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# A systematic study of rheological properties of water-ironoxide nanofluids with graphene nanoflakes

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**Abstract.** Magnetic properties are the concentrated studies in iron oxide based magnetic nanofluid area; however very limited number studies have been conducted on the psychical properties of this nanofluid. The main objective of this study is to investigate the viscosity properties of Maghemite: MH (iron oxide) nanoparticles dispersed de-ionized water (DW) nanofluids (DW-MH) for the addition of graphene (Gr) nanoflakes. DW-MH nanofluids were prepared by two steps technique and graphene was added with the aid of sonication and stirring process. Viscosity were measured for every samples varied for the loading of graphene in DW-MH nanofluids. Every measurement was conducted in rising temperature varied within 20 - 60 °C. Effect of both of loading of graphene and rising temperature on the viscosity properties of the fluid were systemically analysed. Prepared nanofluids were kept stabile about 30 days without any visible sedimentations. After the addition of graphene in the DW-MH nanofluids the viscosity of the final nanofluid samples was increased with the increasing loading of graphene nanoflakes. It was also detected that, hybrid nanofluids sample's viscosity was decreasing for the increasing temperature. This nanofluid can be the viable replacement for the heat transfer purpose in the energy harvesting and storage applications due to the good physical stability.

**Keywords:** Graphene, Maghemite, Viscosity properties, Temperature, Loading of graphene.

## 1. Introduction

Research have been conducting for the enhancements of thermo-psychical characteristics of various heat transfer liquids. Nanoparticles (1-100 nm) suspended fluid mixture offered a wide variety of mechanical, optical, electrical and thermal properties of nanofluids. Until now various nanoparticles have been used in the nanofluids to obtain the different required properties. Different iron oxide nanoparticles, for example magnetite and maghemite have fascinated widespread attention because of their highly magnetic characteristic and possible applications in various sectors including energy



storage system. Inherently maghemite nanoparticles dispersion in water possesses better chemical stability than that of maghemite nanoparticles [1]. Alternatively, deskinments of higher enhancements in thermos-physical properties of working fluids directs to create an idea of the addition of carbon-based materials in the iron oxide nanofluids. Graphene nanoflakes are the most promising carbon-based nanoparticles, as it possesses very high thermal and electrical conductivity, ultra-high mechanical strength along with the enormously large surface area [2-3].

Rheological behaviour of the solid-liquid suspensions is being analysed since the time of Einstein (Einstein, 1906) [4]. Viscosity is the internal resistance between the vicinity layers or particles in the fluid which moves with various speeds (velocities). Controlling of fluid temperature and particle concentration are the vital factors to attain accurate viscosity measurements of nanofluids. In modern nanotechnology viscosity of the nanofluids is considered a very crucial property. Viscosity has the effect on the heat transfer coefficient of the fluids.

In the thermal engineering system fluid flow is involved, thus analysis of viscosity is very crucial [5]. Li et al., (2005) [6] found that water-based  $\text{Fe}_3\text{O}_4$  nanofluid's viscosity raised with the magnetic particle and surfactant concentrations. Ding et al., (2006) [7] detected the similar shear thinning performance of water based MWCNT dispersed nanofluids as like the spherical nanoparticle suspended nanofluids. However, the shear thinning performance of CNT nanofluids was found more radical than that of other shaped such as spherical nanoparticle dispersed nanofluids. Sundar et al., (2014) [8] perceived that the viscosity of water based MWCNT- $\text{Fe}_3\text{O}_4$  hybrid nanofluids this nanofluid increased with the increasing of concentrations and reduced with the rising temperatures. Mehrali et al., 2014 [9] investigated the rheological properties of Graphene nanoparticles dispersed nanofluids with different surface area for the variation of concentration and temperature (20 - 60 °C) of the nanofluids. It was observed that viscosity of both the final nanofluids and their base fluids was intensely reliant on the temperature where, viscosity was found to be decreasing with an increase in the temperatures.

