Iranian Journal of Chemical Engineering
Vol. 15, No. 3 (Summer 2018), IAChE

Research note

An Experimental Investigation of the Effect of Acid Treatment of MWCNTs on the Viscosity of Water-Based Nanofluids and Statistical Analysis of Viscosity in Prepared Nanofluids

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ARTICLE INFO

Article history:
Received: 2017-07-03
Accepted: 2018-04-23

Keywords:
MWCNT,
Functionalized,
Viscosity,
Nanofluid,
Statistical Analysis

ABSTRACT

The effect of temperatures (25, 40, 55, and 70 °C) and weight fraction of MWCNTs (0.125, 0.25, and 0.5 % wt) on the viscosity of nanofluids containing pristine and functionalized MWCNTs is investigated. For this purpose, all of the measurements were carried out in triplicate and were analyzed using the two-factor completely randomized design, and comparison of data means is carried out with Duncan's multiple range tests. The level of statistical significance was determined at 95 %. The experimental and statistical results showed that the viscosity of the both nanofluids increased with respect to the weight fraction and the decreasing temperature. Statistical analysis of viscosity shows that temperature, weight fraction, and interaction effect have significant influence on the viscosity of nanofluids containing pristine and functionalized MWCNTs (α=0.05). Meanwhile, the results show that there is a significant difference at different levels of temperature on the viscosity of the both nanofluids.

1. Introduction

In recent years, Multi-Walled Carbon Nanotubes (MWCNs) with excellent thermal conductivity capacity and high aspect ratio are widely used to prepare the nanofluids. Duo to the hydrophobic nature of MWCNTs and existence of strong Van der Waals forces between tubes, their dispersibility in the conventional heat transfer nanofluids, such as water, is very low. Therefore, the application of raw MWCNTs restricts the thermal properties of nanofluids [1]. The key idea for dispersibility improvement of pristine MWCNTs is surface modification of MWCNTs. The chemical procedure of surface modification can be divided into the application of different surfactants and acid treatment of MWCNTs using single or mixture of acids [2]. The treatment of MWCNTs in acids leads to the functionalization of outer surface of MWCNTs with oxygen containing groups and improvement of dispersion and heat transfer performance [3]. In addition to heat transfer performance, the viscosity of heat transfer nanofluids is an important parameter in required power of nanofluids pumping [4]. The viscosity of nanofluids can be explained

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as the internal fluid resistance with respect to the flow [4, 5]. Therefore, the addition of nanoparticles, such as MWCNTs, can increase the internal fluid resistance and viscosity of nanofluids. There are several factors including type of nanoparticles, particle volume fraction, type of base fluid, temperature and pH that can affect the thermophysical properties of nanofluids, such as thermal conductivity and viscosity [4-6].

The experimental results reported by Garg et al. [2] showed that the dispersing energy and ultra-sonication time have significant effect on the viscosity of nanofluids containing MWCNTs. Meanwhile, their results demonstrated that the studied nanofluids followed the power law viscosity model.

Bobbo et al. [7] investigated the viscosity and rheological behavior of nanofluids including spherical nanoparticles, such as TiO_2, and non-spherical nanoparticles, such as Single Wall Carbon Nanohorn (SWCNH). They reported that both nanofluids exhibit the Newtonian behavior.

The influences of the mass fraction and temperatures in glycol-based nanofluids on the rheological behavior of CNTs nanofluids were investigated by Meng et al. [8]. According to the obtained results, they reported that the viscosity of nanofluids containing 0.5 % wt of CNTs was the same as that of base fluid at room temperature.

Lu et al. [9] studied the viscosity of nanofluids containing CNTs as a function of concentration. They observed that the studied nanofluids exhibited shear-thinning behavior.

The effect of temperature ranging from 2 to 10 ℃ and shearing time on the rheological behavior of water-based nanofluids containing CNT was investigated by Aladag et al. [5]. They reported that prepared nanofluids exhibit the Newtonian behavior only at high shearing time.

