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# STUDY OF THE EFFECT OF ADDING $AL_2O_3$ NANOPARTICLES ON THE THERMAL PROPERTIES OF POLYPROPYLENE GLYCOL WITH DIFFERENT CONCENTRATIONS

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## ABSTRACT

In this study, a comparison between thermal conductivity and dynamic viscosity of a pure propylene glycol liquid as a solar thermal fluid and its nanofluid has been carried out using different concentrations of nanoparticles. Aluminum oxide nanoparticles (α phase - size 50-90 nm) were added to the pure propylene glycol liquid at three different concentrations (0.2%, 0.4%, and 0.6%). The different thermal fluids (pure and nano-propylene glycol) were tested at different temperatures (20, 60, 100, 140, 180°C) on five different days. Regarding pure liquid, as temperature increases the thermal conductivity and viscosity drop for all experiment days. The minimum value for thermal conductivity and viscosity were recorded on the first day test at 180°C temperature with (k=0.13 W/m.K and μ=13.2 centipoise). However, adding the nanoparticles has reversed the temperature effect on the resulting nanofluids thermal conductivity. Where k reached its maximum value (0.307 W/m.K) at 180 °C for 0.6% concentration nanofluid on day (60) recording an improvement of (136.14%). Viscosity in contrast kept decreasing with temperature rise for each nanoparticles concentration. Yet the nanoparticles concentration proportional directly with dynamic viscosity at constant temperature. In this contest, on day (60) test, the viscosity at 20°C for both pure PG and 0.6% nano-PG were 58 and 64 centipoises, respectively. While at 180°C, μ= 14.9 and 21 centipoises respectively. The behaviour of PG nanofluid dynamic viscosity in different concentrations and different temperatures has almost the same response to concentration and temperature for ethylene glycol based nanofluid. Finally, SEM images showed homogeneity and distribution of the nanofluid at a concentration of 0.4%, and some aggregates were detected at a concentration of 0.6%.

**KEYWORDS**

Alumina Nanoparticles, Nanofluid, Propylene Glycol, Viscosity, Thermal Conductivity.

## 1. INTRODUCTION

Utilizing nanofluids to improve the heat transfer capacity of conventional fluids has great potential. Water is the most often used heat transfer fluid. However, in refrigeration systems, it may be essential to mix water with propylene or ethylene glycol in order to decrease the water content. Freezing temperature and impeding ice formation in a manner similar to radiators. Heat exchangers used in industrial or automotive applications. Water's boiling point can be increased by mixing it with glycol-containing substances. There is a rising interest in using nanofluids composed of ethylene or propylene glycol in several industries (Sekrani and Poncet, 2018). Winter temperatures in colder locations like Canada, Alaska, and the Arctic, where they may frequently fall below -40°C, need a significant amount of energy to heat residences and commercial establishments in these areas. In order to decrease the temperature at which liquid water freezes, it is common to mix ethylene glycol or propylene glycol with it.

Either propylene glycol or ethylene glycol plus water (PG-W) can be added to high temperature applications, including industrial heat exchangers or car radiators, to raise the boiling point of water. As Tables 1 and 2 illustrate, ethylene glycol/water solutions have lower freezing temperatures and higher boiling points. in contrast to techniques PG-W. It is highly advised to utilize PG-W kits, nevertheless. Considering that propylene glycol finds usage in human-contact applications as home heating (Kulkarn et al., 2007; Naik, et al.2010; Palabiyik et al., 2011; Satti et al., 2017; and Vallejo et al., 2018) Tables 1 and 2 describe the freezing and boiling values for the groups.

**Table 1. Freezing points of water solutions based on ethylene glycol and propylene glycol at different temperatures (Sekrani and Poncet, 2018)**

| Type of solution | Volume fraction | Temperature |
|---|---|---|
| Solution of ethylene glycol | 0 | 0 |
| | 10 | -3.4 |
| | 20 | -7.9 |
| | 30 | -13.7 |
| | 40 | -23.5 |
| | 50 | -36.8 |
| | 60 | -52.8 |
| Solution of propylene-glycol | 0 | 0 |
| | 10 | -3 |
| | 20 | -8 |
| | 30 | -14 |
| | 40 | -22 |
| | 50 | -34 |
| | 60 | -48 |

**Table 2. Boiling points of aqueous solutions based on ethylene glycol and propylene glycol at different temperature (Sekrani and Poncet, 2018)**

| Type of solution | Volume fraction | Temperature |
|---|---|---|
| Solution of ethylene glycol | 0 | 100 |
| | 10 | 101.1 |
| | 20 | 102.2 |
| | 30 | 104.4 |
| | 40 | 104.4 |
| | 50 | 107.7 |
| | 60 | 111.1 |
| Solution of propylene-glycol | 0 | 100 |
| | 10 | 100 |
| | 20 | 100.5 |
| | 30 | 102.2 |
| | 40 | 103.8 |
| | 50 | 105.5 |
| | 60 | 107.2 |

Unlike ethylene glycol, which is dangerous and has a slower decomposition rate, propylene glycol is non-toxic and readily breaks down in the environment. The thermal conductivity of the ethylene and propylene glycol groups is roughly three times lower than that of water at a temperature of 20 °C, as seen in Table 3. The primary hindrance to developing thermally efficient systems is this. The primary factor contributing to additional constraints is its reduced temperature. Greater volumes and varying thicknesses of fluids, which provide significant constraints on their capacity to retain heat and the level of pressure required to circulate them, respectively. Engineers and academics have made significant efforts in recent decades to raise the heat transfer efficiency of high-temperature thermal fluids (TTFs) by the use of passive or active techniques. These techniques include chaotic advection, turbulence, increased turbulence, employing HTFs with greater thermal characteristics, or a combination of these approaches. The user's text is (Rashidi et al. 2019).

