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Experimental investigation of the effects of temperature and nanoparticles volume fraction on the viscosity of Newtonian hybrid nanofluid

Ashkan Afshari[1], Mohammad Eftekhari Yazdi[1]*

1-Department of Mechanical Engineering, Tehran Markazi Branch, Islamic Azad University, Tehran, Iran

**Corresponding Author: moh.eftekhari_yazdi@iauctb.ac.ir*

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Abstract

In this paper, an experimental study has been conducted on the rheological behavior of Water (80%) and Ethylene-glycol (20%) in presence of Al_2O_3-MWCNTs hybrid nanomaterials. For this purpose, nanofluid samples were prepared by suspending the nanomaterials in a mixture of water and EG with solid volume fractions of 0.0625%, 0.125%, 0.25% and 0.5% Viscosity measurements were performed at various shear rates and in the temperatures range of 25 to 50^{0}C. Experimental data showed that all hybrid nanofluid samples had Newtonian behavior. also Results showed that nanofluid viscosity decreased with increasing temperature and augmented with increasing the volume fraction. Eventually, a new accurate correlation was developed to assist the calculation of the viscosity of the Al_2O_3-MWCNTs/water-EG at different temperatures and volume fractions.

Keywords: Viscosity, Newtonian behavior, Hybrid Nanofluids, Aluminum oxide, Multi-walled carbon nanotubes.

1- Introduction

Nanofluids are colloids made of nanoparticles suspended in a base fluid. During the past decade, many researches are mostly focused on thermal conductivity of nanofluids. However, nanofluid's viscosity is as important as thermal conductivity in thermal application involving fluid flow.

Namburu et al. [1] studied viscosity of copper oxide nanoparticles dispersed in Ethylene-glycol and Water mixture. They developed an experimental correlation based on the data, and related viscosity with particle volume percent and the nanofluid temperature.

Afrand et al. [2] examined the effects of Fe3O4–Ag hybrid nanoparticles on the rheological behavior of ethylene glycol. They measured the viscosity at different shear rates under temperatures ranging from 25°C to 50°C. Their results demonstrated that the nanofluid samples with solid volume fractions of less than 0.3% had Newtonian behavior, while those with higher solid volume fractions (0.6% and 1.2%) had non-Newtonian behavior.

Baratpour et al. [3] examined the viscosity of ethylene glycol containing different volume fractions of single-wall carbon nanotubes (SWCNTs) at different temperatures. They measured the viscosity under different shear rates and revealed that SWCNTs/EG nanofluids had Newtonian behavior. They also reported that viscosity increased with increasing solid volume fraction and decreased with increasing temperature.

Eshgarf and Afrand [4] studied the effects of hybrid nano-additives containing COOH-functionalized multi-walled carbon nanotubes (MWCNTs) and silica (SiO2) nanoparticles on rheological behavior a mixture of 50%-50% EG and water. They measured the viscosity of the suspensions with solid volume fractions ranging from 0.0625% to 2% under various shear rates. Their results specified that adding the hybrid nano-additives to the mixture of EG and water leaded to a non-Newtonian fluid.

Hemmat Esfe [5] investigated the effects of temperature and nanoparticles volume fraction on the viscosity of Copper Oxide-Ethylene-glycol nanofluids. He found that in a given volume fraction when temperature increases, viscosity decreases, but relative viscosity varies. In this paper, the dynamics viscosity of hybrid nanofluid of multi-walled carbon nanotubes (MWCNTs) and Aluminum oxide (Al_2O_3) in a mixture of Water (80%) and Ethylene-glycol(20%) is examined experimentally. To the author's knowledge, there is no comprehensive and thorough investigation to predict the dynamics viscosity of the supposed nanofluid.

Afrand et al. [6], in another work, investigated the effects of temperature and hybrid nanoparticles concentration on the rheological behavior of EG. Hybrid nanoparticles were composed of Fe3O4 and Ag nanoparticles. They measured the viscosity of nanofluid samples at different shear rates. Their results showed that the nanofluid samples with solid volume fractions of less than 0.3% had Newtonian behavior, while those with higher solid volume fractions exhibited non-Newtonian behavior.

Moghaddam et al. [7] measured the rheological properties of grapheme/ glycerol nanofluids in a mass fraction range of 0.0025–0.02 and a shear rate ranging from 1 to 180 s^{-1}. Their results showed that the suspensions exhibited shear-thinning behavior at low shear rates. Shearthinning behavior became more noticeable with an increase in nanoparticles concentration.