Abbasi et al. [4] investigated the rheological behavior of water-based nanofluids containing pristine MWCNTs and oxidized MWCNTs as a function of temperature and concentration. Their experimental results revealed that all of studied nanofluids depict the shear thinning or pseudo plastic behavior.

Until now, the effects of different parameters such as particle volume concentration, temperature and shear rate on the viscosity and rheological behavior of different base nanofluids have been studied by many researchers in previous studies[5, 10]. However, the statistical analysis and response surface of the water-based nanofluids containing MWCNTs have never been investigated elsewhere. Therefore, the main objective of this study is to find that which parameters (temperature, weight fraction and combined effect of them) have the significant effect on the viscosity of studied nanofluids. Meanwhile, the influence of different levels of investigated parameters will be reported.

2. Experimental Analysis

In this study, MWCNTs with average diameter of 40-60 nm and lengths ranging from 5 to 15 micrometers were used as pristine MWCNTs. The functionalization of MWCNTs with oxygen containing groups such as –COOH and –OH was performed using nitric acid, described elsewhere [11]. The formed acid carboxylic (-COOH) and hydroxyl (-OH) groups were attached to the outer surface of MWCNTs and they enhanced dispersibility of MWCNTs in polar solution such as water [12]. The TEM image of oxidized MWCNTs proposed in our previous work [13] revealed that treatment of

MWCNTs in acid nitric acid led to the opening of the end of MWCNTs. The viscosity measurements of nanofluids as a function of temperature and weight fraction were carried out in the range of 25 to 70 °C and 0.125-0.5 % wt, respectively, using a bob and cup rheometer (Malvern Instruments, UK).

The investigation of the significant effect of temperature and weight fraction on the viscosity of nanofluids containing pristine MWCNTs and functionalized MWCNTs was carried out using Mstac (Ver 1.42) according to a two-factor completely randomized design and Duncan's multiple range test. For the aquracy of the results, the reported viscosity is the average of three measurements and data are subjected to analysis of variance (ANOVA). The level of statistical significance was determined at 95 %. The analysis effect of several variables and combination effect of them were obtained by response surface methodology (RSM) using Minitab Release software (Ver 11.12).

3. Results and discussion

3.1. Viscosity behavior of nanofluids

The effect of temperature on the viscosity of pristine and functionalized MWCNTs at different weight fractions in the varying range of 0.125 % wt to 0.5 % wt are demonstrated in Figs. 1 and 2, respectively. It is clear that the viscosity of all studied nanofluids decreases with increasing the temperature and decreasing the weight fraction. The effect of weight fraction on the viscosity of MWCNTs nanofluids can be related to the ability of MWCNTs to the agglomeration at the high concentration. Therefore, by increasing the MWCNTs' weight fraction, viscosity of nanofluids increases. This is in agreement with results of previous investigations [2].