Viscosity is less studied than the thermal properties of the nanofluids. Even though some research report has found in the analysis of rheological properties of nanofluids however, based on knowledge a systematic investigation of rheological properties of water-based Graphene nanoflakes incorporated iron oxide nanofluids with the variation of filler loading and rising temperature is missing. Thus, the main purpose of this study is to conduct a systemic investigation of rheological properties of this nanofluid. The share rate also taken into consideration the investigation of rheological properties. Application of this nanofluid in the energy storage area for the cooling purpose the viscosity properties are in crucial consideration.

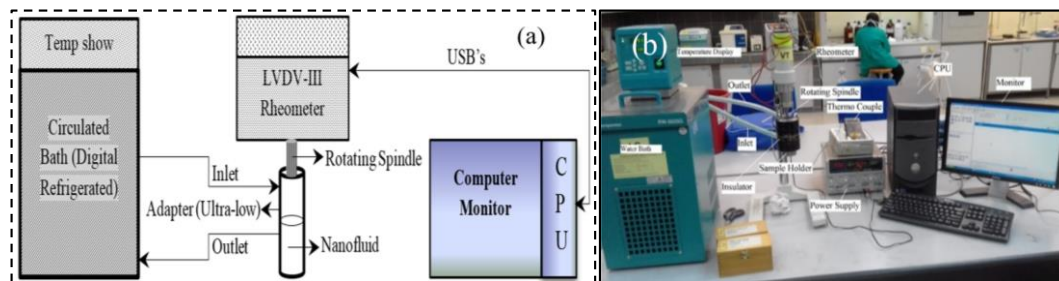
## 2. Materials and Methods

### 2.1. Preparation of Water Based Ironoxide with Graphene Nanofluids

Deionized water (DW) based Maghemite (MH) and graphene (Gr) nanoparticles dispersed nanofluids were produced by two steps solvo thermal method [10]. Firstly, as produced MH particles was synthesized by Massart's process and suspended in DW for the preparation of MH-DW suspension. Then it was stirred for about 2 hours with the aid of magnetic stirrer. Afterwards it was filtered using membrane filter with the pore size of  $\leq 0.22 \mu\text{m}$  by vacuum filtration. Secondly, Gr nanoflakes were synthesized by exfoliation process in NMP organic solvent shown in another place in Arifutzzaman et al., (2019) [11] denoted as Gr-NMP. After that Gr-NMP was loaded as filler in the base suspension MH-DW. Then the final combination was sonicated by in a bath sonicator (ultrasonic BRANSONIC cleaner) for about 15 minutes. At that time mixture was stirred for about 1hr with the aid of magnetic stirrer. A consistent and even dispersion was attained. The final nanofluid system is designated as Gr-NMP/MH-DW. In the ratio of MH nanoparticles and Gr nanoflakes concentrations in final nanofluids samples the Gr-NMP were varied 0.3, 0.45, 0.6, 0.75 and 0.9 respectively with maintaining MH amount in unity and expressed as S1, S2, S3, S4 and S5 respectively.

## 2.2. Viscosity Measurement

Viscosity of the prepared nanofluid samples were investigated using programmable Rheometer (HAAKE Viscotester 550, Thermo Fisher Scientific, USA). The SV (DIN-53019) rotor was used for these measurements. For the measurement of viscosity, the Rheometer was connected to a personal computer (PC) and for interfacing an operating software OS550 was used. Viscosity of nanofluid samples was analysed with the shear rate varied from 10 to 500  $\text{s}^{-1}$ . Every run of the experiment of a sample was conducted by changing the temperature at 25, 40, 50 and 60  $^{\circ}\text{C}$ . Every data was taken five times for the accuracy purpose and average values were taken for the analysis. A modern programmable refrigerated and heating circulator thermal bath with temperature uniformity  $\pm 0.1$   $^{\circ}\text{C}$  and accuracy  $\pm 0.05$   $^{\circ}\text{C}$  (Model RW-0525G, Lab Companion, Jeio Tech. Inc., USA) was implanted for regulating the temperature. The rheometer was calibrated with the manufacturer suggested fluid. The precision of the machine was obtained up to  $\pm 1\%$ . Figure 1a and 1b illustrates the schematic diagram and whole experimental setup in the laboratory respectively for the measurement of the viscosity of the produced nanofluids.