**Table 3. displays the thermophysical characteristics of ethylene- and propylene-glycol in comparison to water at a temperature of 20 °C (Rashidi et al. 2019)**

| Characteristics | ρ(kg.$m^{-3}$) | Cp (J/kg.k) | K(w/m.k) | μ (mPa.s) |
|---|---|---|---|---|
| Ethylene-glycol | 1126 | 2354 | 0.256 | 21 |
| Propylene-glycol | 1035.3 | 2479 | 0.1962 | 57.571 |
| Water | 999 | 4158 | 0.6 | 1.002 |

Scientists did experiments to find out how well five different nanofluids with alumina, copper oxide, zinc oxide, silicon oxide, and titanium oxide nanoparticles could conduct heat. The main fluid is 40 parts propylene glycol to 60 parts water. It is kept at a temperature of -30°C to 90°C. The amount of heat that nanofluids can transfer depends on their temperature, quantity, size, type, and the fluid they are mixed with. It was found that the thermal conductivity of the nanofluids goes up when the concentration or temperature goes up and the size of the nanoparticles goes up (Satti et al. 2017). Narrow-phase fluids can be replaced by nanofluids in most situations where regular fluids are used to heat or cool something. Nanofluids can be used in photovoltaic systems, car heaters, freezers, boilers, drug delivery, cool electronic equipment, heat and cool buildings, desalinate water, absorb carbon dioxide, and make media. Any kind of liquid-based heat exchanges with holes, space, or both (Mahian et al., 2017; Devendiran et al., 2016; Colangelo et al., 2017) Solar technology is one of the best choices because it uses direct sunlight to make heat and electricity without releasing any gases. Boiling is an important part of heat movement in engineering systems. Power plants use it to cool nuclear reactors and high-tech electronics as well as to boil water (Kasaeian et al., 2018; Kasaeian et al., 2015; Kamel et al., 2018). An aqueous solution containing aluminum oxide nanoparticles. Mathematical models were employed to compute viscosity and thermal conductivity (Abed et al., 2023). Bentonite has been employed in four industrial categories. XRF, XRD, and BET were implemented to evaluate the samples. XRF with pH demonstrates the presence of robust metal ions. (Bakhshi et al. 2020)

Solar energy and other types of alternative energy are being used more because fossil fuels are becoming harder to find. All of the study on these solar energy topics is focused on how nanofluids can be used in solar collectors and water heaters. A lot of experts have looked into how well nanofluids conduct heat, and the results show that these materials do it better than other materials of simple liquids (Mahian et al., 2013; Godson et al., 2010; Vanaki et al. 2016 ; Kakaç et al. 2016). Effective models of viscosity for some nanofluids are only based on data from experiments (Khanafer et al., 2017). However, while some other researchers focus on nanofluids properties at temperatures below 60 and 70°C (Barkhordar et al. 2022), this study aims to examine PG nanofluid in high temperatures (above 100°C) in order to use it as a thermal circulating fluid in a solar heating system.

## 2. EXPERIMENTAL WORK:

### 2.1. materials and Nanoparticles.

#### 2.1.1. Propylene glycol (PG)

A propylene glycol solution provided from Thomas Baker Inc. was used with the characteristics of density, ρ (1032 kg/m3), viscosity, μ (57.97 mPa.s.), thermal conductivity, k (0.197 W/m.K), and boiling point (188 °C) and freezing point. (-60 °C) and specific heat (2479 J/Kg.K).

### 2.1.2. Aluminum oxide ($Al_2O_3$)

An aluminum oxide nanomaterial was providing from Skyspring Nanomaterials Inc. it was used as a filler material which has a size of (50-80) nanometers. The Properties of aluminum oxide (α phase) mentioned in the Table 3.

**Table3. Properties of Aluminum Oxide ($Al_2O_3$)**

| Density kg/$m^3$ | specific heat J/kg.k | Particle size nm | concentration | Thermal conductivity w/m.k |
|---|---|---|---|---|
| 3950 | 880 | 50-90 | 99.9% | 35 |

### 2.2. Procedures

The samples were mixed in the magnetic mixing and stirring device shown in Fig.1 for 20 minutes for three concentrations (0.2%, 0.4%, 0.6%) in weight proportions of alumina nanoparticles powder with a propylene glycol solution. Then the suspended particles were dispersed using an ultrasonic device as in Fig.2 for 15 minutes to obtain complete homogeneity. The testing was carried out in the laboratory under stable atmospheric conditions. The purpose was to obtain the results of the properties of both thermal conductivity (k) and viscosity (μ) at temperatures ranging from 20°C to 180°C. The samples were placed on a convection heater, respectively. The temperature of the nanofluid is measured over time using a thermometer, as shown in Fig.3. When the desired temperature is reached, readings are taken for the sample. The thermal conductivity reading is taken by the thermal sensor via a sensor placed in the nanofluid as in Fig.4, and then the viscosity is measured at the same temperature. Using a viscosity device, shown in Fig.5, five readings were taken over a period of 60 days. The period between one reading and the next reading was 15 days. The three concentrations were examined with a scanning electron microscope, and pictorial results were obtained, as shown in Fig.6. Regarding, the specific heat of the PG nanofluid, the following formulas were used to estimate their values. The features of nanofluid and nanoparticles, such as their size, density, and mass were taken into account (Zhou et al., 2010; Sinha et al., 2004; He et al. 2007; Buongiorno 2006; Zhou et al., 2018).