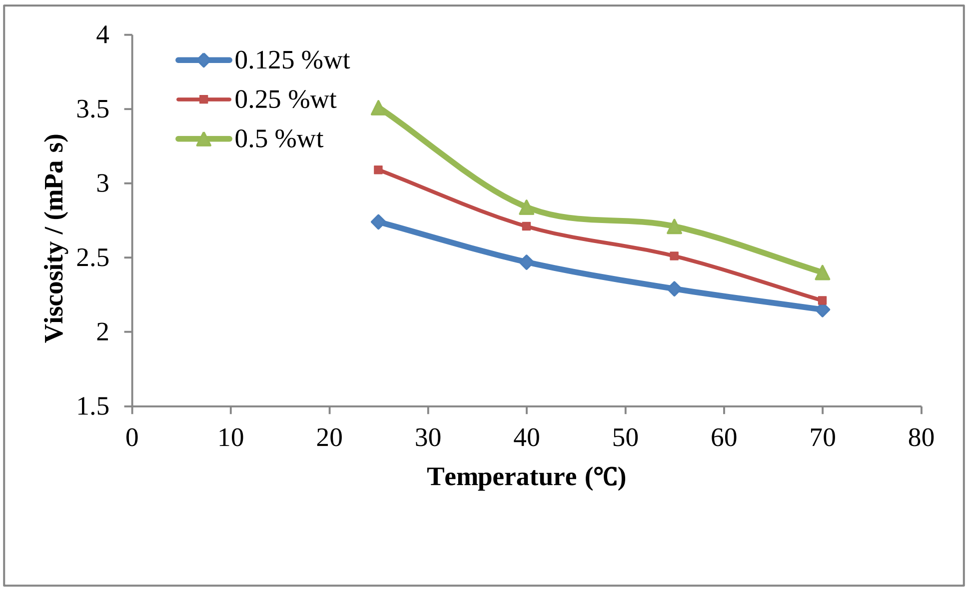

Figure 1. Variation of viscosity of pristine MWCNT nanofluids with temperature.

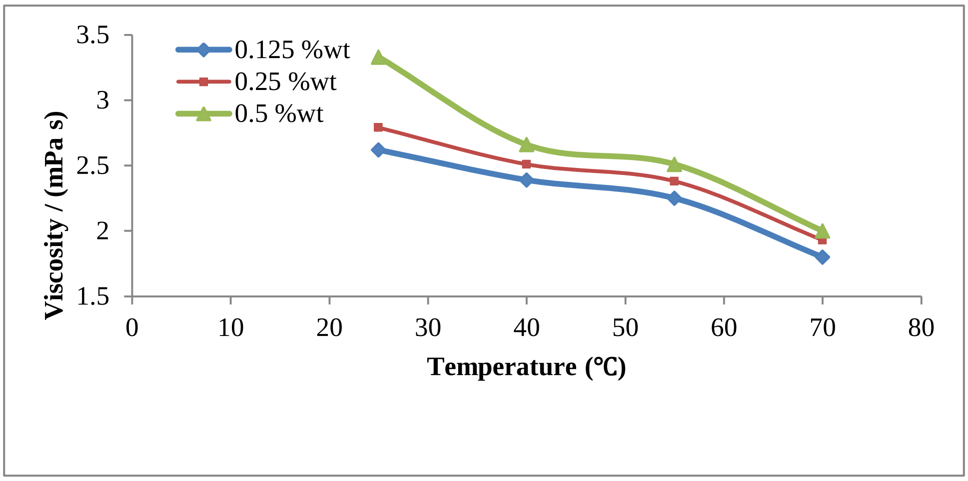

Figure 2. Variation of viscosity of functionalized MWCNT nanofluids with temperature.

A comparison of the viscosity of nanofluids containing pristine and functionalized MWCNTs at weight fraction of 0.5 % wt is shown in Fig. 3. It can be observed that, by increasing the temperature from 25 to 70 °C at 0.5 % wt, the reduction percentage of viscosity in pristine and functionalized MWCNTs nanofluids is equal to 31.5 % and 40 %, respectively. In addition, it can be deducted from this Figure that the treatment of pristine MWCNTs in nitric acid leads to the reduction of viscosity (the same results were observed for all investigating weight fractions, yet data are not shown). It can be attributed to the influence of acid treatment on the structure and lenght of MWCNTs. According to the our previous works [11, 12], duo to the destruction of hexagonal electrophilic of MWCNTs, the length of MWCNTs reduced, thus leading to the cutting and fragmentation of MWCNTs and reduction of MWCNTs bundling and viscosity of nanofluid containing functionalized MWCNTs rather than that of pristine MWCNTs.

