EFFECT OF SURFACTANT CONCENTRATION AND NANOPARTICLES SIZE ON THE HEAT TRANSFER PERFORMANCE OF GNP-MWCNT HYBRID NANOFLUIDS

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ABSTRACT: This study investigates the heat transfer performance of hybrid nanofluids composed of different sizes of multi-walled carbon nanotubes (MWCNTs) and graphene nanoplatelets (GNPs) under distinct concentration of Gum Arabic (GA) surfactant. A tubular heat exchanger was used to assess the heat transfer performance of hybrid nanofluid samples with various combinations of MWCNT lengths (0.5 – 2.0 μm and 10 – 30 μm) with a similar diameter (20–30 nm) and GNP diameters (5 μm and 25 μm) with a similar thickness (6–8 nm), at varying surfactant-to-nanoparticle volumetric ratio of 1:5, 3:5 and 1:1. The study found that the combination of GNP 5 μm and long MWCNT obtained the highest heat transfer coefficient. The finding of the study also shown that the optimal GA-to-nanoparticle volumetric ratio in the GNP-MWCNT nanofluid solution was at 3:5.

KEYWORDS: *Hybrid Nanofluid; Graphene; Carbon Nanotube; Heat Transfer; Nanoparticles Size; Surfactant*

1.0 INTRODUCTION

Heat exchangers are integral to various industrial processes such as in the automotive industry [1], enabling the transfer of thermal energy from systems where it is not required. The performance of these devices is largely dependent on the use of heat transfer fluid (HTF), which transfers heat via convection. Traditional HTFs, such as water, oil, and ethylene glycol, have inherent limitations in heat transfer to meet the demand of a more energy efficient and compact heat exchanger technology. This necessitates the development of more effective alternatives of HTF [2].

Nanotechnology offers a promising solution to this challenge. By combining traditional HTF with nanoparticles to produce nanofluids, the heat transfer performance of these fluids can be significantly enhanced due to their improved thermophysical properties [3, 4]. Among others, carbon-based nanoparticles have attracted considerable attention due to their excellent thermal conductivity [5]. Recently, a more advanced version of nanofluid, known as hybrid nanofluid, has been discovered to produce a more efficient heat transfer than the conventional unitary nanofluids. This is due to the superior thermal properties of hybrid nanofluids, which resulted from the synergistic effects brought about by the different nanomaterials present in the nanofluid solution [6].

The practical application of nanofluids is often hindered by challenges such as dispersion stability. Nanoparticles tend to agglomerate significantly and phase-separate from the base fluids over time, leading to a loss of the enhanced heat transport properties of nanofluids [7]. Hence, surfactants have been used to address this challenge and were found to increase the dispersion stability of nanofluids [8]. Besides, the effect of nanoparticle size was also found as one of the contributors to nanofluid's dispersion stability [9].

Despite the demonstrated effects of surfactants and nanoparticle size on a nanofluid's dispersion stability and thermal performance, most studies have focused primarily on unitary nanofluids. Further research is needed to better understand how surfactant and its concentration as well as nanoparticle size could affect the performance of a hybrid nanofluid. For instance, the influence of surfactant concentrations and nanoparticle size on the heat transfer performance of hybrid nanofluids containing graphene and carbon nanotubes are still unknown. This paper aims to bridge these knowledge gaps by investigating the effects of surfactant concentration and nanoparticle size on the heat transfer performance of a hybrid nanofluid containing multi-walled carbon nanotubes (MWCNTs) and graphene nanoplatelets (GNPs). The overarching goal is to maximize the potential of this type of hybrid nanofluid for practical use, thereby contributing to the advancement of heat transfer systems.

