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A Comparative Study On Stability And Thermal Properties Of Various Nanofluids

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ABSTRACT

The attention of researches 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 aluminium 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 were consisted of (0.025 vol.% $Al_2O_3+0.075$ vol.% SiO_2), (0.05 vol.% $Al_2O_3+0.05$ vol.% SiO_2) and (0.075 vol.% $Al_2O_3+0.025$ vol.% SiO_2). The two-step method was adopted to prepare the nanofluid samples by using 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 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 of temperature, the thermal conductivity and specific heat were increased significantly while density and viscosity were decreased.

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1. Introduction

Improving warmth move rates by using nanofluids has drawn huge considerations 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 utilizing remarkable techniques like as 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, physical properties of nanofluids is 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
k	thermal conductivity ($\text{W m}^{-1} \text{K}^{-1}$)
C	specific heat ($\text{J kg}^{-1} \text{K}^{-1}$)
bf	base fluid
nf	nanofluid

np	nanoparticles
w	the weight(Kg)
μ	viscosity in mpa.s
ρ	the density of the nanoparticles (Kg . m^{-3})
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 that 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 volume portion of 0.3 vol%. As indicated by [7], a superior improvement in warm conductivity can be produced by hybridizing silver nano-particles 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 obvioued that the nano-fluid samples was stable for two weeks and its had a 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 Al_2O_3 and SiO_2 nanoparticles to DW. Adopting the two-step method to prepare nanofluid samples and highlighting on 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: Al_2O_3 nanoparticles produced by (Hongwu, Universal Group.Ltd) and SiO_2 manufactured by US Exploration Nanomaterial's, Inc. (NovaScientific Assets (M) Sdn. Bhd). Both nanofluids were readied with DW as 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) ($\text{W.m}^{-1} .\text{K}^{-1}$)	40 [16]	1.4 [17]
Specific heat (cp) (J / kg.k)	773 [16]	745 [17]

The particles shape and microstructure that studied with scanning electron microscope (SEM) are explain 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 Al_2O_3 and SiO_2 nanoparticles that used to prepare the nanofluid samples are explained in **Table 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.% Al_2O_3	39.04
2	0.1 vol.% SiO_2	24.04
3	0.05 vol.% Al_2O_3 + 0.05 vol.% SiO_2	31.49
4	0.075 vol.% Al_2O_3 + 0.025 vol.% SiO_2	35.24
5	0.025 vol.% Al_2O_3 + 0.075 vol.% SiO_2	27.79

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 the following equations[18]:

$$\text{Volume concentration } (\varphi) = \left[\frac{\frac{W_{np}}{\rho_{np}}}{\frac{W_{np}}{\rho_{np}} + \frac{W_{bf}}{\rho_{bf}}} \right] \times 100 \quad (1)$$

$$\varphi = \left[\frac{\left[\frac{W_{np}}{\rho_{np}} \right]_{Al_2O_3} + \left[\frac{W_{np}}{\rho_{np}} \right]_{SiO_2}}{\left[\frac{W_{np}}{\rho_{np}} \right]_{Al_2O_3} + \left[\frac{W_{np}}{\rho_{np}} \right]_{SiO_2} + \frac{W_{bf}}{\rho_{bf}}} \right] \times 100 \quad (2)$$

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

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

Specific heat of single nanofluids was calculated using Xuan and Roetzel’s [20] equation:

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

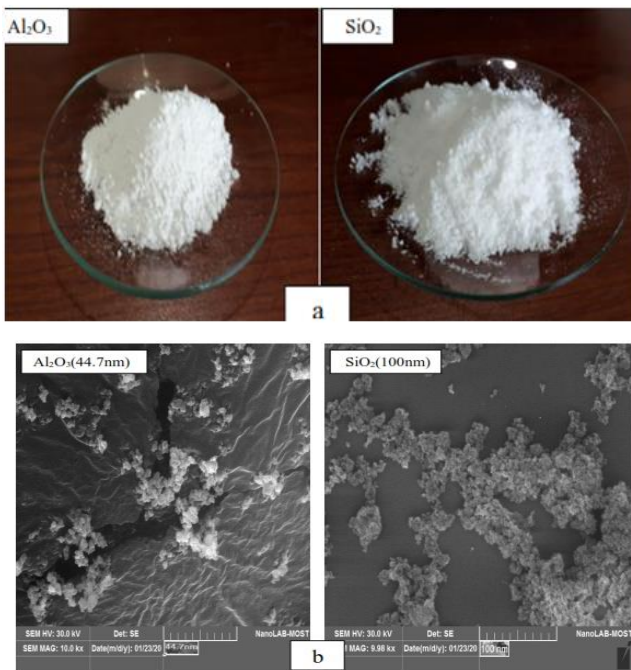


Figure 1: a. General shape of Al2O3 and SiO2 particles b. SEM of nanoparticles

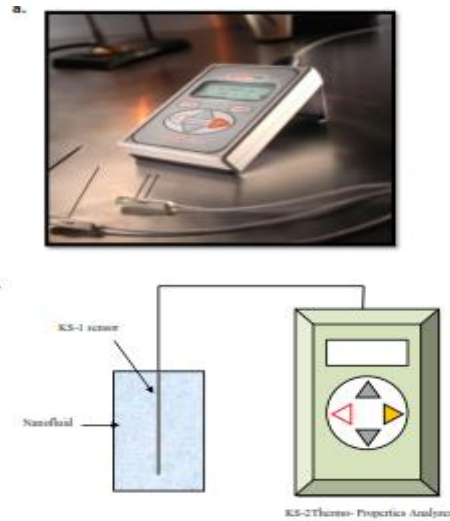


Figure 3: a. Thermo- Properties Analyzer b. schematic diagram of thermal conductivity measuring.

To measure the densities and specific heat of hybrid suspensions of Al₂O₃ and SiO₂ nanoparticles, the theoretical formulas that predicted by Ho et al. [21] were used as follows:

$$\rho_{nf} = [\varphi \rho_{np}]_{Al_2O_3} + [\varphi \rho_{np}]_{SiO_2} + (1 - \varphi_{Al_2O_3} - \varphi_{SiO_2}) \rho_{bf} \quad (5)$$

$$(\rho C)_{nf} = [\varphi \rho C]_{Al_2O_3} + [\varphi \rho C]_{SiO_2} + (1 - \varphi_{Al_2O_3} - \varphi_{SiO_2}) (\rho C)_{bf} \quad (6)$$

To predict the viscosity of nanofluids, the formula derived by Brinkman [22] was used. All samples that used in this study which have different component fractions of Al₂O₃ and SiO₂ were considered to have the same viscosity because of particle’s spherical shape and the volume fraction of samples between 0.01 vol.% and 2 vol.% [23].

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

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



Figure 2: Ultrasonic device

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 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. Ultrasonication technique helps to break these bonds between the nanoparticles and increase the random motion of the nanoparticles that suspended in the base fluid. The augmentation in ultrasonication time lead 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]. 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.% SiO₂, where it recorded the longest period of stability which was about 15 day with ultrasonication time 3 hr. The reason is due to the total weight of nanoparticles that used in 0.1 vol.% SiO₂ is less than weights that 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** explain the sedimentation time for the sample 0.1vol.% of SiO₂ 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 ₂ O ₃	7	9	11
0.1 vol.% SiO ₂	9	11	15
0.05 vol.% Al ₂ O ₃ + 0.05 vol.% SiO ₂	8	10	13
0.075 vol.% Al ₂ O ₃ + 0.025 vol.% SiO ₂	7	9	12
0.025 vol.% Al ₂ O ₃ + 0.075 vol.% SiO ₂	8	10	13



Figure 4: Sedimentation time for the sample 0.1vol.% of SiO₂ after 15day

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 increment in temperature. With the ascent in temperature, while loosening the intermolecular bonds, the random behaviour of nanoparticles - liquid collision will increase [6]. This is known as Brownian motion which 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 weakening molecular bonds [28]. That is called a Brownian motion as proposed by Xuan and Roetzel [29]. Besides, the increase in vol.% of Al₂O₃ at the component of nanofluids, the thermal conductivity will increase. Due to the high thermal conductivity of Al₂O₃ nanoparticles, as compared to SiO₂ nanoparticles, it leads to an important role for the better enhancement in the physical properties of base fluid [16].

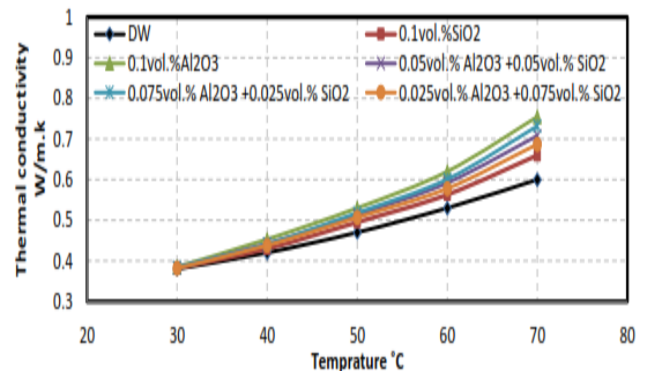


Figure 5: Thermal conductivity of DW and various nanofluids as a function of temperature.