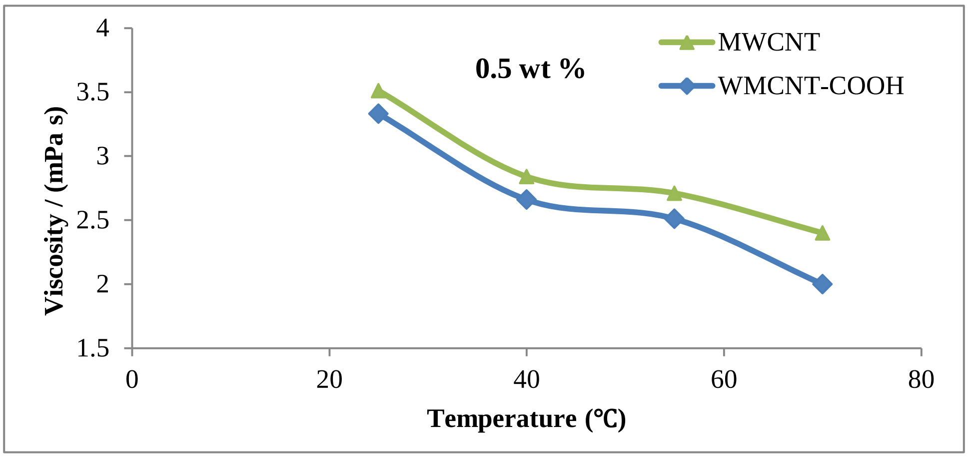

Figure 3. Comparison of the viscosity of pristine and functionalized MWCNTs at 0. 5 % wt.

3.2. Analysis of Variance (ANOVA)

The analysis of variance tables of nanofluids containing pristine and functionalized MWCNTs are shown in Tables 1 and 2, respectively. It is clear that, in both nanofluids, all the variables such as temperature, weight fraction, and combined effect of them have significant influence on the viscosity of studied nanofluids. It should be mentioned that the significant effect of all variables is at 5 % level of probability.

Table 1.
Analysis variance of viscosity of pristine MWCNT nanofluids.

Source	Degrees of freedom	Sum of squares	Mean square	F value	Prob
Temperature	3	3.425	1.142	207.1835	0.0000*
Weight fraction	2	1.054	0.527	95.6588	0.0000*
Temperature and weight fraction	6	0.243	0.04	7.3402	0.0002*
Error	24	0.132	0.006	----	----
Total	35	4.855	----	----	----

*: Significant at 5 % level of probability.

Table 2.
Analysis variance of viscosity of functionalized MWCNT nanofluids.

Source	Degrees of freedom	Sum of squares	Mean square	F value	Prob
Temperature	3	3.842	1.281	88.2803	0.0000*
Weight fraction	2	0.560	0.280	19.2941	0.0000*
Temperature and weight fraction	6	0.505	0.084	3.8053	0.0008*
Error	24	0.348	0.015	----	----
Total	35	5.256	----	----	----

*: Significant at 5 % level of probability.

3.3. Effect of temperature on the viscosity of nanofluids

Fig. 4 demonstrates the effect of temperature on the viscosity of pristine MWCNTs nanofluids. According to this Figure, it can be inferred that there is a significant difference at different levels of temperature on the viscosity of nanofluid. Meanwhile, the obtained results show that the viscosity of nanofluids containing pristine MWCNTs decreases by increasing the temperature, corroborated by previous researches [5, 14]. The viscosity of nanofluid at the temperature of 25 °C and 70 °C is equal to 3.102 mPa s and 2.253 mPa s. Therefore, it can be deducted that the reduction of viscosity in the varying range of 25 °C to 30 °C is equal to 27.36 %.

The effect of temperature on the viscosity of nanofluids containing functionalized MWCNTs is depicted in Fig. 5. According to the Duncan’s multiple range test at 5 % level of probability, it is clear that there is significant difference among the four temperature levels. The maximum and minimum viscosities of nanofluid are attributed to the temperature of 25 °C and 70 °C, respectively. Therefore, it can be observed that the augmentation of temperature from 25 °C to 70 °C leads to the reduction of viscosity equal to 31.5 %.