2.0 METHODOLOGY

2.1 Materials and Preparation of Hybrid Nanofluids

MWCNT with lengths of 0.5 - 2.0 μm and 10 – 30 μm, and GNP with diameters of 5 μm and 25 μm were employed in this study. The MWCNTs, sourced from US Research Nanomaterials, Inc., Texas, USA, possess a specific surface area of at least 110 m^2/g, with outer diameter of 20–30 nm and inner diameter of 5–10 nm. GNPs with a specific surface area of approximately 120–150 m^2/g and thickness of 6 – 8 nm were obtained from XG Science, Inc., Michigan, USA. GA surfactants were acquired from Sigma Aldrich, USA.

The hybrid nanofluid, comprising GNP and MWCNT, were prepared with and without GA surfactant by dispersing the nanoparticles in distilled water at 0.03 vol.% using ultrasonication for 1 hour. Four distinct configurations of hybrid nanofluid samples were prepared and they are named according to the different size combinations of GNP and MWCNT. For instance, GNP5-MWCNTlong, refers to samples containing 5 μm diameter of GNP and MWCNT length of 10–30 μm. The ratio of GNP to MWCNT was fixed at 1:1 by volume, and the surfactant-to-nanoparticle volumetric concentration ratios was fixed at 1:1 for the dispersion stability tests while it was varied at 1:5, 3:5, and 1:1 for the heat transfer experiments.

2.2 Dispersion Stability

The dispersion stability of the nanofluid was assessed using Agilent Cary 60 G6860A UV-vis spectrophotometer, which detects UV light absorption by the nanofluids based on Beer Lambert's Law. This law states that the amount of light absorbed by the nanofluid is influenced by the concentration of solid particles in the sample. Higher particle concentration leads to greater light absorption, indicating better nanoparticle dispersibility. UV-vis spectroscopy provides a quantitative measure of nanoparticle dispersion in the solution. Stability assessments were conducted over 30 days, with readings taken on the first and final days. Nanofluid samples were kept static in vial containers at room temperature throughout the assessment period. For UV-vis measurements, a cuvette was used to allow light passage for accurate optical property measurement. A 1:15 dilution ratio of nanofluid to distilled water was applied to ensure the sample falls within the instrument's measurement range. Scanning was performed across wavelengths from 200 to 800 nm.

2.3 Heat Transfer Coefficient (HTC) Measurement

The heat transfer performance of the nanofluid samples were scrutinized using an Armfield HT31 concentric tube heat exchanger, as illustrated in Figure 1. The experimental setup consisted of a U-shaped concentric pipe extending 660 mm. The inner pipe, made of stainless steel with an outer diameter of 9.5 mm and a wall thickness of 0.6 mm, was surrounded by an acrylic annulus pipe with an outer diameter of 12 mm and a wall thickness of 3.0 mm. During the experiment, cold water from an external source flowed through the annulus pipe at a temperature of 27 °C and a flow rate of 1.0 L/min. The nanofluid, serving as the hot fluid, traversed the inner pipe in counter-flow directions at flow rates of 1.0, 1.5, 2.0, and 2.5 L/min. A 2 kW heater maintained the nanofluid's inlet temperature at 50 °C throughout the tests. The nanofluid was circulated in a continuous loop, passing through the test section before returning to the reservoir. Six type-K thermocouples were strategically positioned in the hot and cold fluid streams to record temperatures. Between experimental runs, the inner tube was cleaned using a 2% Decon 90 solution followed by a thorough water rinse at 8 L/min for 5 minutes. To ensure data accuracy and reproducibility, ten data points were taken during each experimental run.