2- Preparation of Nanofluid

2-1 Material Preparation and Specifications

The first stage of conducting experiments on nanofluids is to prepare the nanofluid. For more precise experiments, the nanofluid should be stable and homogeneous; that is, if the prepared nanofluid is stagnant for a while, sedimentation must not occur. In this study, two-stage method was used to prepare nanofluid. First of all, Al2O3 in a mixture of Water (80%) and Ethylene-glycol (20%), in the range 0.0625% to 0.5% was prepared by mixing dry samples of MWCNTs and Al_2O_3 nanoparticles (50:50) in a certain amount of a dual mixture of Water and Ethylene-glycol (20:80). Tables 1 and 2 show the specifications of MWCNTs and Al_2O_3 nanoparticles and the specifications of Water and Ethylene-glycol that are used in the experiments. The above nanofluid which consists of MWCNTs and Al_2O_3 nanoparticles and Water-Ethylene-glycol is injected into a 600ml beaker. The solution was then mixed with magnetic stirrer for 2 hours and eventually aggregate particles breakdown operation and complete dissolution of nanoparticles in base fluid is occurred by ultrasonic process (Hielscher, Germany) with a 400 W power and a frequency of 24 kHz for 6 hours. Dynamics viscosity of hybrid nanofluid of multi-walled carbon nanotubes (MWCNTs) and Aluminum oxide (Al_2O_3) in a mixture of Water (80%) and Ethylene-glycol (20%) are measured using the DV-I PRIME Brookfield digital viscometer which has a double-wall cylindrical container. It should be noted that in order to measure the viscosity of low-volume liquids in UL Adaptor at different temperatures and temperature adjustments, it is necessary to have a bath of Water. The temperatures used in this study are 25, 30, 35, 40, 45, 50 °C. The Water temperature was brought up to 50 °C and then the Water is pumped back and forth into the UL Adapter unit. For lower temperatures also the Water temperature in the Water bath is brought to the desired temperature. After Water temperature reached the required temperature for the test, the nanofluid is poured into the UL Adapter and the test is carried out at various temperatures by using of a Brookfield Viscometer.

Table 1- Specifications of MWCNTs and Al_2O_3 nanoparticles

	Value	
Specifications	MWCNTs	Al2O3
Purity (%)	>97	>99
Color	Black	White
Size(nm)	Outer Diameter=5-15 Inner Diameter=3-5 Length =50	20
Thermal conductivity (Wm-1K-1)	1500	30
Density (gcm-3)	2.1~	3.89
Specific surface (m2g-1)	>233	>138

Also, the required value of MWCNTs and Al_2O_3 nanoparticles in different volume fractions can be calculated using Eq. (1), where φ is volume fraction, ρ is density and m is mass.

Table 3 shows the required value of MWCNTs and Al_2O_3 nanoparticles in different volume fractions.

$$\varphi\% = \left[\frac{\left(\frac{w}{\rho}\right)_{Al_2O_3} + \left(\frac{w}{\rho}\right)_{MWCNT_s}}{\left(\frac{w}{\rho}\right)_{Al_2O_3} + \left(\frac{w}{\rho}\right)_{MWCNT_s} + \left(\frac{w}{\rho}\right)_{Water} + \left(\frac{w}{\rho}\right)_{EG}}\right] \quad (1)$$

Table 2- Specifications of Water and Ethylene-glycol

No.	Volume Fraction	Dendity (kgm^{-3})		Mass (gr)	
		Al_2O_3	MWCNT	Al_2O_3	MWCNT
1	0.5			5.83	3.15
2	0.25			2.91	1.57
3	0.125			1.45	0.78
4	00.0625			0.729	0.39

Table 3- Required value of multi-walled carbon nanotubes and aluminum oxide nanoparticles in different volume fractions

Specifications	value	
	Ethylene-glycol	Water
Molar mass	62.07	18.02
Appearance	Colorless transparent liquid	Almost colorless transparent
Smell	Smell-less	Smell-less
Density (kgm-3)	1113.20	998.21
Melting point (ºC)	-12.9	0.00
Boiling point (ºC)	197.3	100
Thermal conductivity (Wm-1K-1)	0.224 in 20 ºC	0.6 in 20 ºC
Viscosity (cP)	16.1 in 20 ºC	1 in 20 ºC

3- Investigating the rheological behavior of nanofluid

3-1 Base fluid

First, by measuring the viscosity of the base fluid in different revolutions of the viscometer according to table 4, the rheological behavior of the base fluid is evaluated at 25°C. The conversion factor of shear rate from rpm to s^{-1} for the applied spindle is equal to 1.223.