$$c_{p,nf} = \varphi c_{p,n} + (1-\varphi) c_{p,f} \quad (1)$$

$$c_{p,nf} = \frac{\varphi (\rho c_p)_n + (1-\varphi)(\rho c_p)_f}{\varphi \rho_n + (1-\varphi)\rho_f} \quad (2)$$

$$\varphi = \frac{V_n}{V_{n+V_{PG}}} \quad (3)$$

$$\varphi = \frac{m_n/\rho_n}{m_n/\rho_n + m_{PG}/\rho_{PG}} \quad (4)$$

**Fig. 1. Magnetic stirrer**

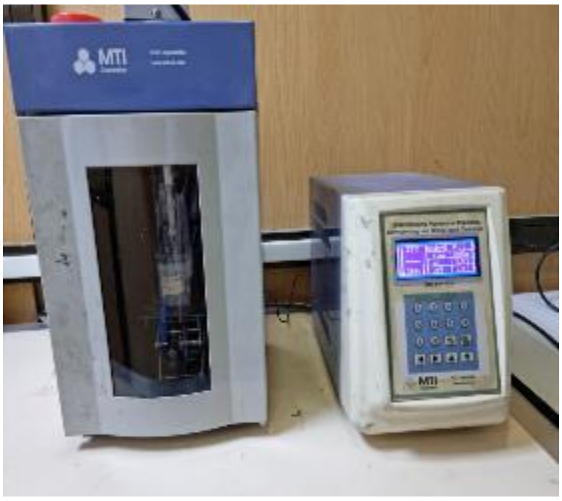


**Fig. 2. Ultrasound device**

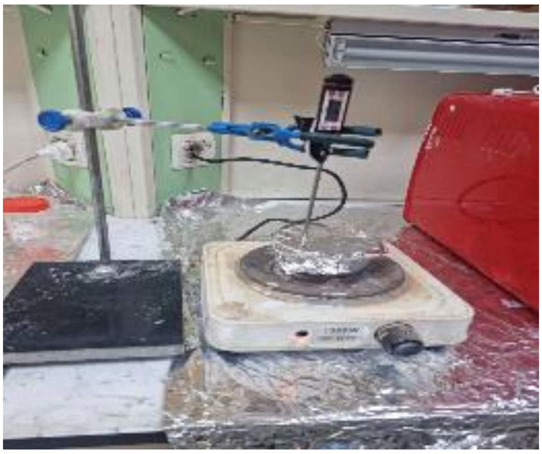
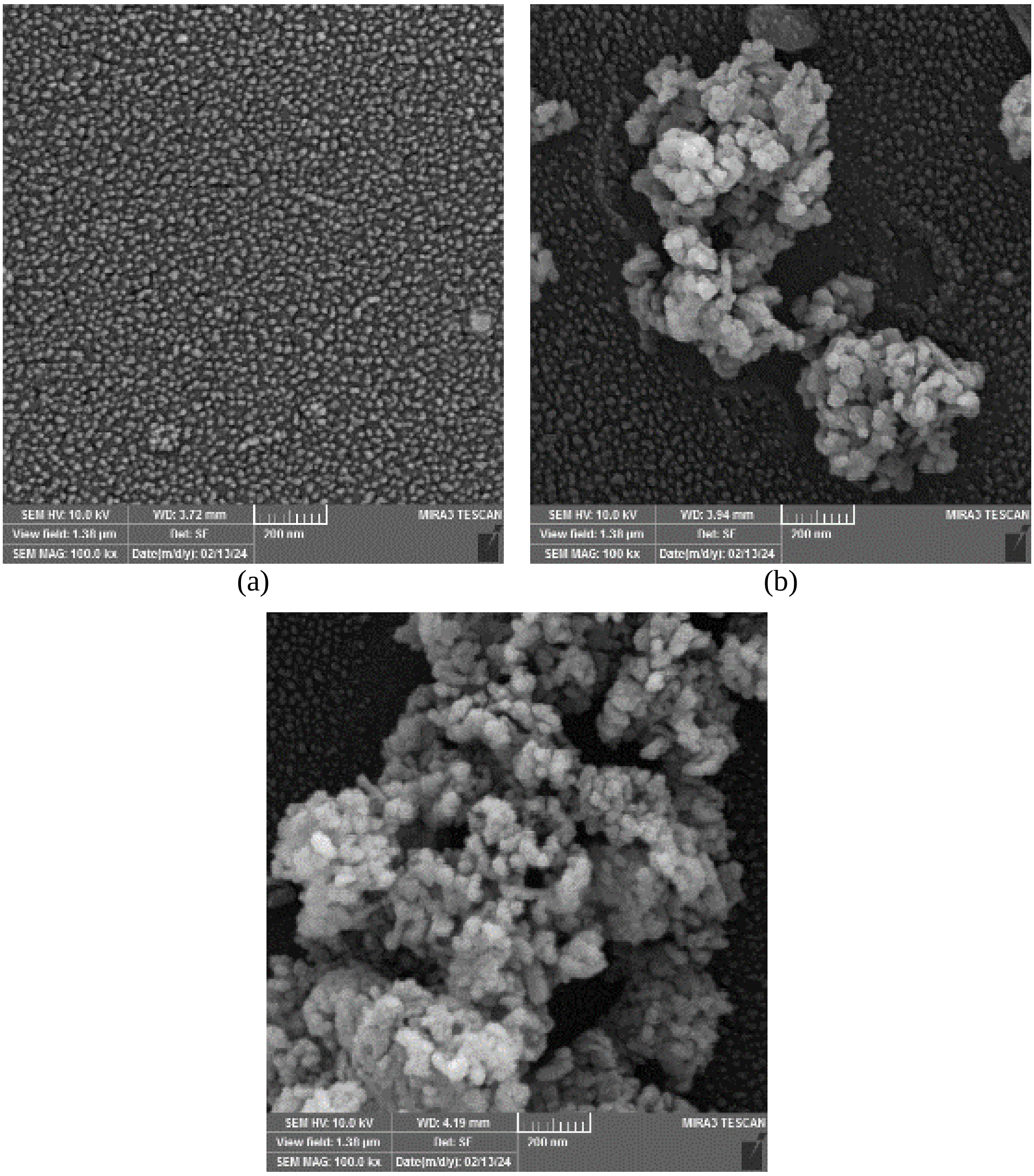


**Fig. 3. Thermal heater with thermometer**

**Fig. 4. Thermal conductivity measuring device**

**Fig. 5. Viscometer**

The sample was examined for particle size distribution under a scanning electron microscope (SEM). Fig.6 shows (SEM) A picture of one of the nanofluid samples consisting of aluminum oxide with a propylene glycol solution at a weight concentration of (0.2%-0.4%-0.6%). The particle size result for this nanofluid is consistent with the data provided by the material manufacturer. Alpha aluminum oxide nanofluid comes in particles of 50-90 nanometers. It was observed from the images that the majority of the size of the nanoparticles is close to the stated size, with a few smaller particles present. It is clear from the images that as the concentration of particles increases, the size of the particles becomes larger and larger in the area.