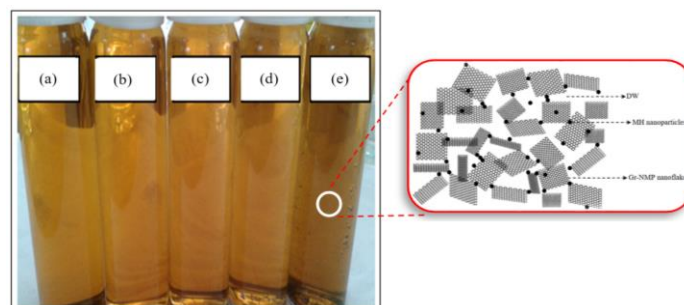


**Figure 1.** Representation of the viscosity measurements: (a) Schematic diagram of the setup and (b) experimental setup in laboratory.

## 3. Results and Discussion

### 3.1. Physical Appearance of the Prepared Nanofluids

Digital pictures in Figure 2(a-e) illustrates the physical outlooks of the as prepared Gr-NMP/MH-DW nanofluids. It is seeming that, suspended particles are prevailed quite uniformly. There is no visible sedimentation apparent in any of the samples. Inset of in the Figure 2 illustrates the schematic orientation of the MH nanoparticles and Graphene nanoflakes in the DW.



**Figure 2.** Digital photos of the as prepared Gr-NMP/MH-DW nanofluids.

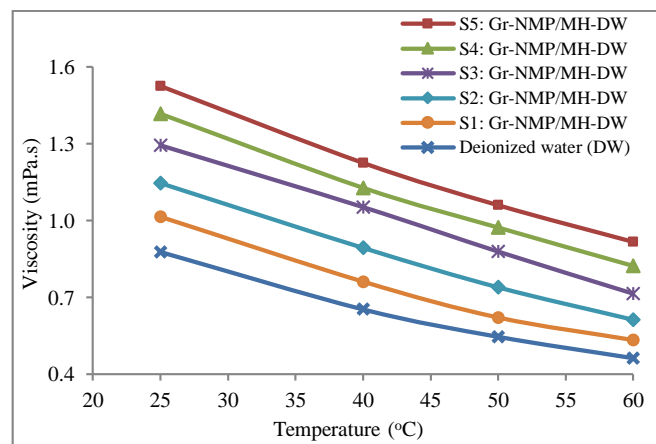
### 3.2. Viscosity Investigation

**3.2.1 Effect of Temperature on Viscosity.** The viscosity characteristic of a nanofluid is one of the most crucial properties, that tells the class of heat transfer fluid. Similar as pure liquids, the temperature is the key effective factor on the viscosity properties of nanofluids. After preparation of final Gr-NMP/MH-DW nanofluid samples, viscosity of every compositions was measured with the variation of

Gr-NMP amount in MH-DW. The viscosity of Gr-NMP/MH-DW nanofluids samples at a high shear rate of  $500\text{s}^{-1}$  in different Gr-NMP amounts in MH-DW for all tested temperatures is reported in Figure 3.

