion of 0.3 vol%. As indicated by [7], a superior improvement in warm conductivity can be produced by hybridizing silver nanoparticles with Multi-Walled Carbon Nanotube (MWCNT). Approximately half nanoparticles have demonstrated an astounding improvement regarding cooling adequacy contrasted with single nanoparticles and water. [8] arranged suspension of TiO_2 and Al_2O_3 nanoparticles by a two-advance technique by scattering 0.05 vol.% and 0.3 vol.% in the blend of water and EG which was mixed for 30 min utilizing an attractive stirrer followed by ultrasonication utilizing an ultrasonication for 2 hr. They proposed that TiO_2 more steady than Al_2O_3 in water/EG blend. [9] Compared to nano-fluid that have single nanoparticles and water, hybrid nanoparticles have exhibited a significant improvement in cooling system performance [10]. Stabilized Single-Walled Carbon Nanotubes (SWCNT) functionalized with the carboxyl group (COOH) –water /EG by. The functionalized SWCNT with different solid volume fractions were added to the base fluid, using a two-step method. The finds obviously that the nano-fluid samples were stable for two weeks and had long stability with no comprehensible precipitation. [11]inspected thermo-physical properties (warm conductivity, thickness, consistency, and explicit warmth) of nanofluids containing Al_2O_3 nanoparticles in water/EG blend (50:50). The ascent in temperature demonstrated improvement in warm conductivity and specific heat while the density and viscosity were decreased.[12] estimated warm conductivity of ZnO-Ag (50 %:50 %)/water by considering different temperatures (25°C– 50°C) at 2 vol.%. The maximum thermal conductivity was achieved at 50°C. [13]analyzed the thermal behavior of a functionalized graphene nanoplatelet platinum (GNP-Pt) hybrid nano-fluid at temperatures ranging from 20°C to 40 °C. They mentioned that the hybrid nano-fluid density was correlated with the temperature. GNP-Pt/water hybrid nano-fluid density decreased with the rise in temperature from the observational investigation. From the findings of Yarmand et al[14]on the activated carbon/grapheme (ACG)/EGG hybrid nano-fluid. It was established that when the temperature increases significantly, the specific heat of nano-fluids was greater than that of the base fluids. For thermal performance testing, nano-fluid viscosity is a parameter as important as thermal conductivity, density and specific heat. Dardan et al[15]demonstrated the viscosity relationship with respect to the difference of Al_2O_3-MWCNT/nano-fluid oil temperatures. And as per the results, with temperature, viscosity was dramatically decreased, with temperature increase.

The main objective of this paper is to get a nanofluid with promising advantages by adding Al2O3 and SiO_2 nanoparticles to DW. Adopting the two-step method to prepare nanofluid samples and highlighting the effect of ultrasonication time on the stability of nano-suspensions. The thermophysical properties of nanofluids were evaluated at temperatures from 30 °C to 70 °C.

2. Experimental steps

2.1. Nanofluids preparation

Two kinds of oxide nanoparticles were utilized for this investigation: Al2O3 nanoparticles produced by (Hongwu, Universal Group. Ltd) and SiO2 manufactured by US Exploration Nanomaterial's, Inc. (NovaScientific Assets (M) Sdn. Bhd). Both nanofluids were readied with DWas base fluid. The properties of these nanoparticles are shown in Table 1.

Table 1. Physical, morphological, and thermo- properties of Al_2O_3 and SiO_2 nanoparticles.