Fig. 1a shows the shear stress versus shear rate at different temperature at φ=0 and Fig. 1b shows the viscosity versus shear rate at different temperature at φ=0. Fig. 1 clearly shows that in this study, the base fluid has a Newtonian behavior. As shown in Fig. 1, no change occurred in the base fluid's rheological behavior. It can also be observed that by decreasing temperature and increasing the shear rate, the apparent viscosity is constant.

Table 4- The rheological behavior of the base fluid at 25°C

Temperature (°C)	Shear Rate		`Viscosity (cP)		Shear Stress
	Rpm	S-1	cP	poise	(dyne/cm2)
25	20	24.46	1.51	0.0151	0.3693
	30	36.69	1.51	0.0151	0.5503
	40	48.92	1.49	0.0149	0.7289
	50	61.15	1.47	0.0147	0.8989
	60	73.38	1.45	0.0145	1.0640

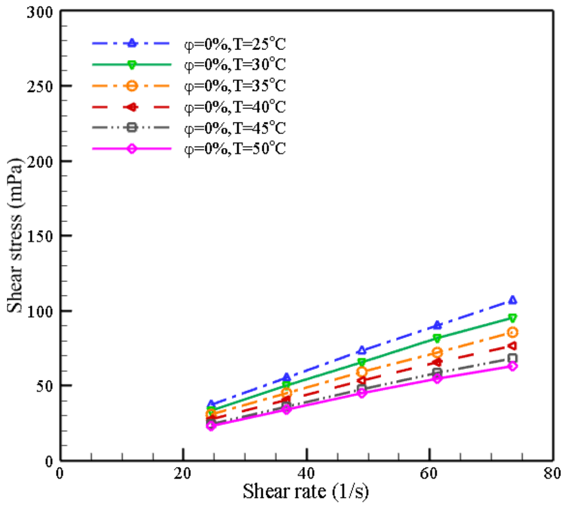

Fig. 1a Shear stress versus shear rate at different temperature at φ = 0

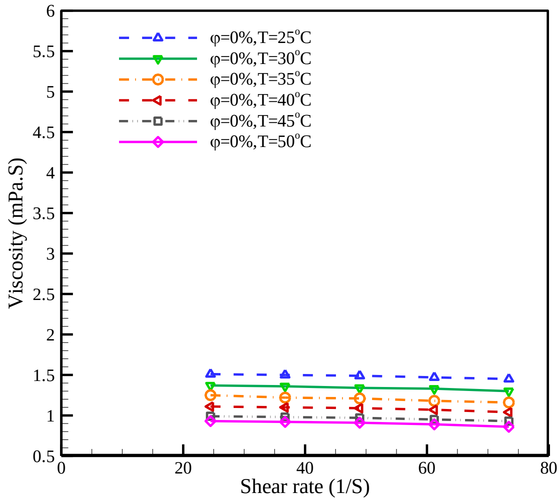

Fig. 1b viscosity versus shear rate at different temperature at φ = 0

3-2 The nanofluid sample with φ=0.0625% to φ=0. 5%

By measuring the nanofluid viscosity in different revolutions according to table 5 at 45 °C, the rheological behavior of the nanofluid is evaluated. Fig. 2a shows the shear stress versus shear rate at different temperature at φ=0.125% and φ=0. 5% and Fig. 2b shows the viscosity versus shear rate at different temperature at φ=0.125% and φ=0. 5%. Fig. 2 clearly shows that in this study, nanofluid has a Newtonian behavior. As can be seen in Fig. 2, by adding a small amount of solid nanoparticles to the base fluid, the fluid's rheological behavior was not changed. It can also be seen that by decreasing temperature and increasing the shear rate, the apparent viscosity is constant.

Table 5- the value of nanofluid viscosity in different revolutions of viscometer and corresponding shear stress at 45 °C and φ=0. 5%

Temp. (°C)	Concen. (%)	Shear Rate		Viscosity (cP)		Shear Stress
		Rpm	S-1	cP	poise	(dyne/cm2)
45	0.5	20	24.46	1.87	0.0187	0.45740
		30	36.69	1.85	0.0185	0.67876
		40	48.92	1.83	0.0183	0.89523
		50	61.15	1.8	0.018	1.1007
		60	73.38	1.75	0.0175	1.28415