It can be perceived that viscosity increases with the increasing addition of Gr-NMP loading in MH-DW. This can be realized in such a way that once the amount of filler loading is increased, there is an opportunity increase the resistance among the layers in liquid. As nanofluid is the combination of nanoparticles and liquids, thus, there are interactions among the particles and as well as its surrounding. This subsequently directs to the rise of inner shear stress inside the nanofluid as bigger force essential for dispersion of solid particles in the suspension and thus a growth of viscosity [1]. At room temperature the viscosity of nanofluid sample S5: Gr-NMP/MH-DW is enhanced by near 74 % over the DW. Though both of base fluids and nanofluids are greatly relay on temperature. Besides it is also perceived that the viscosity of the nanofluids reduces with rising temperatures.

The effect of temperature on the viscosity is associated with the failing of the inter particle and inter molecular adhesion forces. Additionally, it could be clarified as: due to the rise of nanofluid temperature, the regular motion of molecules enhances and required time of interaction among the adjacent molecules reduces. Therefore, by the intensification of temperature, the regular inter-molecular attestations decline which, in sequence, decreases the viscosity [12]; Mehrali et al., 2014 [9]).



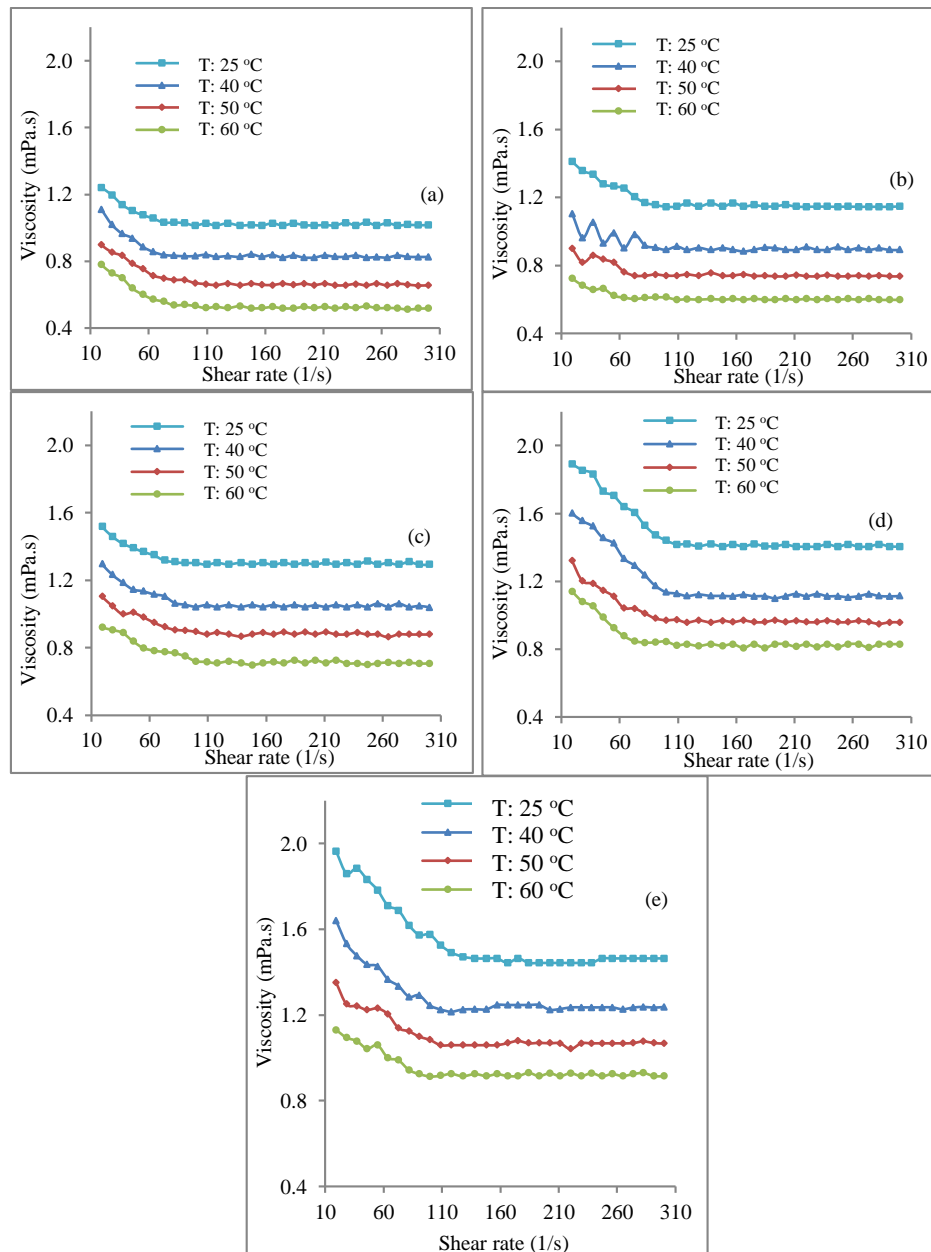
**Figure 3.** Viscosity of Gr-NMP/MH-DW nanofluids samples with the increasing temperature for the varying loading of Gr-NMP in the MH-DW.

