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Thermo – physical characterization of Paraffin based Fe_3O_4 nanofluids

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Abstract

In this study, the thermal conductivity and viscosity of Fe_3O_4 nanoparticles in paraffin were investigated up to a volume fraction range of 0.01 – 0.1 of nanoparticles. The nanofluid was prepared by dispersing Fe_3O_4 nanoparticles in paraffin by using ultrasonic equipment. The mean diameter of Fe_3O_4 nanoparticles was 25 nm. The thermal conductivity of nanofluids has been measured using the transient hot-wire method based KD2Pro. Viscosity of nanofluids also studied with TA instruments rheometer.

The experimental results showed that the thermal conductivity increases with an increase of particle volume fraction, and the enhancement observed to be 20 % over the base fluid for a paraffin nanofluid with 0.1 volume fraction of Fe_3O_4 nanoparticles at room temperature.

Same effect on viscosity also, the increase in viscosity with the increase of particle volume fraction was much less than predicted by the Einstein model. From this research, it seems that the increase in the nanofluid viscosity is smaller than the enhancement in the thermal conductivity.

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Keywords: Nanoparticles; Ethylene glycol; Paraffin oil; Thermal conductivity; Viscosity.

Nomenclature	
k	thermal conductivity (Wm/K)
A	radius of (m)
B	position of
C	further nomenclature continues down the page inside the text box
Greek symbols	
μ	viscosity (Pa.s)
Subscripts	
0	base fluids
eff	effective

1. Introduction

Nanofluids are liquid suspensions of particles with their dimensions smaller than 100 nm. After the revolutionary work of Choi [1], nanofluids become a new class of heat transfer fluids and nonmetallic nanoparticles increases the thermal

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conductivity of such mixtures, thus enhancing their overall energy transport capability [2].Their potential benefits and applications in many industries from electronics to transportation have attracted great interest from many researchers both experimentally and theoretically. Recent papers [3,4] provide a detailed literature review of nanofluids including synthesis, potential applications, and experimental and analytical analysis of effective thermal conductivity, effective thermal diffusivity, and convective heat transfer.

Masuda et al. [5] studied the thermophysical properties of the metallic oxide nanoparticles (Al_2O_3 and TiO_2) dispersed in water. The transient hot-wire method was used for measuring the thermal conductivity of nanofluids and reported that the thermal conductivity of nanofluids was 32% and 11% larger than the base liquid for Al_2O_3 and TiO_2 respectively.

Das et al. [6] demonstrated the thermal conductivity of Al_2O_3 and CuO nanoparticles suspended in water as a function of temperature. The thermal conductivity was measured for temperatures ranging from 21 ^{0}C to 51 ^{0}C with the temperature oscillation technique. The results showed that thermal conductivity increased with increasing nanofluids temperature as well as particle concentrations. Moreover, the results compared with the predicted value by the Hamilton–Crosser model (H–C model) [7] agreed well with the measured value at room temperature only.

Some researchers' results [8,9] showed that the thermal conductivities of nanofluids were strongly dependent on the size of the suspended particles, with the conductivities decreasing with nanoparticle sizes, contrary to this some [10,11] results showed that the larger size particles gave about twice the enhancement as compared to the lower particles size since suspensions containing small nanoparticles clusters were more effective in improving thermal conductivity than that of individual dispersed nanoparticles because the clustered nanoparticles may provide a long path for heat transfer.

Recently, [12] effect of sonication and elapsed time were demonstrated on CuO based nanofluids and thermal conductivity enhancement in water and ethylene glycol reported.

At present the thermal conductivity data measured by different researcher are scattered, and for same nanofluids, different groups reported different enhancements. For instance, Lee et al. [13] reported an increase in thermal conductivity ratio of 14% compared to pure water with 3.5 vol.% CuO particles, while Eastman et al. [14] obtained a 40% increase at the same volume fraction.

The above facts demonstrate that several factors affect the measured thermal conductivity values, such as the temperature of fluid, particle size, the settlement time after nanofluid preparation, sonication time and the stability of nanofluid. It should be noted that the stability of nanofluid is vital, because it not only affects the accuracy of measurement for the thermal conductivity of nanofluid,

In the present paper, we prepared stable nanofluids containing ferrite nanoparticles through a two-step method. The thermal transport properties including thermal conductivity and viscosity were measured. The effects of the particle volume fraction on the thermal conductivity and viscosity were further investigated in detail.

2. Experimental Section

2.1. /Chemicals and reagents

Fe_3O_4 nanoparticles used in this present study were prepared by ethylene glycol route [15]. These Fe_3O_4 nanoparticles were directly used for the synthesis of nanofluids without any further purification and Paraffin light oil manufactured by Fisher Scientific was used as the basefluid.