Properties	(Al_2O_3)	(SiO_2)
Color	White	White
Particle size	50 nm	50 nm
Purity	99.99%	99.8%
Morphology of Particles	Spherical	Spherical
Form	Powder	Powder
Density (g.cm^{-3})	3.9	2.4
Thermal conductivity (K) (W.m^{-1} .K^{-1})	40 [16]	1.4 [17]
Specific heat (cp) (J / kg.k)	773 [16]	745 [17]

The particle shape and microstructure that were studied with a scanning electron microscope (SEM) are explained in Fig. 1a-b. The examination was conducted in the Scientific Research Department / Ministry of Higher Education and Scientific Research. The nanoparticle suspensions in DW were subjected to ultrasonic vibration for 1hr,2hr, and 3hr at room temperature as in Fig. 2. The weight of Al2O3and SiO2 nanoparticles that were used to prepare the nanofluid samples are explained in Table 2. In the next step, adequate quantities of DW were added to the underlying suspensions and altogether blended to accomplish the expected nanofluids. The volume concentrations of single and hybrid nanofluids are evaluated from Eqs. 1 and 2[18]:

$$\text{Volume concentration } (\varphi) = \left[\frac{\frac{Wnp}{\rho np}}{\frac{Wnp}{\rho np}+\frac{Wbf}{\rho bf}}\right] \times 100 \tag{1}$$

$$\varphi = \left[\frac{\left[\frac{Wnp}{\rho np}\right]_{Al2O3}+\left[\frac{Wnp}{\rho np}\right]_{SiO2}}{\left[\frac{Wnp}{\rho np}\right]_{Al2O3}+\left[\frac{Wnp}{\rho np}\right]_{SiO2}+\frac{Wbf}{\rho bf}}\right] \times 100 \tag{2}$$

Table 2. The weights in gm of Al_2O_3 and SiO_2 nanoparticles in the samples.

No.	sample	Weight
1	0.1 vol.% Al2O3	39.04
2	0.1 vol.% SiO2	24.04
3	0.05 vol.% Al2O3 + 0.05 vol.% SiO2	31.49
4	0.075 vol.% Al2O3 + 0.025 vol.% SiO2	35.24
5	0.025 vol.% Al2O3 + 0.075 vol.% SiO2	27.79

2.2. Evaluation of the physical properties of nanofluids

The thermal conductivity of nanofluids is a significant property when evaluating warm proficiency. Estimations were performed with temperature assorted variety between 30 °C and 70 °C. To evaluate the warm conductivity of nanofluids, KD2 Ace Warm Properties Analyzer (Decagon Gadgets, USA) was used as in **Fig. 3a-b**.

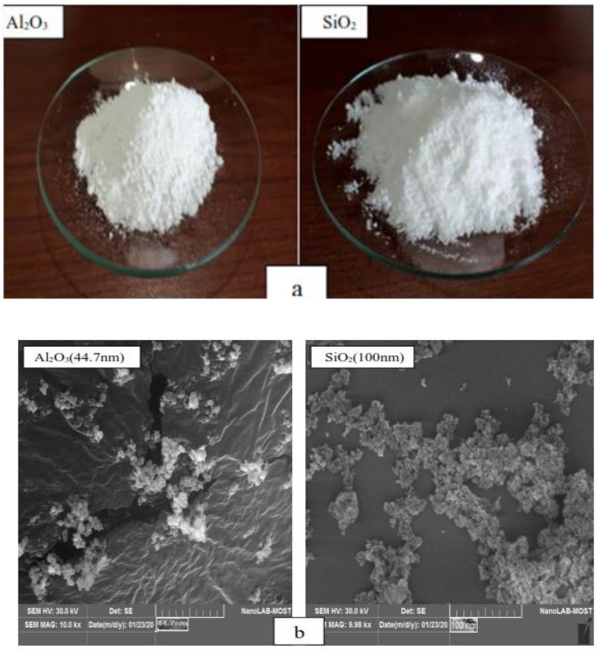

Figure 1. a) General shape of Al2O3 and SiO2 particles b) SEM of nanoparticles

Figure 2. Ultrasonic device

The examination was conducted at the University of Babylon / College of Engineering / Department of Chemical Engineering. The KD2 was adjusted by utilizing DW at room temperature before estimations, and the exactness of these estimations was fated to be inside 1%.