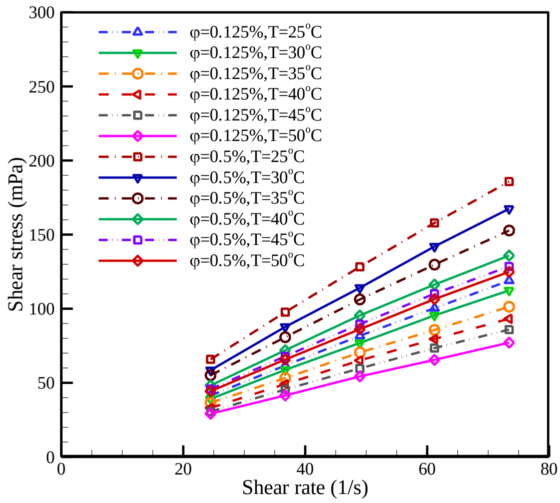

Fig. 2a Shear stress versus shear rate at different temperature at φ=0.125% and φ=0. 5%

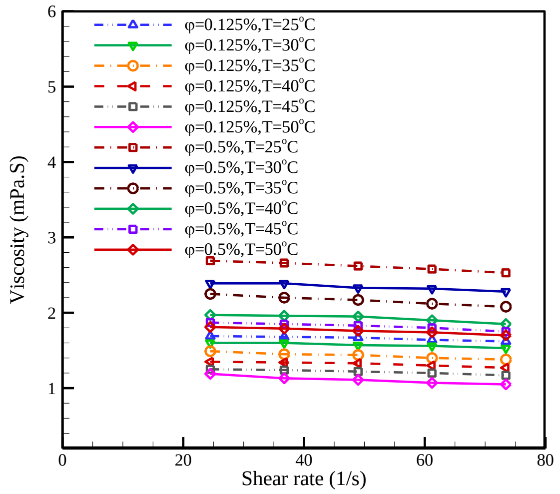

Fig. 2b viscosity versus shear rate at different temperature at φ=0.125% and φ=0. 5%

3-3 Effect of volume fraction

Fig. 3 shows the effect of volume fraction on dynamic viscosity at different temperatures. As can be seen in Fig. 3, According to this figure, dynamic viscosity of fluid increases with increasing the volume fraction; whereas, the diagram shows that the dynamic viscosity decreases with increasing temperature.

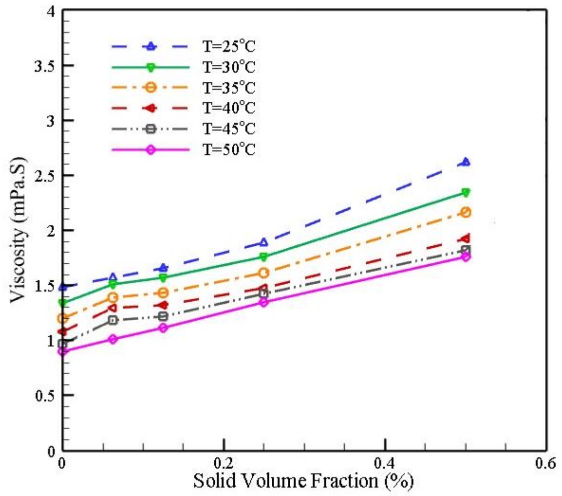

Figure 3. Effect of volume fraction on dynamic viscosity at different temperatures

Reasons for justifying this phenomenon are as follows:

1. Brownian motion: This random motion of nanoparticles in base fluid is one of the factors affecting the viscosity. This random motion occurs due to continuous collisions between nanoparticles and base fluid molecules.

2. When nanoparticles are added to base fluid, these nanomaterials are dispersed in base fluid and symmetrical and larger nano-clusters are formed due to van der Waals force between the nanoparticles and base fluid. These nano-clusters inhibit the movement of Ethylene-glycol on one another, resulting in an increase in viscosity.

3. Since nanostructures have a super-high surface-to-volume ratio, qualities such as density are changed due to being nano, and floating forces and weight loose their importance due to their ultra-small size and super-low mass, and superficial and inter-molecular forces play an important role.

4. The presence of nanomaterials in the base fluid causes an increase in intermolecular forces that increase viscosity.

3-4 Effect of temperature

Fig. 4 shows the effect of temperature on dynamic viscosity in different volume fractions.

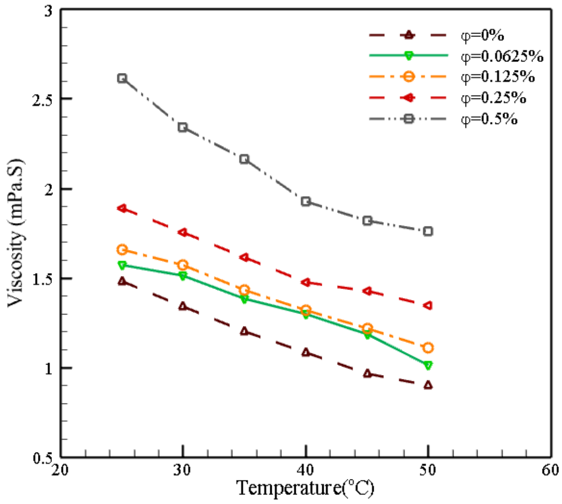

Fig. 4. Effect of temperature on dynamic viscosity in different volume fractions

As shown in Fig. 4, by comparing the changes in viscosity with changing the temperature in different volume fractions, it can be observed that the nanofluid viscosity decreases with increasing the temperature in a constant volume fraction.

