Experimental Investigations on Thermo Physical Properties of Al_2O_3/DMAC Nanofluid

V. Mariappan*, M. Udayakumar**, S. Suresh***, R. B. Anand**** and K.P. Shafeeq*****

Department of Mechnaical Engineering, National Institute of Technology, Tiruchirappalli-620 015, India
*vmari@nitt.edu, **muday@nitt.edu, ***ssuresh@nitt.edu, ****rbanand@nitt.edu,
*****shafeeq.dazzlar@gmail.com

ABSTRACT

Thermo physical properties of working fluids significantly affect its overall performance and compactness in vapour absorption refrigeration (VAR) system. Tetrafluoroethane (R134a) - Dimethylacetamide (DMAC) pair is one of popular working fluids in VAR system. Towards the aim of improving the performance of R134a-DMAC VAR system, this research is started to improve thermo physical properties of DMAC by adding Al_2O_3 nano particle. This paper investigate the thermo physical properties such as thermal conductivity and viscosity of Al_2O_3/DMAC nanofluid both by experimental and theoretical. It is found from the results that both thermal conductivity and viscosity of nanofluids increase with the nanoparticle volume concentration. The increase in viscosity is substantially higher than increase in the thermal conductivity.

Keywords: VAR, R134a, Al_2O_3/DMAC, thermal conductivity, viscosity

1 INTRODUCTION

Nanofluid acquired wide applications in thermal engineering such as microelectronics, energy supply, transportation and HVAC etc. Nanofluid is prepared by dispersing solid nanoparticles on the order of 1 – 50 nm in the base fluids like water, dimethyl acetamide (DMAC) and ethylene glycol which are poor heat transfer fluids. when the nanoparticles is dispersed in base fluids, the nanofluid will acquire superior properties like high thermal conductivity, minimal clogging in flow passages, long term stability and homogeneity due to the nano size and large surface area of nanoparticle. High thermal conductivity of nanofluids at low nanoparticle concentration was reported in subsequent researches of Eastman et al. [1] and Choi et al. [2]. The past researches showed that thermal conductivity of nanofluids is higher than their base fluids even when the concentrations of suspended nanoparticles are very low. Murshed et al. [3] summarized the reported results of the effective thermal conductivity of nanofluids from various research groups. Recently Choi et al. [4] reported that the thermal conductivity of the transformer oil is more than 20% at 4% volume concentration of Al_2O_3 nanoparticles while with aluminium nitride (AlN) nanoparticles thermal conductivity is enhanced by 8%.at a volume concentration of 0.5% with referance to the base fluid. Lee et al. [5] measured the effective thermal conductivity of Al_2O_3/water nanofluids with lower volume concentrations from 0.01% to 0.3% at 21°C and observed a maximum enhancement of 1.44% at a volume concentration of 0.3%. Researches are still going on to find out the exact reason for this anonymous increase in thermal conductivity. Resesarches reported that this increase is due to mechanisms like Brownian motion of nano particles and nano convection.

Like thermal conductivity, viscosity is another important thermophysical property used in designing nanofluids for heat transfer applications because pressure drop and the pumping power depends on viscosity. Only few investigations have yet reported about viscosity of nanofluids. Prasher et al. [6] reported that the viscosity of alumina-proylene glycol nano fluids was independent of shear rat, proving that the nanofluids are Newtonian in nature and increases as nanoparticle volume concentration increases. They found a 30% increase in viscosity at 3 % volume concentration and attributed this increase to aggregation of the nanoparticles in the nanofluid with the size of the individual nanoparticles. Nguyen et al. [7] found that for alumina/water nano fluids, in general dynamic viscosity increase considerably with particle volume concentration but decreases with a temperature temperature increase. Xie et al. [8] reported that the viscosity enhancement of ethylene glycol based Al_2O_3 suspensions are smaller than those of water based suspensions, showing the influence of the base fluid on the viscosity of the nanofluids. They also studied the dependence of the viscosity on pH values. When pH value is far from the isoelectric point, the nanoparticles are well dispersed because of the very large repulsive forces among the nanoparticles. The repulsion decreases when pH value is close to isoelectric point. This leads to nanoparticles aggregation and increase in viscosity. The effective viscosity of nanofluids can be calculated theoretically by many theoretical models. One of the effective theoretical model [9] was used for the calculation of viscosity by many of the researchers but this model have their own limitations. Till this time many works has been carried out on theoretical, experimental and numerical research in order to find out the thermophysical properties of nanofluids like viscosity and thermal conductivity. Though many have presented the effective viscosities and thermal conductivities for Al_2O_3 based nanofluids with basefluid as water, ethylene glycol and engine oil, no one has yet reported any work on the thermophysical property study of Al_2O_3 based nanofluids with basefluid as Dimethyl acetamide (DMAC). Hence with a motive to contribute something valuable to the nanofluid engineering, comparative investigations on thermal conductivity and viscosity of Al_2O_3/DMAC nanofluid having volume fraction up to 1.5 % was carried out and the results are opresented in this paper.