The nanoparticles are weighed on a Uni Bloc AUW220D (Shimadzu). The weighed nanoparticles were suspended in paraffin with various volume fractions taking the volume of the base fluid as 80ml. A ChromTech sonicator (Taiwan) with 40 kHz and 1200W with variable intensities was used to ensure that the nanoparticles were well dispersed in the paraffin. After 240 minutes of intense sonication nanofluids appeared completely homogeneous

2.2. Thermal conductivity measurement

Experimental setup for measuring thermal conductivity consists of KD2 Pro digital recorder, handheld controller and a container for nanofluids of 30 mm in diameter. The thermal conductivity of nanofluids was measured by using a KD2 Pro thermal property analyser (Decagon Devices, Inc., USA). It consists of a handheld microcontroller and sensor needles. The single-needle sensors measure thermal conductivity and resistivity; while the dual-needle sensor also measures volumetric specific heat capacity and diffusivity. For the present study, needle of length 6cm is taken which measures the thermal conductivity or the specific resistivity. All the measurements were performed at an ambient temperature of 26 °C.

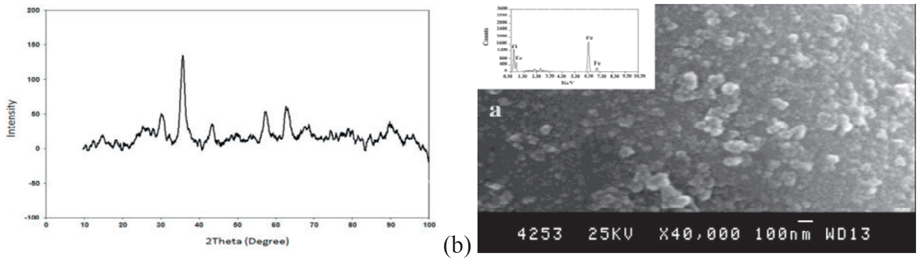
2.3. Viscosity measurement

Experimental setup for measuring viscosity and shear stress consists of Rheometer (AR-G2, TA instruments, USA). it is an advanced controlled stress, direct strain and controlled rate rheometer with a magnetic-levitation thrust bearing and a drag cup motor to allow nanotorque control. A wide range of cones and plates often called as geometry is available for use with a Peltier setup or oven. A double wall couette cell is also available to maintain adiabatic conditions. Temperature control can be achieved using a Peltier plate with upper heated plate setup (UHP), a fluid bath or an oven, allowing temperatures from -20°C to 600°C with typical ramp rates of 30°C/min and a temperature resolution of 0.02°C. The advanced drag cup motor further reduces system friction and delivers a faster transient response and an extended angular velocity control range up to 300 rad/s with a displacement resolution of 25nrad. The dynamic frequency range is between 7.5×10^{-7} and 628 rad/s. The device is controlled by the Rheology Advantage software. For the present study, geometry of 1^0 cones, with a diameter of 40mm was employed. Before the measurements, the rheometer was carefully calibrated with pure basefluid.

A constant quantity of 350µl sample was considered ideal for analysis and was placed on the Peltier plate of the instrument and the cone which goes down and covers the sample was supported and controlled by the rheometer. The rheometer records the values of shear stress and viscosity at different shear rates in the range of 0.5 s^{-1} to 250s^{-1}.

3. Results and discussion

Fig. 1(a) depicts the XRD pattern and all the peaks can be readily indexed to pure copper (JCPDS file No. 77-1545), indicating the Fe_3O_4 powder is stable crystalline in air. Fig. 1 (b) presents the TEM image of a typical sample of the Fe_3O_4 particles. It appears that the product consists of spherical particles with a narrow size distribution



(a) (b)

Fig. 1. A Physical characterization of ferrite particles (a) typical X-ray diffraction patterns of nanoparticles and (b) Selected TEM images of nanoparticles used for nanofluid.

Fig. 2 represents the thermal conductivity enhancement ratios $((k_{eff}- k_0)/k_0))$ for Fe_3O_4 nanofluids. In this article, k and k_0 represent the thermal conductivities of the nanofluid and base fluid, respectively. Nanofluids were prepared without surfactant and homogenised with sonicator for better dispersion stability. The sonication improves the stability of the nanofluids significantly, and the nanofluids show no precipitation during experimentation.