Some reasons for justifying this phenomenon are as follows:

1. Viscosity is a property caused by intermolecular cohesive forces in liquids which changes with temperature change. Liquids' viscosity reduces with increasing the temperature. Molecules of liquids are under the influence of more energy at higher temperatures and can overcome the intermolecular cohesive forces. As a result, energetic molecules move more easily. Reduction of intermolecular forces due to an increase in temperature reduces the resistance to flow. As a result, Newtonian nanofluid viscosity decreases with increasing temperature.

2. The effect of the nanoparticle's Brownian motion with increasing temperature on nanofluid viscosity is also justifiable.

3. As the temperature increases, the intermolecular distance between nanoparticles and base fluid increased, resulting in reduced flow resistance and viscosity.

3-5 Suggested relation

By fitting the diagram curve in SigmaPlot 12.3, relations with the coefficients for each temperature (6 temperatures in the experiment range) were extracted. In these equations, φ is the volume fraction of the nanoparticles to the base fluid, μ_{bf} is the viscosity of the base fluid, μ_{nf} is the nanofluid viscosity, and μ_r is the relative viscosity (the ratio of nanofluid viscosity to fluid viscosity).

The equation of relative viscosity at a temperature of 25°C-50°C:

$$\mu_r = \frac{\mu_{nf}}{\mu_{bf}} = y0 + (a \times \emptyset^{b}) + (\emptyset^{a})^5 \tag{4}$$

Table 6- the Coefficients of relative viscosity at a temperature of 25°C-50°C:

Temperature (°C)	Coefficients		
	$y0$	a	b
25	1.0560	8.5662	3.0971
30	1.1262	9.0211	3.3657
35	1.1699	8.8939	3.4919
40	1.2245	9.1468	3.8255
45	1.2913	9.3580	3.8180
50	1.3038	9.5283	4.2613

3-6 Margin of deviation

The margin of deviation between laboratory results and extracted experimental equations can be obtained using following equation:

The Rsqr value of each mathematical equation is close to 0.997, which is satisfactory for equations obtained from curve fitting operation Fig. 5. This figure also shows the computed margin of deviation between laboratory results and experimental equations in different volume fractions and temperatures. According to the figure, the margin of deviation is equal to 8%.

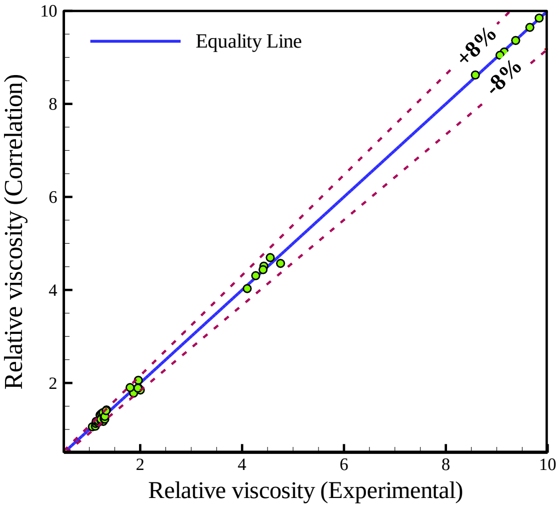

Figure 5. Margin of deviation for all data

4- Conclusion

In this paper, experimental investigation of the effects of volume concentration and temperature on dynamic viscosity of the hybrid nanofluid of multi-walled carbon nanotubes and aluminum oxide in a mixture of Water (80%) and Ethylene-glycol (20%) has been presented. The nanofluid was prepared with solid volume fractions of 0.0625%, 0.125%, 0.25% and 0.5% and experiments were performed in the temperature range of 25 to 50^{0}C. Following results were deduced:

- The nanofluid viscosity decreases with increasing the temperature in a constant volume fraction
- Dynamic viscosity of fluid increases with increasing the volume fraction.
- For φ=0.0625%, 0.125%, 0.25% and 0.5% nanofluid showed a Newtonian behavior

5- References

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