**3.2.2 Effect of Shear Rate on Viscosity.** For the evaluation of rheological properties of produced Gr-NMP/MH-DW nanofluids, measurement of viscosity was conducted with changing shear rate in four specified temperatures separately within 25 to 60 °C range. Figure 4 illustrates the viscosity discrepancy of Gr-NMP/MH-DW nanofluid samples with the varying shear rate for four separate temperatures of varying loading of Gr-NMP in MH-DW.

It is observed that, Gr-NMP/MH-DW nanofluid's viscosity decline rapidly with the increase of shear rate within the investigated limit, which specifies the shear thinning (pseudoplastic) characteristics. This non-Newtonian shear thinning behaviour usually could be clarified as, with the lower shear rates, the rotational motion of the spindle in nanofluid and the structure of the liquid molecule deviates for the time being and steadily bring themselves into line with the way of rising shear force which created lower resistance and thus lessening of viscosity. During the sufficiently increase of share rates an optimum ordering of molecules is reached, the agglomerations are segmented into reduced size declining the frictions and henceforth viscosity as well [12].

If the share rate increases more, the viscosity of the nanofluids will not make any difference. Because of the smaller and bigger surface area of the nanoparticles, there is an opportunity for forming at lower shear rates and deformation and reorganization at higher shear rates [9]. Therefore, nanofluid also tracks the similar trends. It is seen at all the investigated temperatures that the shear thinning behaviour is more prominent at increased loading of Gr-NMP flake.

The acquired viscosity outcomes show that, the produced nanofluid samples are appropriate to apply in the resinizing temperatures. By rising the temperature of the samples, movement of molecules due to thermal influences and the Brownian motion increase and intra-molecular contacts turn out to be deteriorated. Correspondingly, rheological test on the nanofluids exposed that increasing addition of Gr-NMP filler enhances the viscosity of the nanofluids; nevertheless, other inspected parameters for example temperature have a vital impact on the viscosity characteristics of the nanofluids.



**Figure 4.** Kinematic viscosity of the prepared Gr-NMP/MH-DW nanofluids with the increasing shear rate in different temperatures: (a), (b), (c), (d) and (e) presented the nanofluids of S1, S2, S3, S4 and S5 respectively.

#### 4. Conclusion

Deionized water (DW) based graphene incorporated MH nanofluids were prepared by two steps technique. Viscosity were measured for every samples varied with the graphene loading in the DW-MH nanofluids with the increasing temperature varied within the range of 20 to 60 °C. Effect of both

loading of graphene and rising temperature on the viscosity properties of the as prepared nanofluids were systemically analysed effectively. After the addition of graphene in the DW-MH nanofluids the viscosity of the final nanofluid samples was increased with the increasing loading of graphene nanoflakes. It was also detected that, viscosity behaviour of these nanofluid samples was decreasing with the increasing temperature. This nanofluid can be the viable replacement for the heat transfer purpose in the energy harvesting and storage applications due to the good physical stability.

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