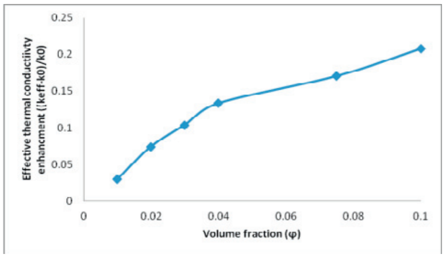


Fig. 2. Thermal conductivity enhancement of Fe_3O_4 paraffin nanofluids versus nanoparticle volume concentration at room temperatures

It is believed that viscosity is as critical as thermal conductivity in engineering systems that employ fluid flow. Pumping power is proportional to the pressure drop, which in turn is related to fluid viscosity. In laminar flow, the pressure drop is directly proportional to the viscosity [16-18]. In general, the viscosities of nanofluids are abnormally increased contrary our results.

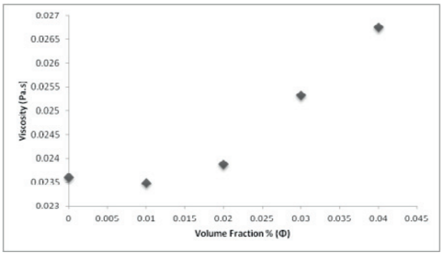


Fig. 3. Apparent viscosity of Fe_3O_4 paraffin nanofluids versus nanoparticle volume concentration at room temperatures.

Our measurements are in the volume fraction range as same as for thermal conductivity. The measured viscosities are given in Fig. 3. It is shown that the addition of nanoparticles decreases the viscosity by about 5 % compared to the corresponding value of pure paraffin. For nanofluids, the dispersed nanoparticles would reduce hindrance in the fluid flow. The decrease in the viscosity makes for an increase in the average velocity of Brownian motion of the nanoparticles.

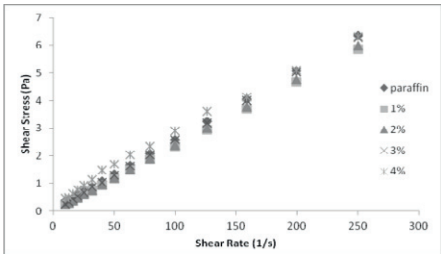


Fig. 4. Shear stress versus shear rate of Fe_3O_4 paraffin nanofluid at room temperature influence of volume concentration.

According to the statistics and analysis of Murshed, all reported results show that the viscosity of nanofluids is increased anomalously and cannot be predicted by classical models. No firm conclusion can be drawn from the above fluctuating data of several nanofluids. The facts illustrate that nanofluid is a complicated two phase system, and several important factors such as volume fraction, particle size and shapes, clustering of particles, temperature of the fluid, and the interface interaction between nanoparticles and fluid, have great effect on the viscosity.

Nanofluid behaviour is always Newtonian, as can be deduced by Figure 4, where shear stress is represented as a function of shear rate for the different volume fraction nanofluid. All isotherms are linear and converge to the origin of the diagram.

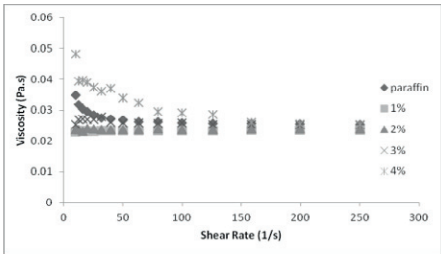


Fig. 5. Dynamic viscosity versus shear rate of Fe_3O_4 paraffin nanofluid at room temperature influence of volume concentration.

Fig. 5 reports the evolution of the effective viscosity depending of shear rate for the different volume fraction of Fe_3O_4 nanofluid. First at all, it is observed that the shear flow behaviour of Fe_3O_4 nanofluid is obtained within a large shear rate range. Figs. 5 shows that the Fe_3O_4 suspension behaves as a non-newtonian shear thinning fluid under the experimental conditions of this work, as the apparent viscosity of the Fe_3O_4 suspension decreases when the shear rate increases. As shown in Fig. 5, the shear viscosity of the Fe_3O_4 suspension mainly decreases for a shear rate lower than 30 s^{-1}. Over this shear rate value, the apparent shear viscosity tends to a Newtonian plateau.

4. Conclusion

In this paper, we have demonstrated viscosity and thermal conductivity data for paraffin based Fe_3O_4 nanofluids at low concentration. The effects due to concentration and shearing rate on the thermal conductivity and rheological properties respectively of nanofluids were investigated. Nanofluids composition showing enhancement in both thermal conductivity and viscosity, moreover percent increases in viscosity is much lower as compared to thermal conductivity. Fe_3O_4 paraffin nanofluid is showing non- Newtonian behavior in lower shear rate range and is Newtonian only for high shear rate. In this complex problem of nanofluid rheology, agglomeration phenomenon, surfactant impact, stability and shape are influencing parameter and need better understanding for the flow properties of such fluids. These will the objective of future works.

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