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Influence of Base Fluid on the Thermal Conductivity of Nanofluid Suspended with Silicon Carbide Nanoparticles

Kanthimathi Tumuluri[1],

[1]Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram Green Fields Guntur Dt., Andhra Pradesh, 522302, India

Bhramara P[2]

[2]Department of Mechanical Engineering, Jawaharlal Nehru Technological University, Kukatpally, Telangana, 500085, India

Abstract.

Nanofluids are potential heat transfer fluids due to the flexibility associated with the customization of thermophysical properties. In the present paper, the effect of working fluid on the thermal Conductivity of Silicon Carbide (SiC) nanoparticle suspensions is determined experimentally at temperature of 40, 45 and 50°C. Three different working fluids, viz., Distilled Water (DW), a mixture of Ethylene glycol and Distilled water in the ratios of 20:80 and 40:60 (20:80 EG-DW and 40:60 EG-DW) are considered to prepare SiC nanofluid in the particle fraction ranging from 0.02% to 0.08% by volume. For the same particle concentrations of SiC suspensions, a significant enhancement in thermal conductivity is observed. DW based SiC nanofluid has exhibited higher thermal conductivity whereas 40:60 EG-DW based nanofluid exhibited lower thermal conductivity among the nanofluids considered. The thermal conductivity of DW based SiC nanofluid is 1.005 times that of 20:80 EG-DW and 1.17 times that of 40:60 EG-DW based SiC nanofluids 0.08% particle concentration and at temperature of 45^{0}C. The relative thermal conductivity of DW based nanofluid has exhibited a lower enhancement compared to the EG-DW based SiC nanofluid.

Keywords: nanoparticle, nanofluid, particle concentration, thermal conductivity

1. Introduction

In the past few decades, nanofluids have gained significance as the new class of working fluids with superior thermophysical as well as transport properties. Vasu et al. [12, 13]

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conducted an analytical research to develop correlations for the thermophysical properties and Nusselt number of water based Al_2O_3, Cu, CuO and TiO_2 nanofluids, Propylene glycol-water [14, 3, 5] on the heat transfer performance of different nanofluids. In order to improve the heat transfer enhancement most of the researchers have conducted study on the improvement in the design of heat exchangers [8, 10]. Huminic et al. [4] experimentally investigated the thermo-physical properties and heat transfer enhancement of Water based SiC nanofluid using a two-phase closed-loop thermosyphon for particle concentration of 0.5% and 1% by volume within the temperature range of 20°C to 50°C. Maximum heat transfer enhancement of 24.4% was reported at a 1% particle concentration by volume for the maximum temperature difference. Li et al.[6] experimentally investigated the thermo-physical properties of 40:60 EGW based SiC nanofluids in the particle concentration ranging from 0.1 to 0.5% by volume for the temperatures ranging from 10 to 50°C. Based on their experimental results a maximum of 53.81% enhancement was obtained in thermal conductivity at 0.5% particle concentration by volume and at 50°C. Nikkam et al. [7] experimentally investigated the thermophysical properties of water-based and 50:50 EGW based SiC nanofluids for weight percentage of 3%, 6% and 9% concentrations at 20°C. They reported a maximum enhancement of 15.2% and 20% in thermal conductivity and maximum enhancement of 22.7% and 14% in viscosity for SiC/Water and SiC/50:50 EGW nanofluids respectively at 9% particle concentration by weight. Results revealed that the average enhancement in the heat transfer coefficient was about 13% for SiC/50:50 EGW nanofluid when compared with 50:50 EGW base fluid. Timofeeva et al. [11] experimentally determined the effect of temperature and base fluid on the heat transfer characteristics of SiC/50:50 EGW and SiC/Water nanofluids. The experiments were carried out in the Reynolds number range of 4500 to 7500 for a particle concentration of 4% by volume for temperatures ranging from of 57°C to 71°C for different particle sizes ranging from 16nm to 90nm. Their results reported a maximum enhancement of 14.2% in the heat transfer coefficient for 90 nm SiC/50:50 EGW at 71°C whereas the enhancement of water-based SiC nanofluid is very less compared to EGW based SiC nanofluid. Azmi et al. [1] experimentally investigated the forced convection heat transfer of Al_2O_3 nanoparticles suspended in Water and Ethylene Glycol mixture in the volume ratio 60:40, 50:50, and 40:60. The particle concentration considered by them are in the range of 0.2% to 1% for operating temperatures of 30, 50 and