(c)

**Fig. 6. SEM images for $Al_2O_3$ / PG solutions (a) 0.2% $Al_2O_3$ / PG, (b) 0.4% $Al_2O_3$ / PG, (c)0.6% $Al_2O_3$ / PG**

## 3. RESULTS AND DISCUSSION

### 3.1. Thermal Conductivity (k)

Fig.7 shows the relationship between temperature and thermal conductivity for the three concentrations prepared with different weight ratios of aluminum oxide particles and propylene glycol solutions with alumina molecular size (50-90) nanometers. Five readings were taken between temperatures (20 to 180 °C), and it was noted from the first readings that the thermal conductivity increases with the rise of nanoparticles concentration and temperature. However, the thermal conductivity decreases with temperature rise for the pure liquid.

The nanofluid with a concentration of 0.6% showed the highest improvement in thermal conductivity by (0.307 W/m.K) at a temperature of (180°C) after mixing the nanofluid preparation for a period of (60 days) compared to the value of thermal conductivity on the first day for pure PG, which is (k=0.13 W/m.K). Moreover, it was found that there was an increase in the value of thermal conductivity (0.221 - 0.281 W/m.K) at the temperature (20°C - 180°C) in the first readings on the first day. The second readings after 15 days within the same temperature range showed an increase in thermal conductivity values for the same concentration (0.230 - 0.284 W/m.K). On the 30$^{th}$ day, the third readings were taken for the same concentration (0.6%) showed that thermal conductivity was gradually rising (0.232 - 0.292 W/m.K). The fourth readings were taken after 45 days for the same conditions. Thermal conductivity in these tests were (0.241 - 0.301 W/m.K). After 60 days at the same concentration and temperature range, the highest thermal conductivity range were recorded in these groups of experiments with (0.247 - 0.307 W/m.K).

Physically, when the temperature of pure liquid rises, liquid molecules will move further apart making the liquid expands. In this case, the heat transfer between molecules will decrease due to the widening gap among them. This gap widening also affects liquid thermal conductivity inversely, so that thermal conductivity of liquids decreases with temperature rise. However, adding nanoparticles to a pure liquid under specific conditions is a game changer. The movement of nanoparticles in the resulting nanofluid is subjected to Brownian motion theory. According to this theory, nanoparticles move and collide through liquid molecules. The continues collision among solid nanoparticles enhances solid to solid heat transfer which is in turn increase the thermal conductivity of the overall nanofluid. Brownian motion can be considered as a diffusive process having a diffusion coefficient (D). (Mukherjee et al. 2016)

The famous Stokes – Einstein – Sutherland formula which connect between diffusion coefficient (D) in one side and friction coefficient (ξ) and temperature on other side. Friction coefficient is inversely related to diffusion coefficient, while temperature is directly related to diffusion coefficient as in equation (5): (Baer et al., 2024)

$$D = \frac{k_B \cdot T}{\xi} \tag{5}$$

Where $k_B$ is Boltzmann constant and friction coefficient, $\xi = b \cdot \pi \cdot \mu \cdot R_p$. Here, b - is particlesolvent interface function, b = 4 for a perfect slip and b = 6 for a perfect stick boundary condition. $\mu$ is dynamic viscosity and $R_p$ is particle radius. Thus, temperature rise result in higher diffusivity which means higher thermal conductivity of the nanofluid.

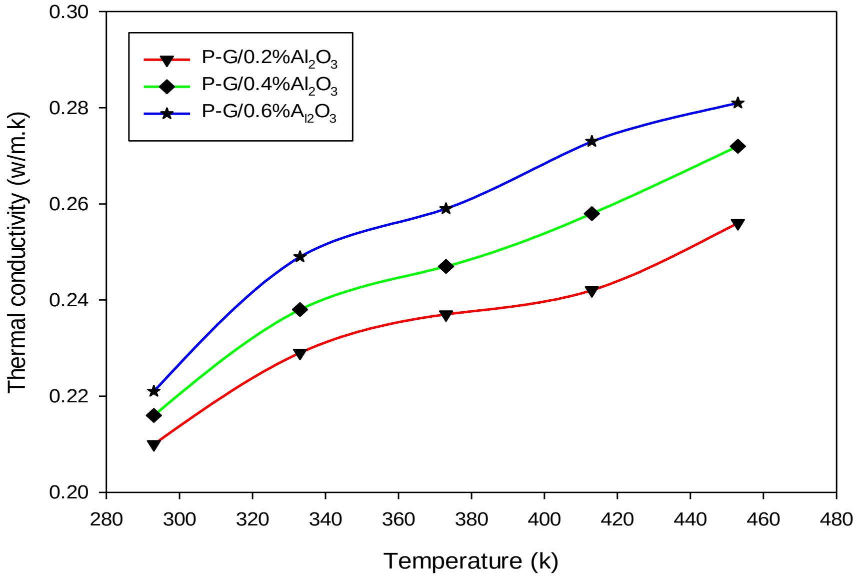



**Fig. (7-a). Relationship between temperature and thermal conductivity of propylene glycol with different concentrations of Al2O3 at (1day)**