2 THEORETICAL MODELS

2.1 Thermal conductivity

The theoretical thermal conductivity values of the nanofluid was calculated using Maxwell model [10] which was the first mathematical model developed to determine the thermal conductivity of liquid – solid suspensions. It can be applied to homogeneous and low volume fractions liquid – solid suspensions. The Maxwell equation is given by

$$\frac{k_{nf}}{k} = \frac{k_s + 2k + 2\phi(\Delta k)}{k_s + 2k - \phi(\Delta k)} \qquad (1)$$

in the above equation $\Delta k = k_s - k$

where k_s, k_{nf} and k are the thermal conductivities of solid nanoparticle, nanofluid and base fluid respectively, and Φ is the volume concentration of nanoparticles. Various modifications have been carried out on the Maxwell equation. These modifications take various factors into account related to thermal conductivity like particle shape, particle Brownian motion induced nanoconvection, high volume concentration, liquid layering, interface contact resistance and particle clustering. Table. 1 shows the thermophysical properrties of DMAC and Al_2O_3 nanoparticles used in the present study.

Property	DMAC	Al_2O_3
Density (kg/ m^3)	932	3880
Specific heat (J/kgK)	2018	729
Molecular weight (kg/kmol)	87	101

Table 1. Thermo - physical properties of Dimethyl acetamide and alumina nanoparticles at 300K.

2.1 Viscosity

The theoretical dynamic viscosity values of the nanofluid were calculated using the Batchelor model [9]. Here in this model Brownian motion of the nanoparticles and the interaction between them was taken into account and it is an extension of the Einstein model. Einstein model is applied when there is no interaction between the particles and when volume concentration is limited to less than 1 %. But Batchelor model can be applied to volume concentration even greater than 5%. The Batchelor equation is given by

$$\frac{\mu_{nf}}{\mu} = 1 + \eta\phi + (\eta\phi)^2 \qquad (2)$$

where η is the intrinsic viscosity which is equal to 2.5 for hard spheres.

3 EXPERIMENTS

3.1 Preparation of Al_2O_3/DMAC nanofluids

Al_2O_3/DMAC nanofluids of required volume concentrations of 0.1% to 1.5% were prepared by dispering specified amount of Al2O3 nanoparticles in to Dimethylacetamide using an Ultrasonic bath which generates ultrasonic pulses at a frequency of 25kHz. To get a uniform dispersion of the particles in the base fluid, the mixture was sonicates for one hour(Fig.1). Fig. 2 shows the prepared nanofluids.

Fig.1 Photograph of Ultrasonic bath

Fig.2 Photograph of prepared nanofluids

3.2 Thermal conductivity measurement

Al_2O_3/DMAC nanofluids of volume concentrations up to 1.5% were used for thermal conductivity and viscosity measurements. The thermal conductivity of Al_2O_3/DMAC nanofluid was measured using a KD2 pro thermal properties analyzer (Fig.3). It consists of a handheld microcontroller and sensor needles. The KD2's sensor needle contains a heating element and a thermistor. The basic assumptions made for thermal conductivity measurements are : (1) the long heat source can be treated as an infinitely long heat source; (2) the medium is homogeneous and isotropic, and at uniform initial temperature T_o. The sensor needle can be used for measuring thermal conductivity of fluids in the range of 0.2 – 2 W/mK with an accuracy of ±5%. Each measurement cycle consists of 90 s. During the first 30 s, the instrument equilibrates which is then followed by heating and cooling of sensor needle for 30 s each. The microcontroller computes the thermal conductivity using the temperature change – time data from

$$k = \frac{q(\ln t_2 - \ln t_1)}{4\pi(\Delta T_2 - \Delta T_1)} \quad (3)$$

where q is constant heat rate applied to an infinitely long and small line source, ΔT_1 and ΔT_2 are the temperature changes at times t_1 and t_2 respectively. The calibration of the sensor needle was carried out first by measuring the thermal conductivity of distilled water, glycerine and ethylene glycol. The measured values for distilled water, glycerine and ethylene glycol were 0.611, 0.292 and 0.263 W/mK respectively which are in agreement with the literature values of 0.613. 0.285 and 0.252 W/mK respectively, within ±5% accuracy. 50 ml nanofluid samples were taken in a test tube of 3 cm diameter whose mouth is closed using a septum through which the sensor needle was inserted. For accurate measurements, the needle was inserted fully into the fluid and was oriented vertically inside the test tube without touching it's side walls.