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70°C under the Reynolds number range of 3000 to 25000. They reported that at the higher operating temperature of 70^{0}C, the maximum heat transfer enhancement obtained was 24.6% for 60:40 W-EG based Al_2O_3 nanofluid, 24.2% for 40:60 W-EG based nanofluid and 19% for 50:50 W-EG based Al_2O_3 nanofluid. They concluded that the variation in temperature and thermophysical properties of the base mixtures greatly influence the heat transfer coefficient of nanofluids. The heat transfer characteristics of nanofluid majorly depends on the thermal conductivity and viscosity of the nanofluids.

In the present paper, the effect of base fluid on the thermal conductivity of SiC nanofluids is studied experimentally. The base fluids considered are Demineralized Water (DW), mixture of Ethylene Glycol and Distilled Water in the volume ratios of 20:80 and 40:60 (20:80 EG-DW and 40:60 EG-DW).The SiC nanoparticles are suspended in the base fluids in the fractions of 0.02%, 0.04%, 0.06% and 0.08% by volume at temperatures 40, 45 and 50°C.

2. Preparation of Nanofluids

SiC nanoparticles are procured from Nano amor Texas USA. The average particle size of the SiC nanoparticles is tested using TEM images shown in Figure 1, the size of the nanoparticles is approximately 50 nm.

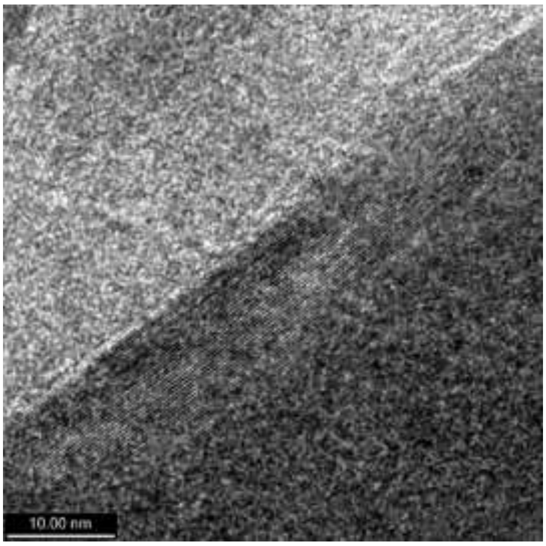

Figure 1. TEM Image of SiC nanoparticles

The SiC nanoparticles are mixed in three different base fluids viz., Distilled water, 20:80 EG-DW, and 40:60 EG-DW in the particle concentrations of 0.02%, 0.04%, 0.06% and 0.08% by volume. Surfactant is not used in the preparation of nanofluid as its presence

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affects the original properties of nanofluids. The weight of nanoparticles to be mixed in each base fluid is evaluated using Eq. (1), where ϕ is the particle concentration by volume of the nanofluid.

$$\phi = \frac{\frac{m_{np}}{\rho_{np}}}{\left(\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}\right)} \times 100 \qquad (1)$$

Stable nanofluids are prepared by two step method, the nanoparticles are suspended in the required concentration in the base fluids and are stirred continuously using Probe sonicator shown in Figure 2 for about 4 to 6 hours depending on the particle concentration.