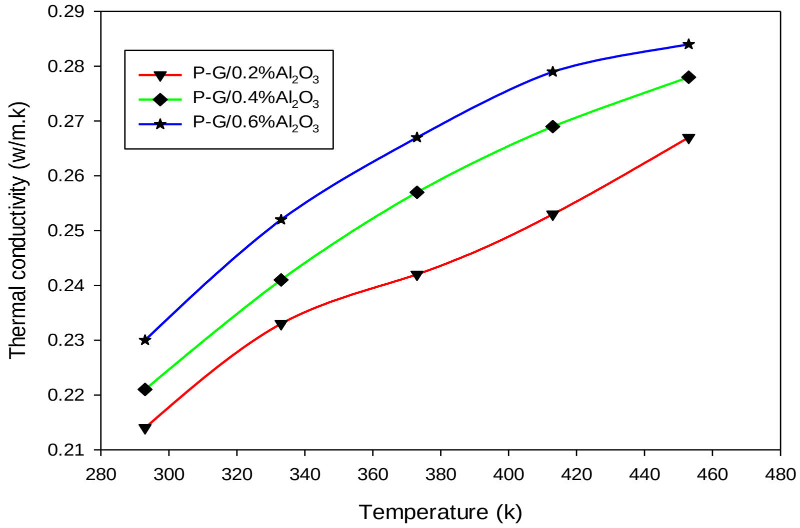



**Fig. (7-b). Relationship between temperature and thermal conductivity of propylene glycol with different concentrations of $Al_2O_3$ at (15 day)**

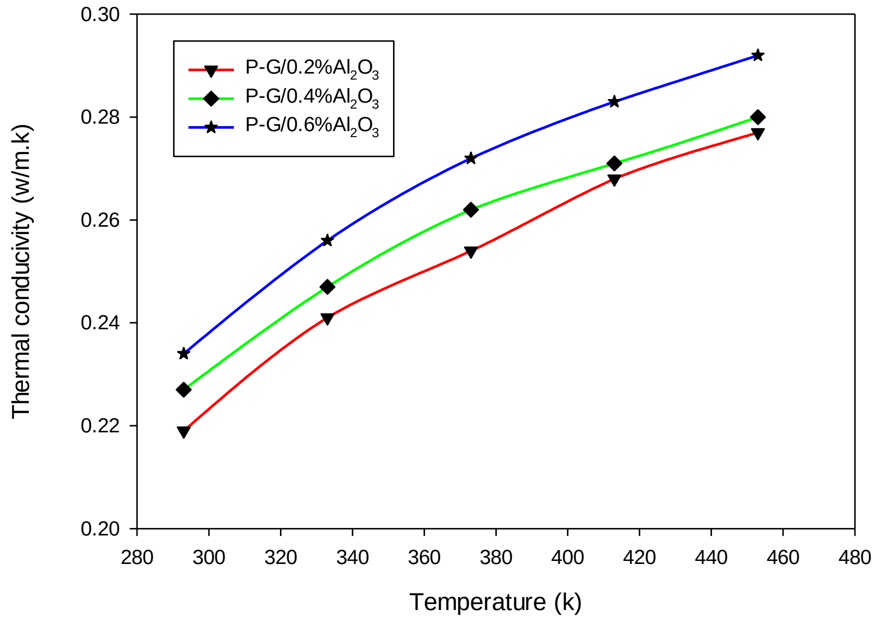



**Fig. (7-c). Relationship between temperature and thermal conductivity of propylene glycol with different concentrations of $Al_2O_3$ at (30 day)**

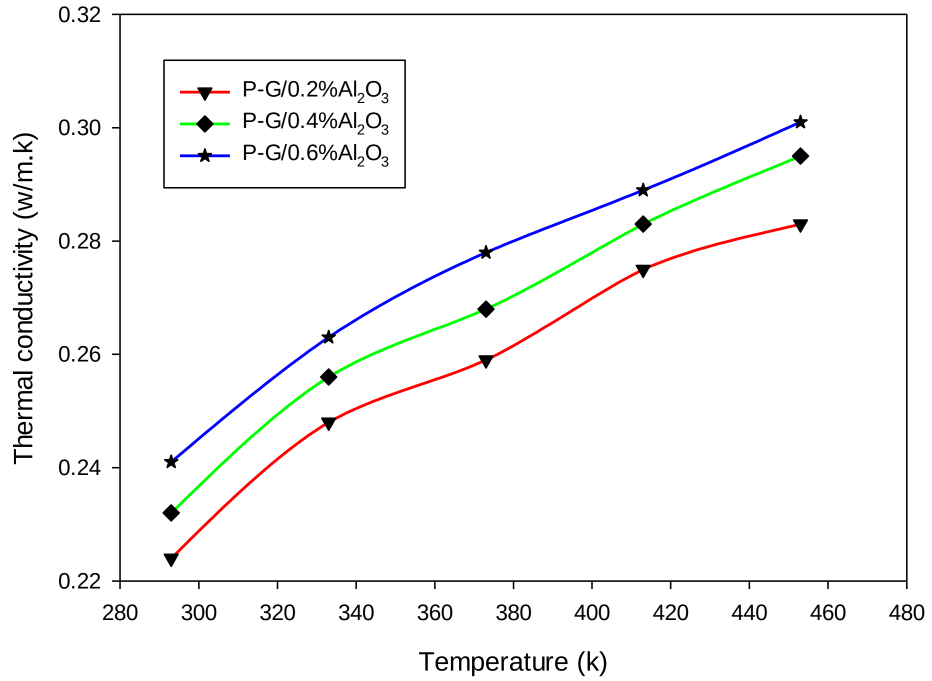



**Fig. (7-d). Relationship between temperature and thermal conductivity of propylene glycol with different concentrations of $Al_2O_3$ at (45 day)**