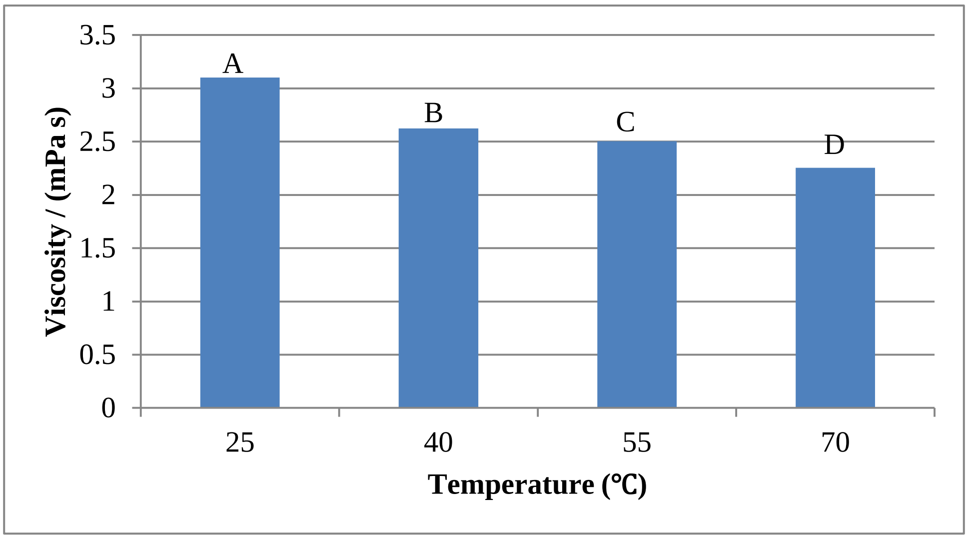

Figure 4. Effect of temperature on viscosity of pristine MWCNT nanofluid; Means with different letters are significantly different based on Duncan's multiple range test (α=0.05).

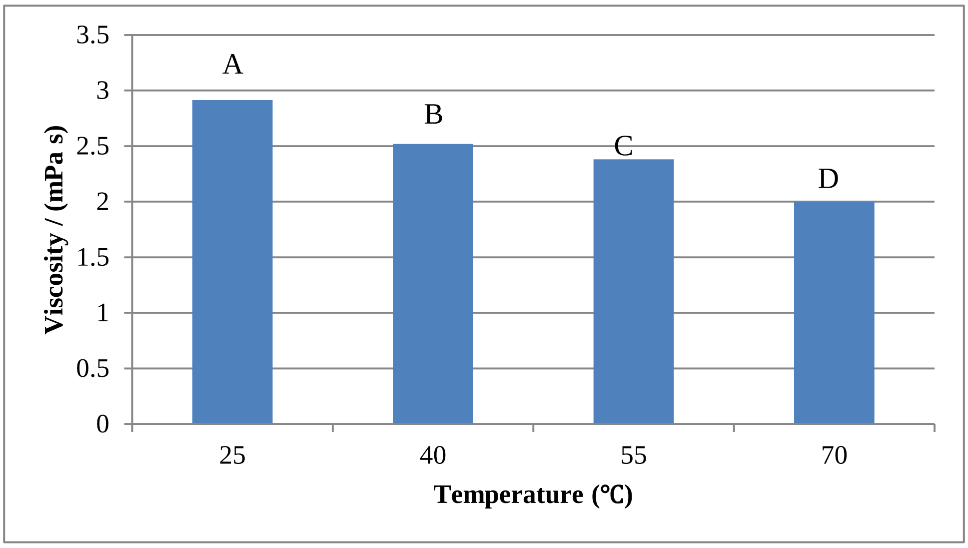

Figure 5. Effect of temperature on viscosity of functionalized MWCNT nanofluid; Means with different letters are significantly different based on Duncan's multiple range test (α=0.05).

3.4. Effect of weight fraction on the viscosity of nanofluids

The effect of weight fraction on the viscosity of nanofluids containing pristine MWCNTs is depicted in Fig. 6. The results of statistical analysis of viscosity using Duncan's multiple range tests at the statistical level of 5 % shows that there is a completely significant difference among the three levels of weight fraction. In addition, the results show that the viscosity of nanofluid increases with respect to the weight fraction. It can be attributed to the incensement of bundling and agglomeration of MWCNTs at the high level of weight fraction [4]. Minimum viscosity is related to the weight fraction of 0.125 % wt, which is 17.48 % less than that at weight fraction of 0.5 % wt.