Fig. 3 Photograph of KD2 Pro thermal property analyser

3.3 Viscosity measurement

Viscosity of the nanofluid was measured using Brookfield cone and plate viscometer equipped with a 2.4 cm 0.8° cone supplied by the Brookfield engineering laboratory of USA. The cone is connected to the spindle drive while the plate is mounted in the sample cup. Spindle used was CPE – 40 which can be used for samples in the viscosity range of 0.3 – 1028 cP. A gap of 0.013mm is maintained between the cone and the plate within which the test fluid is placed. As the spindle rotates , the viscous drag of the fluid against the spindle is measured by the deflection of the calibrated spring. A sample volume of only 0.5 - 2 ml can be used for viscosity measurement and hence the temperature equilibrium is achieved rapidly within a minute. Satisfactory results will be obtained if the applied torque is between 10% and 100% of the maximum permissible torque. So during measurements readings were neglected if the applied torque does not fall within the prescribed range. The viscometer was calibrated using distilled water, glycerine and ethylene glycol at room temperature. The measured values of their viscosities were 0.82, 10.9 and 360.5 cP respectively which are in good agreement with the literature values of 0.79, 10.7 and 352 cP respectively with ±5% accuracy.

4 RESULTS AND DISCUSSIONS

During thermal conductivity measurements, the temperature rise of the nanofluid sample observed during 30 s heating time was in the range of 0.3 – 0.4°C (0.01 - 0.0133°C/s). This ensures that the heat pulse given by the sensor needle is very small and hence, thermally driven convection currents in the sample are avoided which in turn avoids any disturbances in the sample during measurements. Thermal conductivity for each volume concentration of the nanofluid was measured for a period of about 3h after sonication at an interval of 15 minutes. Fifteen minutes time was allowed between successive measurements for the temperature of the sensor needle and sample to re-equilibrate. The average of data points that did not appreciably vary over the last 1h is reported here.

Fig. 4 shows the experimental and theoretical (Maxwell model) thermal conductivity values of Al_2O_3/DMAC nanofluids as a function of particle volume concentration. It was found that the thermal conductivity of nanofluids significantly increases almost linearly with increasing particle volume concentration. The thermal conductivity enhancements of Al_2O_3/DMAC nanofluids are 11.81%, 19.62%, 30.04% and 38.52% at 0.1%, 0.5%, 1% and 1.5% volume concentrations respectively. The relationship between the thermal conductivity and volume concentration is usually non linear for nanoparticles with a high aspect ratio (such as MCNTs, nanorod etc.), or nano particle alignment [11].

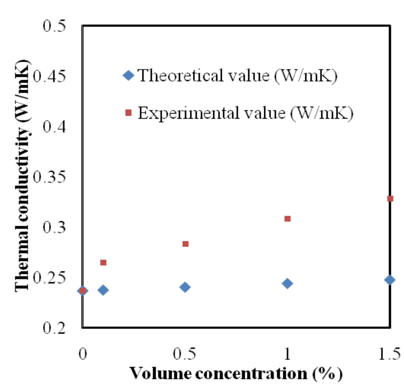

Fig.4 Variation of thermal conductivity of Al_2O_3/DMAC nanofluid with volume concentration

Slighter deviations are there between the thermal conductivity values obtained experimentally and through Maxwell equation. So the theoretical values have to be found out using a modified Maxwell equation in order to minimize the deviations between theoretical and experimental thermal conductivity values.

Fig. 5 shows the dynamic viscosity of Al_2O_3/DMAC nanofluids as a function of particle volume concentration. A maximum increase in viscosity of Al_2O_3/DMAC nanofluids is observed as 77.28% at 1.5% volume concentration. The experimental results show that the viscosity increases vigorously up to 0.1% volume concentration and there after it increases linearly with increasing volume concentration.

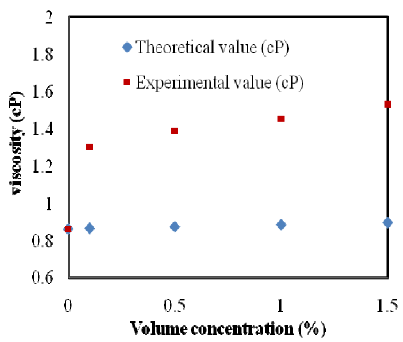

Fig.5 Variation of Dynamic viscosity of Al_2O_3/DMAC nanofluid with volume concentration

CONCLUSIONS

In this paper, we have experimentally investigated the thermal conductivity and viscosity of DMAC based nanofluids containing Al_2O_3 nanoparticles (Al_2O_3/DMAC nanofluids). Al_2O_3/DMAC nanofluids were prepared at various volume concentrations from 0.1% to 1.5% using ultrasonic bath without adding surfactants. The thermal conductivity was measured by KD2 pro thermal property analyser and viscosity was measured by Brookfield cone and plate viscometer. The measured thermal conductivity and viscosity of Al_2O_3/DMAC nanofluids are found to increase with increasing volume concentrations. The thermal conductivity and viscosity of Al_2O_3/DMAC nanofluids increase linearly with volume concentration.

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