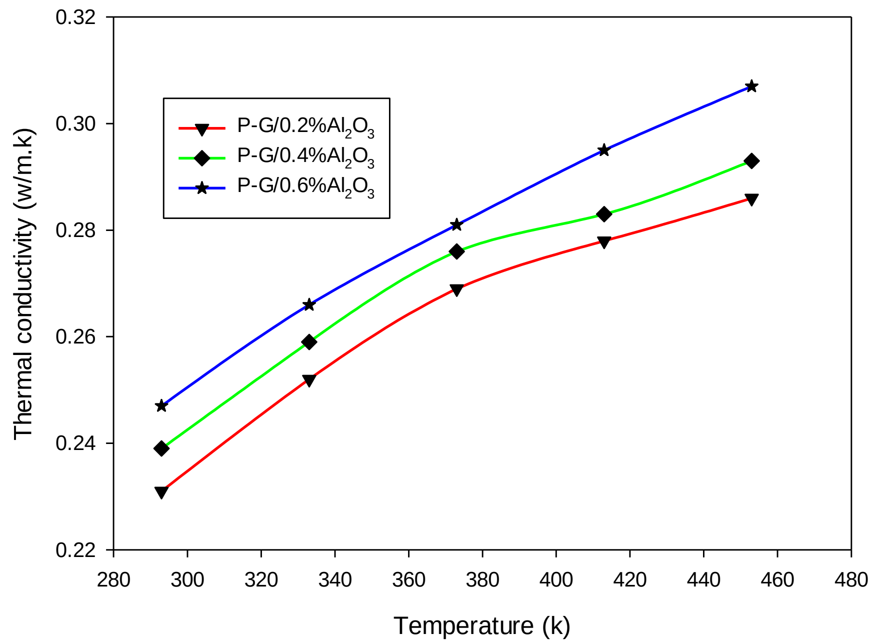



**Fig. (7-e). Relationship between temperature and thermal conductivity of propylene glycol with different concentrations of $Al_2O_3$ at (60 day)**

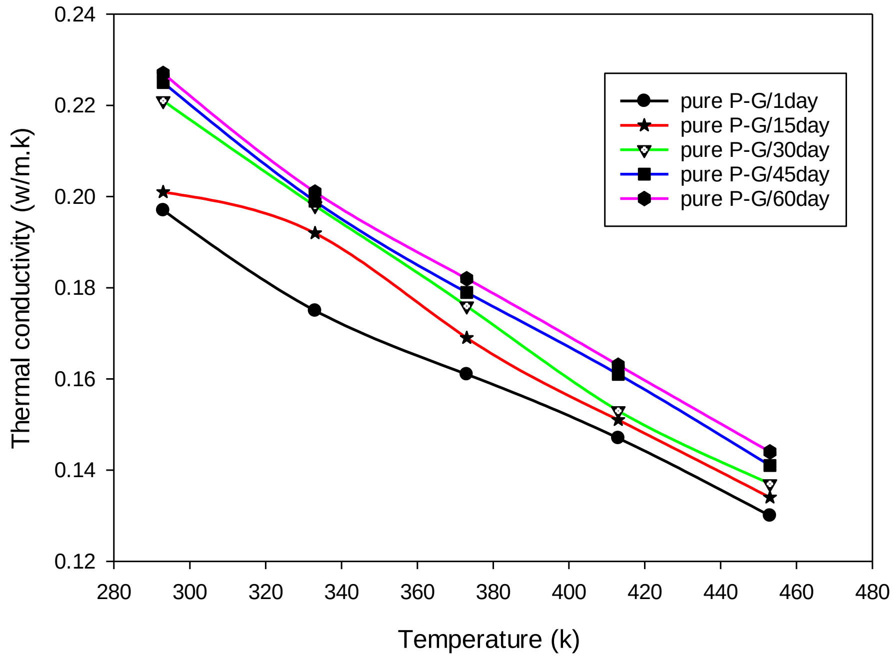



**Fig. (7-f). The relationship between temperature and thermal conductivity of pure propylene glycol liquid at different time periods**

### 3.2. viscosity (μ)

Fig.8 shows the relationship between dynamic viscosity (μ) and temperatures. Three nanofluid concentrations prepared with different weight ratios of aluminum oxide nanoparticles with molecular size of alumina (50 - 90 nm) in a propylene glycol solution. It was observed that the viscosity of PG nanofluid increases with the increase of nanoparticles concentration and decreases as temperature increases. The pure liquid viscously, on the other hand, has the same response to temperature, it decreases when temperature increases. Yet the decrease in viscosity of the pure PG was slightly higher than that of PG nanofluid with respect to temperature. The highest recorded value of viscosity was (64 centipoise) at a temperature of (20°C) for PG-nanofluid at concentration of (0.6%) on the day (60) after the nanofluid preparation process. While, the lowest recorded viscosity in these groups of experiments was (13.2 centipoise) at (180°C) for pure PG on the first day tests.

On day (60) testes, the viscosity was on the highest value among most of other days' tests. For example, at (20°C) temperature the viscosity of pure PG was (58 centipoise) while it was (64 centipoise) for 0.6% nano PG fluid. Moreover, at the highest temperature (180°C), the viscosity for pure liquid was (14.9 centipoise) which is lower by (74.31%) than that at (20°C). Regarding 0.6% concentration nanofluid the viscosity was (21 centipoise) which is lower by (67.19%) than at (20°C). Here, the lower nanofluid viscosity, the lower pumping power needed for nanofluid circulation in the solar thermal systems, for instance.

The behaviour of PG nanofluid dynamic viscosity in different concentrations and different temperatures has almost the same response to concentration and temperature for ethylene glycol based nanofluid (Barkhordar et al 2022., and Asmaa et al., 2020).