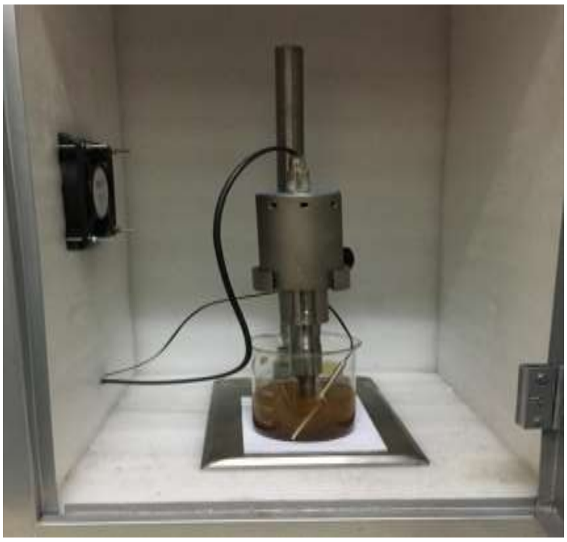

Figure 2. Probe Sonicator

The stability of the nanofluids prepared is tested by measuring Zeta Potential. The Zeta potential obtained for all the concentrations considered is greater than -30mV indicating the better stability of the nanoparticles in the base fluid. The thermal conductivity of SiC nanoparticle suspensions in DW, 20:80 EG-DW, and 40:60 EG-DW is measured using the Tempos thermal Property Analyser shown in Figure 3, for different particle concentration ranging from 0.02 to 0.08% by volume. The viscosity of these nanofluids is measured at a temperature of 40, 45 and 50°C.

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Figure 3. tempos Thermal Property Analyzer

3. Results and Discussion

The thermal conductivity of nanofluids is determined using the Tempos Thermal Property Analyzer. The experimental values of thermal conductivity are compared with Sharma et al. [9] and Corcione [2] correlations given by Eqs. (2) and (3) respectively.

$$\frac{k_{nf}}{k_{bf}} = \left[0.8938\left(1+\frac{\phi}{100}\right)^{1.37}\left(1+\frac{T_{nf}}{70}\right)^{0.277}\left(1+\frac{d_p}{150}\right)^{-0.0336}\left(\frac{\alpha_p}{\alpha_w}\right)^{0.01737} \right] \qquad (2)$$

The Sharma correlation is valid $0 \le \phi \le 3.7$, $20 \le T_{nf} \le 70$, $20 \le d_p \le 150$.

$$\frac{k_{nf}}{k_{bf}} = 1 + 4.4(\mathrm{Re})^{0.4}(\mathrm{Pr}_{bf})^{0.66}\left[\frac{T}{T_{fr}}\right]^{10}\left[\frac{k_p}{k_{bf}}\right]^{0.03}\left[\frac{\phi}{100}\right]^{0.66} \qquad (3)$$

Where the Reynolds number (Re) of the nanoparticle is given as $\mathrm{Re} = \frac{2\rho_{bf} K_b T}{\pi(\mu_{bf})^2 d_p}$ and K_b is the Boltzmann constant.

The measured and predicted values of thermal conductivity of DW, 20:80 EG-DW and 40:60 EG-DWbased SiC nanofluids at 40, 45 and 50°C are represented in Figure 4, 5 and 6 respectively

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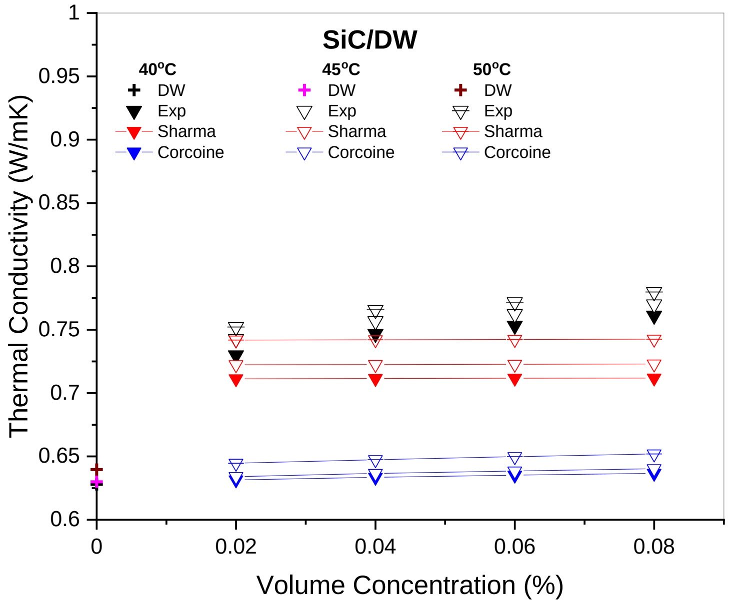