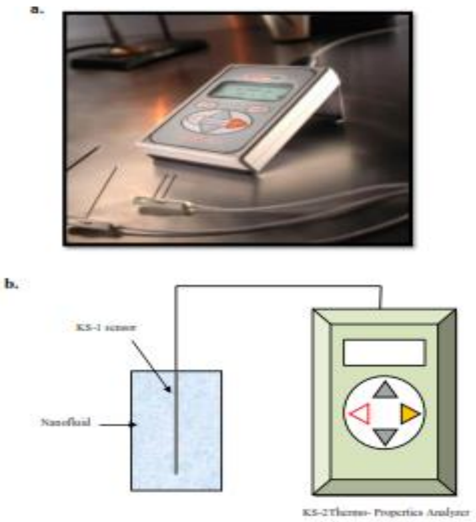

Figure 3. a) Thermo-properties analyzer; b) Schematic diagram of thermal conductivity measuring

The measurements of Physico-thermal properties for nanofluids (density, specific heat and viscosity) are necessary to apply for practical applications. Appropriate correlations to assess the density of single nanofluids were provided by Pakand Chu [19]that have been identified as follows:

$$\rho_{nf} = \varphi\rho_{np} + (1-\varphi)\rho_{bf} \tag{3}$$

The specific heat of single nanofluids was calculated using Xuan and Roetzel's [20] equation:

$$(\rho C)_{nf} = \varphi(\rho C)_{np} + (1-\varphi)(\rho C)_{bf} \tag{4}$$

To measure the densities and specific heat of hybrid suspensions of $Al_2O_3$and SiO_2nanoparticles, the theoretical formulas predicted by Ho et al.[21]were used as follows:

$$\rho_{nf} = [\varphi\rho_{np}]_{Al2O3} + [\varphi\rho_{np}]_{SiO2} + (1-\varphi_{Al2O3} - \varphi_{SiO2})\rho_{bf} \tag{5}$$

$$(\rho C)_{nf} = [\varphi\rho C]_{Al2O3} + [\varphi\rho C]_{SiO2} + (1-\varphi_{Al2O3} - \varphi_{SiO2})(\rho C)_{bf} \tag{6}$$

To predict the viscosity of nanofluids, the formula derived by Brinkman [22]was used. All samples used in this study which have different component fractions of Al_2O_3 and SiO_2were considered to have the same viscosity because of the particle's spherical shape and the volume fraction of samples between 0.01 vol.% and 2 vol.% [23].

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\varphi)^{2.5}} \tag{7}$$

3. Results and discussion

Tests were performed with DW and various samples of nano-fluids which were prepared with different ultrasonication times (1hr,2 hr, and 3 hr). The study was carried out with the range of temperature (30,40,50,60 and 70°C) at 0.1vol.%. The observation obtained from the present investigation is discussed below.

3.1. Dependability time of nanofluids

The impact of ultrasonication times on the resting period as appeared in **Table 3**. Due to the little size of nanoparticles, it has a high propensity to shape groups or agglomerates because of van der Waals powers. The ultrasonication technique helps to break these bonds between the nanoparticles and increase the random motion of the nanoparticles that are suspended in the base fluid. The augmentation in ultrasonication time leads to an increment in the random motion of this nano-powder and will create a slip speed between the particles and the liquid medium[24].

Figure 4. Sedimentation time for the sample 0.1vol.%of SiO_2 after 15day

The experimental results show a good agreement with the previous articles [25, 26]. Besides, the challenge of how to effectively prevent nanoparticles from agglomeration or aggregation, the key issue is the weight of nanoparticles that are used to form more stable nanofluids. The best consequences were gotten for the sample 0.1 vol.% SiO_2, where it recorded the longest period of stability which was about 15 days with an ultrasonication time of 3 hr. The reason is due to the total weight of nanoparticles used in 0.1 vol.% SiO_2 is less than the weights utilized in other samples to prepare them with the same volume concentration, which ensures the possibility of better distribution and a longer sedimentation time[25]. Fig. 4 explains the sedimentation time for the sample 0.1vol.%of SiO_2 after 15day.