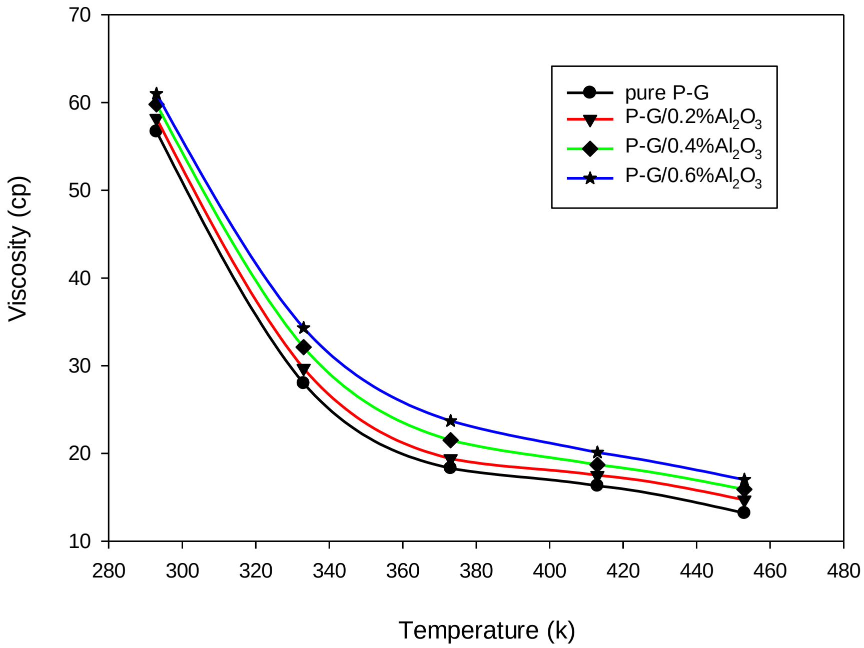



**Fig. (8-a). Relationship between temperature and viscosity of propylene glycol with different concentrations of $Al_2O_3$ at (1 day)**

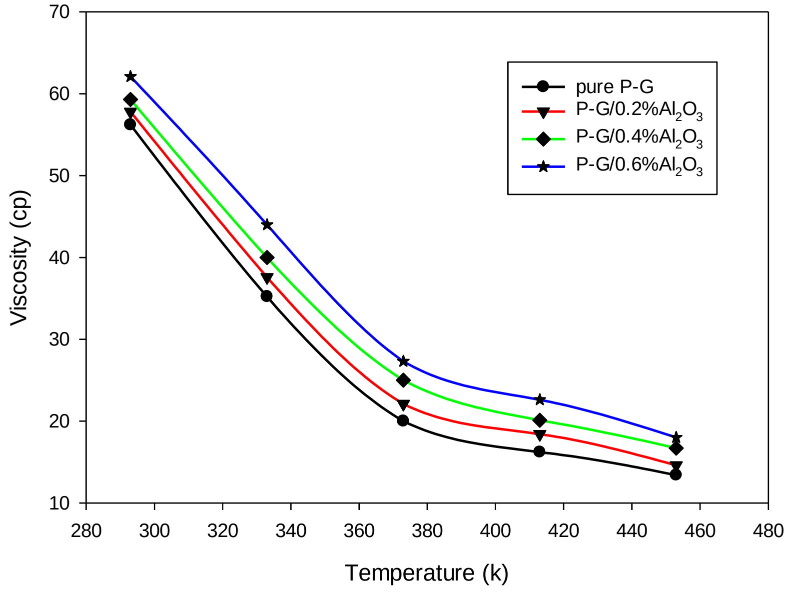



**Fig. (8- b). Relationship between temperature and viscosity of propylene glycol with different concentrations of $Al_2O_3$ at (15 day)**

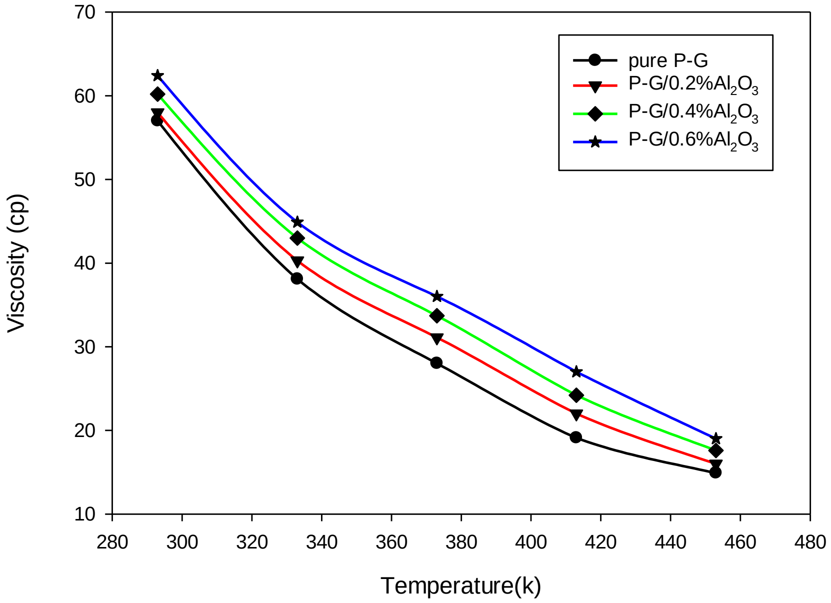



**Fig. (8 - c). Relationship between temperature and viscosity of propylene glycol with different concentrations of $Al_2O_3$ at (30 day)**

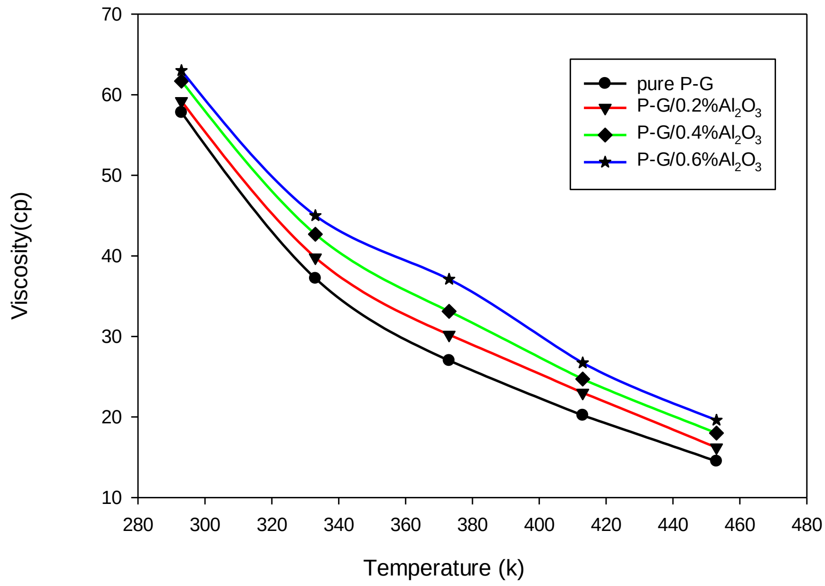



**Fig. (8 -d). Relationship between temperature and viscosity of propylene glycol with different concentrations of $Al_2O_3$ at (45 day)**

