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Research Paper

Optimization of conditions for an enhancement of thermal conductivity and minimization of viscosity of ethylene glycol based Fe_3O_4 nanofluid

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HIGHLIGHTS

- Measurement of thermal conductivity and viscosity of Fe_3O_4/EG nanofluid.
- Experiments are undertaken for diff. concentration, temperature, sonication time.
- Parameters are optimized for minimum viscosity and maximum thermal conductivity.
- RSM is employed to evaluate linear, quadratic and interactive effects.
- Statistical models are developed for viscosity and thermal conductivity.

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ABSTRACT

Present study deals with experimental measurement of thermal conductivity and viscosity of Fe_3O_4 ethylene glycol nanofluid and multi-response optimization of conditions for maximum thermal conductivity and minimum viscosity of nanofluid. The thermal conductivity and viscosity were measured at 0.2, 0.5 and 0.8 vol% of concentration, 20, 50 and 80 °C temperature and 1, 2.5 and 4 h of ultrasonication time. Response surface methodology was employed to evaluate linear, quadratic and interactive effects of response variables. The multi response optimization yields the conditions: concentration 0.8 vol%, temperature 80 °C and ultrasonication time of 3.6 h. The optimum values of thermal conductivity and viscosity were 0.702 W/m K and 3.14 mPa s respectively and experimental values of thermal conductivity and viscosity were 0.694 W/m K and 3.10 mPa s with composite desirability (D) equal to 0.993.
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1. Introduction

Day by day increasing demand of energy across the globe is mainly supplied through limited fossil fuel, whose combustion contributes to air pollution and green house gases. To curb the disastrous and long-lasting effects of traditional fossil fuel, researchers are paying attention to alternative clean fuels and reduction in consumption of fossil fuel through increasing efficiency of existing energy systems. Nanotechnology, especially nanofluids is potential option for increasing efficiency and reducing the size of existing energy systems. In this scenario research on nanofluid progressed rapidly since its enhanced thermal conductivity was first identified several years ago [1].

Nanofluids are colloidal solution of nanoparticles dispersed in base fluids such as water, ethylene glycol, and diesel oil. Enhanced thermal conductivity of nanofluid plays important role in improving the heat transfer coefficient of heat transfer equipments. Several researchers across the globe explored the variety of nanofluids for thermal conductivity enhancement with increasing concentration of nanoparticle in base fluid. Choi et al. [2] reported 20% enhancement in thermal conductivity of Al_2O_3 nanoparticles dispersed in transformer oil at 4 vol% concentration. Maximum enhancement of 10.7% was found by Lee et al. [1,3] at 0.10 wt.% in water based copper nanofluid. Timofeeva et al. [4] studied alumina nanofluid and found increasing thermal conductivity with an increase in nanoparticle loading, in the experimental range of concentration. Sheikholeslami and Ganji [5] studied hydrothermal behaviour of Al_2O_3 and CuO in Water nanofluid analytically using Differential Transformation method (DTM). The thermal conductivity and viscosity was calculated by KKL (Koo–Kleinstreuer–Li) correlation. The Brownian motion was considered in calculation of thermal conductivity. Khedkar et al. [6] reported increase in thermal conductivity with an increase in concentration of nanoparticle in base fluid for CuO, water and monoethylene glycol based nanofluid. Sheikholeslami and Ganji [7] calculated the effective thermal conductivity and viscosity of Cuo-water nanofluid using

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KKL correlation. The results show that the heat transfer rate and Dimensionless entropy generation number increase with increase of the Rayleigh number and nanoparticle volume fraction but it decreases with increase of the Hartmann number.

Ferrofluids, nanofluids containing Fe_3O_4 nanoparticles are gaining attention of researchers due to its unique magnetic property. Philip et al. [8] reported 300% enhancement in thermal conductivity of magnetite nanofluid at 6.3 vol% particle loading. In the temperature range of 25–65 °C, Parekh and Lee [9] reported 30% increment in thermal conductivity at 4.7 vol% particle loading of Fe_3O_4-kerosene nanofluid. Temperature-dependent thermal conductivity of hydrocarbon based ferrofluids was investigated by Fertman et al. [10] in the range of 0.01–0.2% concentration and 20–80 °C temperature. At 5 vol% concentration Gavili et al. [11] reported 200% enhancement in thermal conductivity for aqueous Fe_3O_4 nanofluid. Influence of an external magnetic field on ferrofluid flow and heat transfer in a semi annulus enclosure with sinusoidal hot wall is investigated by Sheikholeslami and Ganji [12]. Effect of thermal radiation on magnetohydrodynamics nanofluid flow between two horizontal rotating plates is studied by Sheikholeslami and Ganji [13]. The significant effects of Brownian motion and thermophoresis have been included in the model of nanofluid. Ferrofluid flow and heat transfer in a semi annulus enclosure is investigated by Sheikholeslami and Ganji [14] considering thermal radiation. The enclosure has a wall with constant heat flux boundary condition. Combined effects of Ferro hydrodynamic (FHD) and magneto hydrodynamic (MHD) are considered.