Table 3. Stability period (day) of nanofluid samples at room temperature

Samples	Ultrasonication time		
	1hr	2 hr	3 hr
0.1 vol.% Al_2O_3	7	9	11
0.1 vol.% SiO_2	9	11	15
0.05 vol.% Al_2O_3 + 0.05 vol.% SiO_2	8	10	13
0.075 vol.% Al_2O_3 + 0.025 vol.% SiO_2	7	9	12
0.025 vol.% Al_2O_3 + 0.075 vol.% SiO_2	8	10	13

3.2.Effect of temperature on physical properties

3.2.1.Thermal conductivity

Fig. 5 introduces the variation of nanofluid thermal conductivity as a function of temperature for DW and all the studied nanofluid samples. By observing the results, the warm conductivity of the nanofluids increments with an increment in temperature. With the ascent in temperature, while loosening the intermolecular bonds, the random behavior of nanoparticles-liquid collision will increase [6]. This is known as Brownian motion which was suggested by Xuan and Roetzel [20]. Moreover, these results agree with the literature [27]. The spontaneous behavior of suspended nanoparticles in liquid media will increase as temperature goes up, and weaken molecular bonds [28]. That is called a Brownian motion as proposed by Xuan and Roetzel [29]. Besides, the increase in vol.% of Al_2O_3 at the component of nanofluids, the thermal conductivity will increase. Due to The high thermal conductivity of Al_2O_3 nanoparticles, as compared to SiO_2 nanoparticles, it leads to an important role for the better enhancement in the physical properties of base fluid [16].

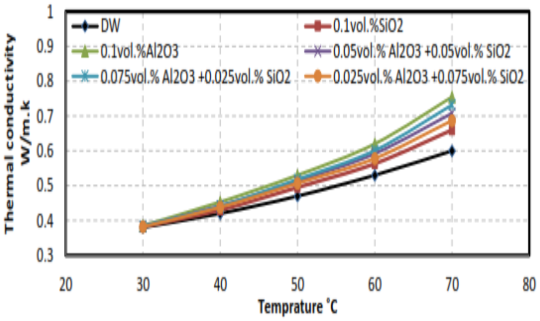

Figure 5. Thermal conductivity of DW and various nanofluids as a function of temperature.

3.2.2.Density

The physical properties of nanofluid are specified by each of the nanoparticles and base fluid. The density of nanofluid is one of these properties that changes according to the density of nanoparticles and the base fluid. Since the solid has a density greater than the liquid, the addition of the nanoparticles will raise the density of the base fluid. Fig. 6 presents the experimental data of densities that were measured for DW and nano fluids (single and hybrid phase) with different temperatures. The figure shows that the Al_2O_3/DW has a higher density than other nanofluids at all temperatures, because of the high density of Al_2O_3 nanoparticles[16]. For the hybrid nanofluids, density increased with an increase in the quantity of Al_2O_3 nanoparticles due to its high density compared to SiO_2 nanoparticles[21]. It is shown also that density decreases with the increase of temperature to 70 °C for all samples and the decreasing tendency was slight. With the temperature rise, the volume usually increases because the faster-moving molecules are further apart, which is cause a slightly decreasing in the density [21].