3.2.2. Density

The physical properties of nanofluid is specified by each of 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 have a density greater than the liquid, the adding of the nanoparticles will raise the density of the base fluid. **Fig. 6** presents the experimental data of densities that measured for DW and nano fluids (single and hybrid phase) with different temperatures. The figure shows that the Al₂O₃/DW has a higher density than other nanofluids at all temperatures, because of the high density of Al₂O₃ nanoparticles[16]. For the hybrid nanofluids, density increased with increase in the quantity of Al₂O₃ nanoparticles due to its high density compared to SiO₂ 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 rise in temperature, the volume usually increases because the faster-moving molecules are further apart, which is cause a slightly decreasing in the density [21].

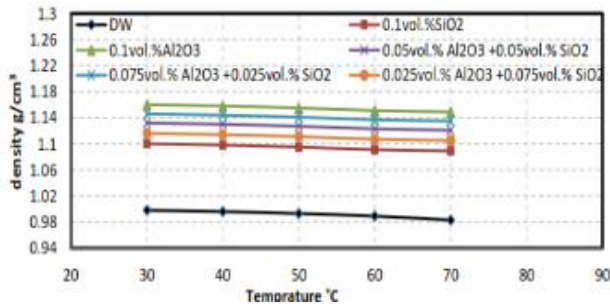


Figure 6: Densities of DW and various nanofluids as a function of temperatures

3.2.3. Specific heat

Heat transfer is significantly influenced by specific heat. Specific heat of nanofluid as the other physical properties depends on suspended nanoparticles and the base fluid. Fig. 7 shows the changes in specific heat for all nanofluids samples at various temperatures. Moreover, as shown in this figure, the specific heat of DW is higher than 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 turn to happen, at that point adds to the inside vitality and raises the particular warmth [30]. It seems that specific heat of produced nanofluid depends on the type of dispersants where with increase the volume fraction of SiO₂ to Al₂O₃ in base fluid, the specific heat will decrease. That because of the specific heat capacity of SiO₂ nanoparticles less than Al₂O₃ 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 among temperature and consistency of all trials in all conditions contrasted with the base liquid. 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].

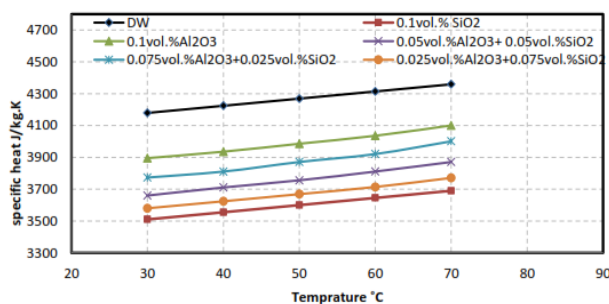


Figure 7: Specific heat of DW and various samples as a function of temperatures.

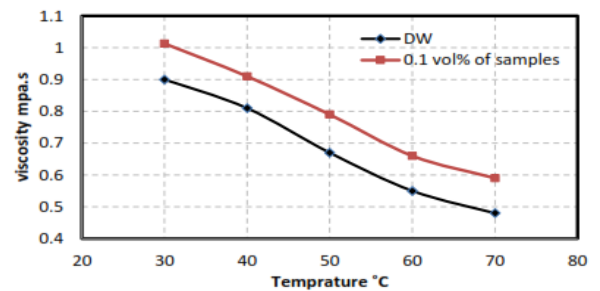


Figure 8: Results of DW and 0.1vol.% sample viscosities relative to temperatures.

4. Conclusions

In the present experimental study, the stability period of aluminium oxide (Al₂O₃), silicon dioxide (SiO₂) and Al₂O₃-SiO₂ 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 SiO₂ nanofluid was found to be the most stable coolant, while Al₂O₃ was found the lowest stable nanofluid. For the hybrid samples, the stability period increases with the increasing volumetric concentration of SiO₂ nanoparticles in the nanofluid.

The thermal properties of nanofluids 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.% Al₂O₃/DW has good results when compared to other working fluids. This means that the Al₂O₃ nanoparticles had a preferable thermal performance than SiO₂ suspensions. For the hybrid nanofluids, the thermal properties showed good results with expanding the volume part of Al₂O₃ nanoparticles in the base fluid.

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