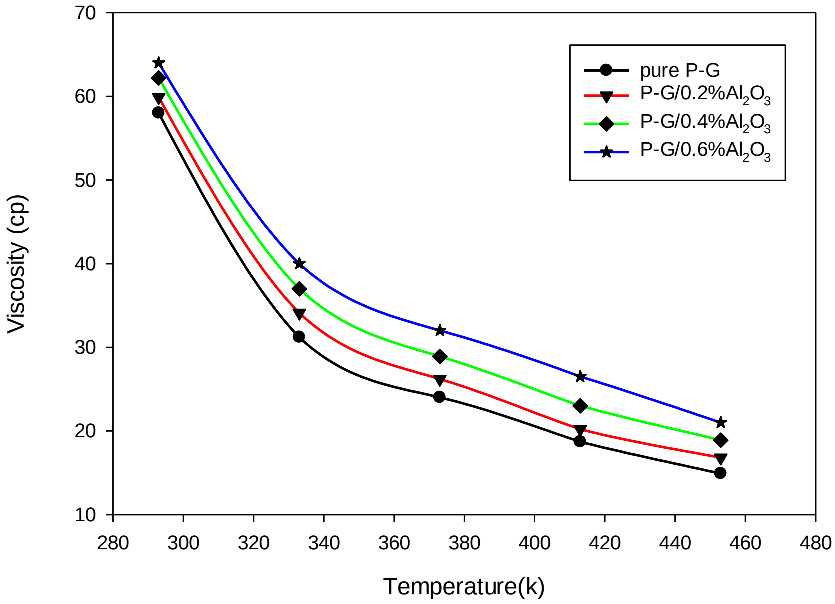



**Fig. (8-e). Relationship between temperature and viscosity of propylene glycol with different concentrations of $Al_2O_3$ at (60 day)**

## 3.3. Specific Heat

Fig.9 shows the relationship between the three alumina concentrations in a propylene glycol solution and the specific heat capacity of two models of theoretical equations. The results showed a decrease in the specific heat with increasing concentration. Quantifying the specific heat of aqueous nanofluids containing aluminum oxide at different levels of volumetric concentration. The highest concentration of the liquid was associated with a decrease in its specific heat. This behavior is similar to the results of the specific heat that appeared in Fig.9.

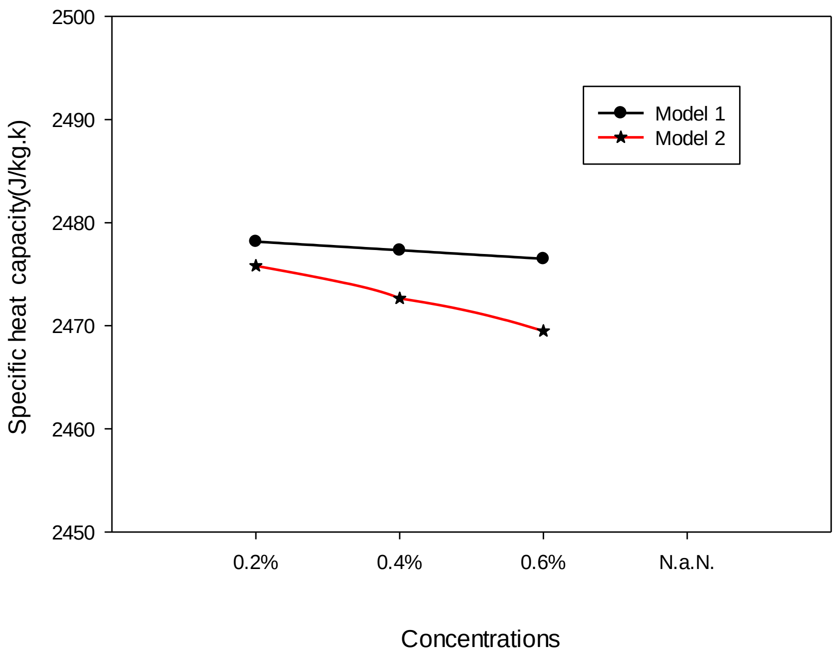



**Fig. 9. The relationship between the concentration of alumina in propylene glycol solution and the specific heat capacity**

## 4. CONCLUSIONS

The properties of propylene glycol-based nanofluids were measured in a temperature range from 20°C to 180°C using laboratory tests. This study used alumina particles with molecular size ranging from 50 to 90 nm, and at different concentrations of 0.2%, 0.4%, and 0.6 wt%. The results showed that with regard to pure liquid, as the temperature increases, the thermal conductivity decreases and the viscosity decreases for all days of the experiment. The lowest value of thermal conductivity and viscosity was recorded in the first day test at 180°C with (k=0.13 W/m.K and μ=13.2 centipois). However, the addition of nanoparticles reversed the effect of temperature on the thermal conductivity of the resulting nanofluids. Where k reached its maximum value (0.307 W/mK) at 180 °C for the nanofluid at a concentration of 0.6% per day (60), recording an improvement of (136.14%). In contrast, the viscosity continued to decrease with increasing temperature for each concentration of nanoparticles. However, the nanoparticle concentration is directly proportional to the dynamic viscosity at constant temperature. In this competition, on test day (60), the viscosities at 20 °C for both pure PG and 0.6% nano-PG were 58 and 64 centipoise, respectively. While at 180 degrees Celsius, μ = 14.9

and 21 centipoise, respectively, which shows a decrease in viscosity by (74.31%) for the pure liquid, while the viscosity of the nanofluid with a concentration of 0.6% decreases by (67.19%). Finally, the SEM images showed the homogeneity and distribution of the nanofluid at a concentration of 0.4%, and some aggregates were detected at a concentration of 0.6%. We can conclude that their use in high temperature settings will benefit their use in refrigeration systems and can be applied in industrial applications to improve industrial energy efficiency.

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