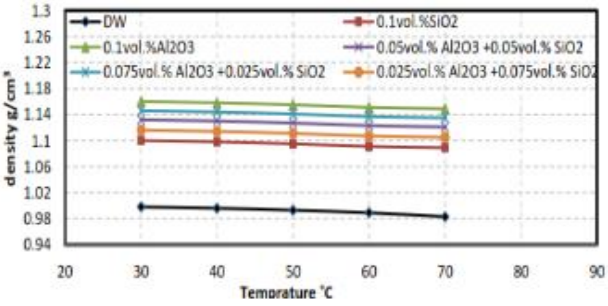

Figure 6. Densities of DW and various nanofluids as a function of temperatures

3.2.3.Specific heat

Heat transfer is significantly influenced by specific heat. Specific heat of nanofluid as the other physical properties depend on suspended nanoparticles and the base fluid. Fig. 7 shows the changes in specific heat for all nanofluid samples at various temperatures. Moreover, as shown in this figure, the specific heat of DW is higher than in other samples. The lower specific heat of nanoparticles is the reason that explains why the specific heat value of the mixture becomes lower than that of base fluid (4179.6 J / kg.k) [11]. According to the data of this study, with an increase in temperature, the specific heat is raised steadily and linearly. As the substance warms up, the normal dynamic vitality of the atoms increments. The crashes give enough vitality to permit the turn to happen, at that point adds to the inside vitality and raises the particular warmth[30]. It seems that the specific heat of produced nanofluid depends on the type of dispersants where with an increase in the volume fraction of SiO_2 to Al_2O_3in base fluid, the specific heat will decrease. That is because the specific heat capacity of SiO_2 nanoparticles is less than Al_2O_3 nanoparticles[31].

3.2.4.Viscosity

Viscosities of tried examples were estimated in the temperature scope of 30 °C–70 °C and plotted in Fig. 8. [6, 32] indicated that there is an immediate connection between temperature and consistency of all trials in all conditions contrasted with the base liquid.

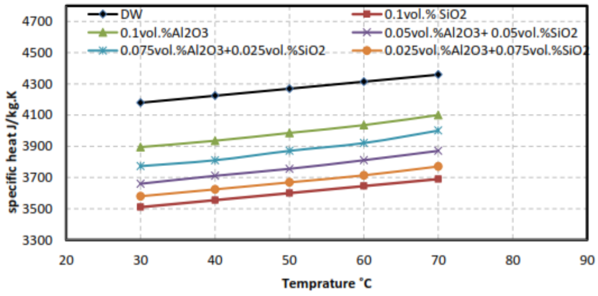

Figure 7. Specific heat of DW and various samples as a function of temperatures.

It is observed that expanding temperature of the nanofluid diminishes its thickness. As the temperature expands the vitality level of fluid particles increments and the separation between the atoms increments and causes an abatement in intermolecular fascination between lessening inconsistency [16].

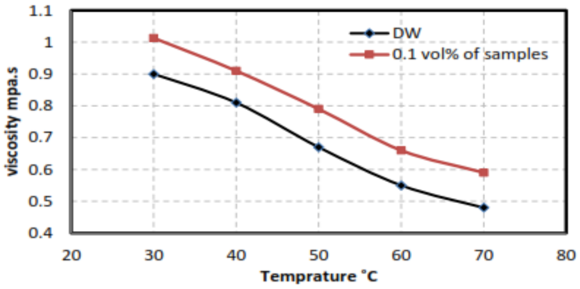

Figure 8. Results of DW and 0.1vol.% sample viscosities relative to temperatures.

4. Conclusions

In the present experimental study, the stability period of aluminum oxide(Al_2O_3), silicon dioxide(SiO_2), and Al_2O_3–SiO_2 hybrid was investigated at various ultrasonication times. Also, the thermal properties of DW and samples have been estimated at five different temperatures. The conclusions of the study are elaborated below:

The stability period increases with increasing the ultrasonication time for all samples. The SiO_2 nanofluid was found to be the most stable coolant, while Al_2O_3 was found the lowest stable nanofluid. For the hybrid samples, the stability period increases with the increasing volumetric concentration of SiO_2 nanoparticles in the nanofluid.

The thermal properties of nanofluids are dependent directly on the temperature. Moreover, with increasing temperature, the thermal conductivity and specific heat of nanofluid increase, while density and viscosity decrease. The outcome of physical properties (thermal conductivity, density, and specific heat) show that 0.1 vol.% Al_2O_3/DW has good results when compared to other working fluids. This means that the Al_2O_3 nanoparticles had a preferable thermal performance than SiO_2 suspensions. For the hybrid nanofluids, the thermal properties showed good results with expanding the volume part of Al2O3 nanoparticles in the base fluid.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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