Figure 4. Thermal Conductivity of SiC/DW nanofluid

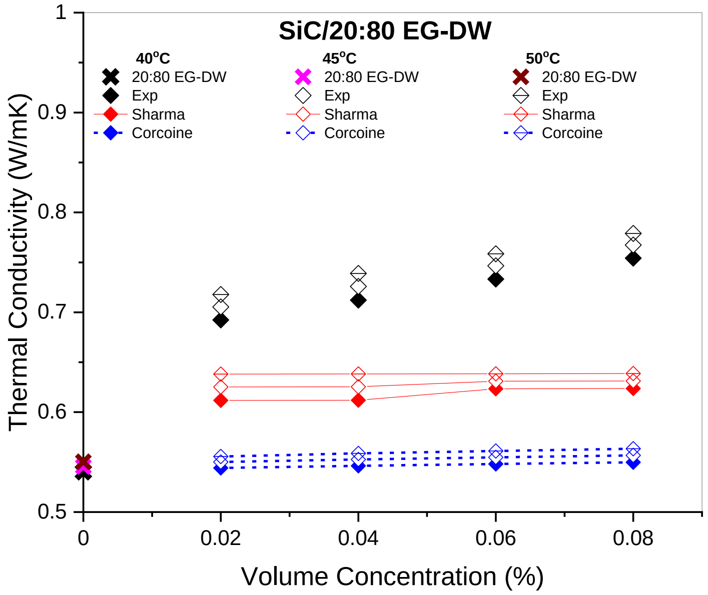

Figure 5. Thermal Conductivity of SiC/20:80 EG-DW Nanofluid

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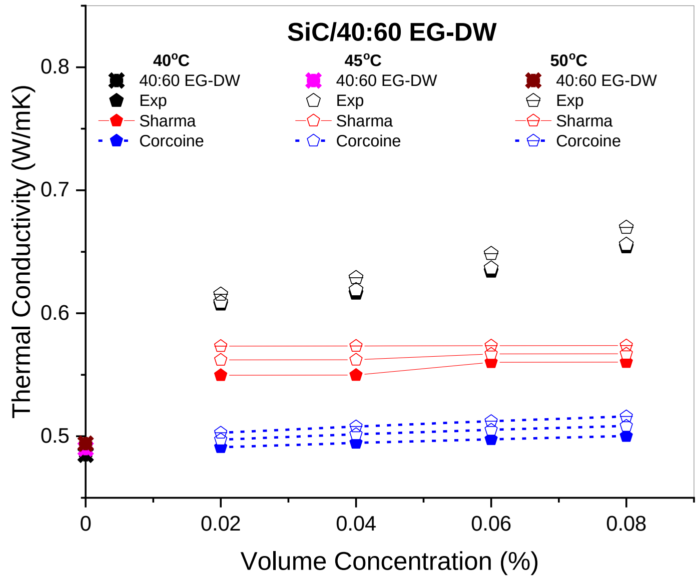

Figure 6. Thermal Conductivity of SiC/40:60 EG-DW Nanofluid

DW based SiC nanofluid has exhibited higher thermal conductivity whereas 40:60 EGW based nanofluid exhibited lower thermal conductivity among the nanofluids considered. The percentage increment in the thermal conductivity of DW, 20:80 EGW and 40:60 EGW based SiC nanofluid vary from 17.87% to 22.23%, 29.28% to 40.63% and 24.28% to 33.87% respectively compared with their respective base fluids as the particle concentration by volume varies from 0.02% to 0.08% at 45°C, similar trend was observed for 40 and 50°C. The thermal conductivity of DW based SiC nanofluid is 1.005 times that of 20:80 EGW and 1.17 times that of 40:60 EGW based SiC nanofluids The correlations considered not only underestimated the experimental values but also could not capture the effect of particle loading on thermal conductivity. Comparison of the thermal conductivity of SiC nanofluids at 45°C in the 3 different base fluids is shown in Figure 7 and the relative thermal conductivity is shown in Figure 8.