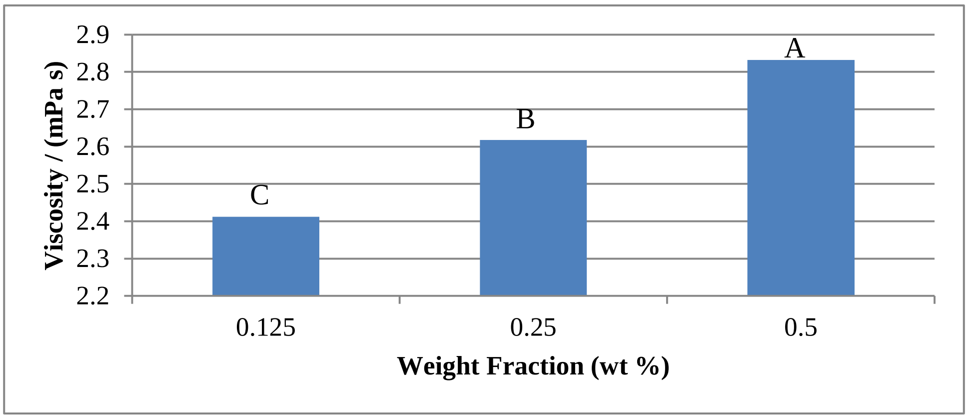

Figure 6. Effect of weight fraction on viscosity of pristine MWCNT nanofluid; Means with different letters are significantly different based on Duncan's multiple range test (α=0.05).

The influence of weight fraction on the viscosity of nanofluids containing functionalized MWCNTs is shown in Fig. 7. It can be seen that, at statistical level of 5 %, there is not a significant difference among level 1 (0.125 % wt) and level 2 (0.25 % wt) of weight fraction. However, between level 2 (0.25 % wt) and level 3 (0.5 % wt) of weight fraction, there is a significant difference with respect to the aspect of viscosity of nanofluids containing functionalized MWCNTs. The enhancement of viscosity in nanofluids containing functionalized MWCNTs with respect to the weight fraction is 12.56 %. A comparison of the enhancement of the viscosity of pristine and functionalized MWCNTs nanofluid with concentration revealed that the increasing of viscosity of nanofluid containing pristine MWCNTs with weight fraction (17.41 %) is higher than that of nanofluid containing functionalized MWCNTs (12.56 %), which is consistent with the results obtained by Abbasi et al. [4].

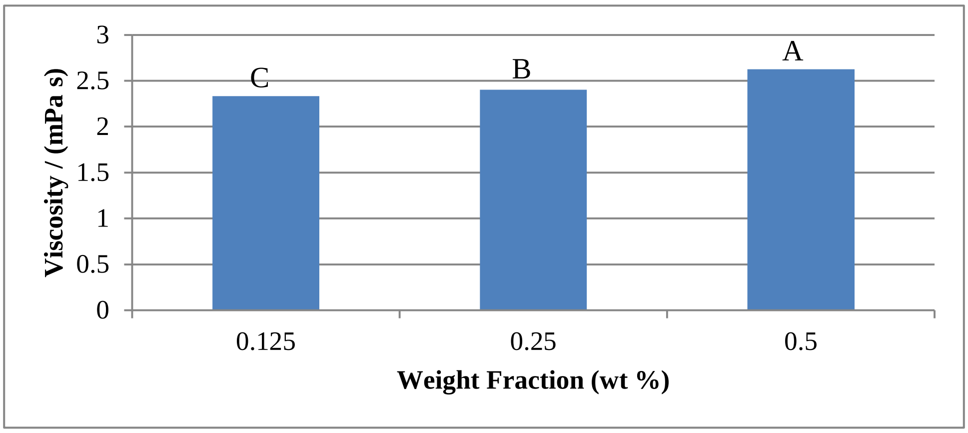

Figure 7. Effect of weight fraction on viscosity of functionalized MWCNT nanofluid; Means with different letters are significantly different based on Duncan's multiple range test (α=0.05).