Viscosity of nanofluid is an important parameter for estimating flow behaviour of nanofluid, it is equally important as thermal conductivity in thermal application involving fluid flow [15]. Chen et al. [16] reported that viscosity is strong function of temperature, nanoparticle loading and level of aggregation for TiO_2 ethylene glycol nanofluid. Kulkarni et al. [17] reported exponential decrease in viscosity of CuO, Al_2O_3 and SiO_2 ethylene glycol and water based nanofluid. Ferrouillat et al. [18] reported increase in viscosity at higher concentration for SiO_2 water based nanofluid. Nguyen et al. [19] studied Al_2O_3 aqueous based nanofluid and reported effect temperature and nanoparticle concentration on viscosity. Sundar et al. [20] investigated water based Fe_3O_4 nanofluid and found that the thermal conductivity and viscosity of the nanofluid were increased with an increase in the particle volume concentration and increase in temperature enhances thermal conductivity but decreases viscosity. Nanofluid flow and heat transfer characteristics between two horizontal parallel plates in a rotating system are investigated by Sheikholeslami and Ganji [21]. The effective thermal conductivity and viscosity of the nanofluid are calculated by KKL correlation.

Increase in nanoparticle concentration enhances thermal conductivity and viscosity of naofluid [22]. At higher concentration, nanoparticles tend to agglomerate due to its high surface energy. Due to agglomeration sedimentation of nanoparticle takes place, which adversely affects the thermal conductivity of nanofluid [23]. Increase in viscosity due to agglomeration results in high pressure drop and increase in pumping cost which in turn decreases the heat transfer rate [26,23]. To obtain uniformly dispersed nanofluid and to break up cluster formation ultrasonication treatment is applied to nanofluids. Kole and Dey [24] reported enhancement of thermal conductivity of nanofluid with an increase in sonication time and maximum value obtained at 60 h of sonication time for ZnO ethylene glycol nanofluid. Yang et al. [25] observed that viscosity of CNT oil based nanofluid kept decreasing with increasing ultrasonication time. Mahbubul et al. [26] studied alumina water nanofluid and reported that viscosity of nanofluid decreases with temperature and extension of ultrasonication treatment, at lower temperatures extended ultrasonication time was required to reach to lowest viscosity when compared with higher temperature. Thermal conductivity of nanofluid increases with increasing ultrasonication exposure.

The thermal conductivity and viscosity of nanofluid were found to be increasing with an increase in nanoparticle concentration. However, temperature and ultrasonication exposure shown negative effects on viscosity and positive effect thermal conductivity [26]. For an ideal heat transfer media, minimum viscosity and maximum thermal conductivity are fundamental requirements. The condition of maximum thermal conductivity and minimum viscosity can be meeting through multi-response optimization of independent variables.

Up to recent times, measurements of thermal conductivity and viscosity of various nanofluids and studies on factors affecting these two properties were done adequately. The effects of factors affecting viscosity and thermal conductivity such as temperature, concentration and ultrasonication time were studied independently but the interactive effect of these parameters on the thermophysical properties was rarely studied in the literature. Interactive effect plays major role in deciding the optimum parameters of the nanofluid to exhibit enhanced heat transfer coefficient. The knowledge of interactive effect may reduce the number of trials to get desired heat transfer coefficient. To establish nanofluid as commercial thermic fluid, optimization of factors affecting thermophysical properties is the best option but in literature, information about this aspect is yet not reported. Present study aims at experimental finding of viscosity and thermal conductivity of ethylene glycol based Fe_3O_4 nanofluid and to study individual as well as interactive effects of temperature, concentration of nanofluid and ultrasonication time on these properties. The development of the statistical models for viscosity and thermal conductivity of the nanofluid with close approximation with observed values within experimental range of parameters was done. Full factorial design of Response surface methodology (RSM) was employed to find individual and interactive effects of affecting factors. Multi-response optimization of temperature, concentration and ultrasonication time was carried out to find optimum condition for maximum thermal conductivity and minimum viscosity.

2. Materials and method

2.1. Nanoparticle synthesis

Fe_3O_4 nanoparticles were synthesized by ethylene glycol route [27]. 100 ml of mixed salt solution of $FeCl_2{\cdot}H_2O$ (0.15 M) and anhydrous $FeCl_3$ (0.3 M) was taken into three necked round bottom flask fitted with air condenser. 16 g of urea and 400 ml of ethylene glycol were added. The reaction mixture was mixed properly, and it was refluxed at 160 °C. Continuous magnetic stirring was done for 6 h. The colour of solution turns black and after one and half-hour and afterwards was started. The reaction mixture was cooled to room temperature. The colloidal black precipitate was centrifuged at 2000 rpm. Precipitate was washed with methanol and acetone then dried at 60 °C for 6 h in a vacuum.

2.2. Experimental

2.2.1. Viscosity and thermal conductivity measurement

In the experimental work, Fe_3O_4 nanoparticles with average size of 100 nm were used. Fig. 1 shows AFM image of Fe_3O_4 nanoparticles. Nanofluids with different volume concentration of 0.2%, 0.5% and 0.8% were dispersed in ethylene glycol. Ethylene glycol of Fisher Scientific of SQ grade was used. A ChromTech sonicator (Taiwan) with 40 kHz and 1200 W was used for ultra sonication treatment. The ultrasonic unit had maximum power output of 1.2 kW. Ultrasonic treatment was given to each sample for 1 h,

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