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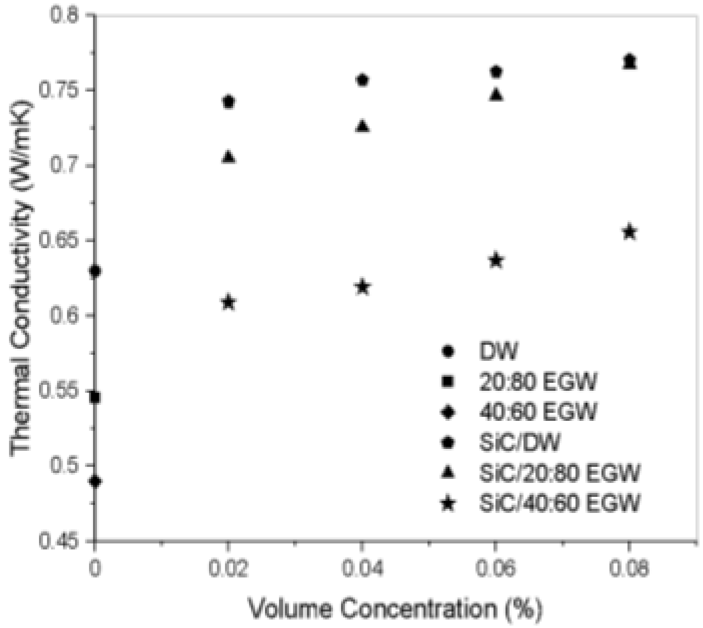

Figure 7. Comparison of Thermal Conductivity of SiC nanofluid in 3 Different base fluids

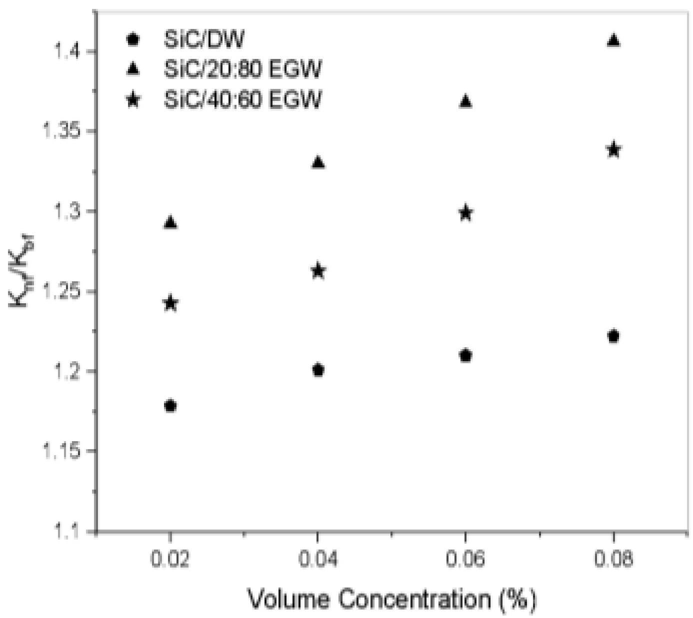

Figure 8,. Relative Thermal Conductivity of SiC Nanofluids

For the same particle concentration by volumes considered, the relative thermal conductivity of DW based nanofluid has exhibited a lower enhancement compared to the EG-DW based SiC nanofluid. It can be observed that though the thermal conductivity of EG-DW based nanofluids is less than DW based nanofluids the enhancement in the thermal

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conductivity with the base fluid is higher for EG-DW based SiC nanofluid. Higher enhancements were observed for 20:80 EG-DW based SiC nanofluid.

4. Conclusions

The thermal conductivity of DW, 20:80 EG-DW, and 40:60 EG-DW based SiC nanofluids is experimentally investigated for low particle concentration of 0.02% to 0.08% by volume at temperatures 40, 45 and 50°C. It is observed that the thermal conducitivty of the nanofluids increase with increase in the particle concentration temperature. DW based SiC nanofluids exhibited greater thermal conducitvity values than EG-DW based nanofluids. The thermal conductivity of DW based SiC nanofluid is 1.005 times that of 20:80 EGW and 1.17 times that of 40:60 EGW based SiC nanofluids. Though the thermal conductivity values of DW based nanofluids is greater than EG-DW based SiC nanofluids, the relative thermal conductivity of EG-DW based SiC nanofluid is found to be greater than DW based nanofluids in particular 20:80 EG-DW based nanofluids exhibited higher enhancements in thermal conductivity than base fluid indicating the effect of base fluid. Hence, it is observed that the base fluids chosen for the preparation of the nanofluids are having greater impact on thermal conducitivty of nanofluids and the combination of nanoparticle and base fluid also pays a major role on the thermal conductivity of nanofluids.

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