3.5. Effect of temperature and weight fraction on the response surface of viscosity

The interaction effects of temperature and weight fraction on the viscosity of pristine and functionalized MWCNT are depicted in Fig. 8 and Fig. 9, respectively. It can be seen from these figures that the viscosity of both nanofluids increases upon increasing weight fraction of pristine and functionalized MWCNTs. The augmentation of viscosity with respect to the weight fraction can be related to two effects. First, according to the previous work, it is clear that the viscosity of all suspensions is higher than that of the base fluid. Meanwhile, the viscosity of nanofuids increases with respect to the weight fraction [15]. Secondly, MWCNTs have excellent surface area and surface activity. Therefore, it can be led to the agglomeration of MWCNTs and enhancement of viscosity [16]. In addition, it can be deducted from Fig. 8 and Fig. 9 that the viscosity of both nanofluids decreases by increasing the temperature. It can be attributed to the influence of temperature on the destruction of water molecules. The augmentation of temperature leads to the weakness of the hydrogen bond of water, enhancement of free water molecules, and reduction of viscosity [1, 17].

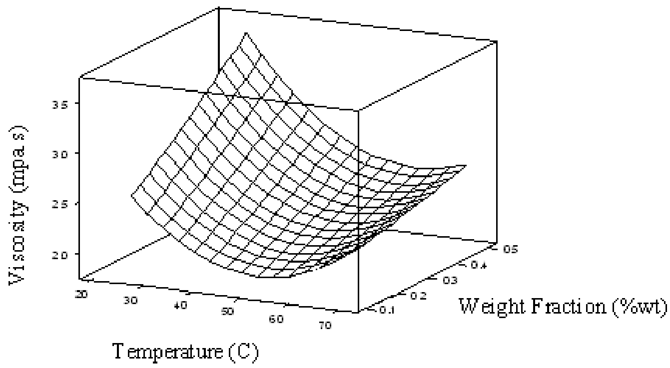

Figure 8. The effect of temperature and weight fraction on the response surface of viscosity of pristine MWCNT nanofluid.

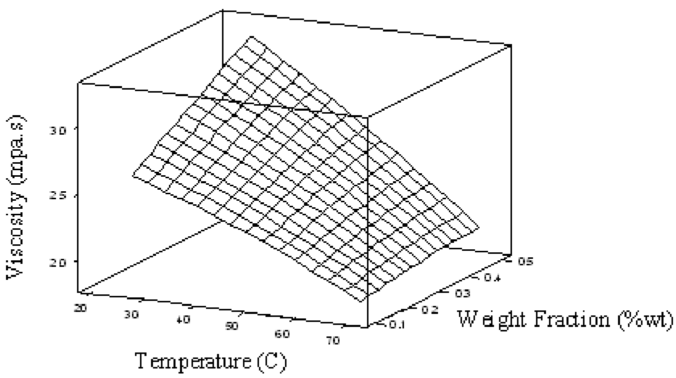

Figure 9. The effect of temperature and weight fraction on the response surface of viscosity of functionalized MWCNT nanofluid.

4. Conclusions

This study investigated the viscosity of nanofluids containing pristine and functionalized MWCNTs as a function of temperature and weight fraction. The results showed that, at 5 % level of probability, temperature, weight fraction, and combined effect of them had significant effect on viscosity of both nanofluids. Meanwhile, the results revealed that by reducing temperature and increasing the weight fraction, the viscosity of all tested nanofluid increases. The comparison of the viscosity of nanofluids containing pristine and functionalized MWCNTs shows that the viscosity of functionalized MWCNTs nnofluid is lower than that of pristine MWCNTs nanofluids.

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