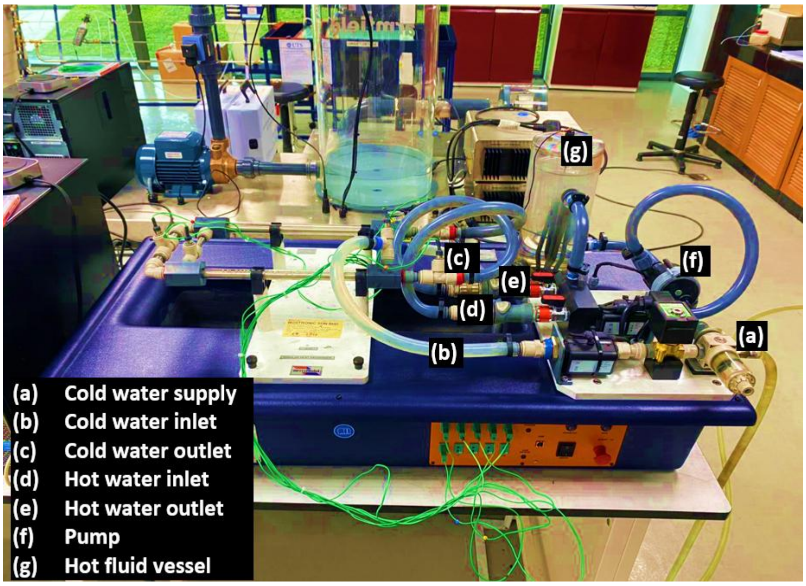


Figure 1: The setup of concentric tube heat exchanger unit used for the HTC measurement

2.4 Data Calculation

The thermal performance of nanofluids is determined by the heat transfer coefficient, U:

$$U = \frac{Q}{A \times LMTD} \tag{1}$$

where LMTD is the logarithmic mean temperature difference, which reflects the temperature driving force of heat transfer in a heat exchanger, A is the area of heat transmission, and Q is the rate of heat transfer from nanofluid. The equation used for calculating Q and LMTD is:

$$Q = \dot{m}_{hnf} \times Cp_{hnf}(T_{hnf,in} - T_{hnf,out}) \quad (2)$$

$$LMTD = \frac{(T_{hnf,out} - T_{w,in}) - (T_{hnf,in} - T_{w,out})}{\ln(\frac{T_{hnf,out} - T_{w,in}}{T_{hnf,in} - T_{w,out}})} \quad (3)$$

where $T_{hnf,in}$ and $T_{hnf,out}$ are the hybrid nanofluid temperatures at the inlet and outlet of the inner pipe, respectively, and $T_{w,in}$ and $T_{w,out}$ are the water temperatures at inlet and outlet in the annulus pipe, respectively, and $\dot{m}_{hnf}$ is the mass flow rate of hybrid nanofluid. The hybrid nanofluid specific heat capacity, Cp_{hnf} may be determined [10]:

$$Cp_{hnf} = \frac{(1 - \phi_{total})(\rho C_p)_{bf} + \phi(\rho C_p)_{GNP} + \phi(\rho C_p)_{MWCNT}}{\rho_{hnf}} \quad (4)$$

where ϕ, Cp_{bf}, CpGNP and Cp_{MWCNT} refers to volume fraction and specific heat capacity of base fluid, GNP and MWCNT, respectively. Cp_{bf} value is 4.1855 kJ/kg. K, while Cp_{GNP} and Cp_{MWCNT} value is 0.643 and 0.6606 kJ/kg. K, respectively. According to Scott et al. [11], one may determine the hybrid nanofluid density, ρ_{hnf}, from:

$$\rho_{hnf} = (1 - \phi_{total})\rho_{bf} + \phi_{GNP}\rho_{GNP} + \phi_{MWCNT}\rho_{MWCNT} \quad (5)$$

where ρ_{GNP} and ρ_{MWCNT} refers to density of GNP and MWCNT, respectively, and ρ_{bf} refers to density of base fluid. The value of ρ_{GNP} and ρ_{MWCNT} is 2.2 and 2.1 kg/L, respectively, and the value for ρ_{bf} is 0.99823 kg/L.

3.0 RESULTS AND DISCUSSION

3.1 Dispersion Stability

Figure 2 illustrates the UV-vis absorption spectra of the nanofluid samples during Day 1 and Day 30. Notably, the peak absorbance is evident within the 250 - 270 nm wavelength range. This pattern is consistent across other hybrid nanofluid configurations. Such a wavelength range is indicative of the typical UV absorbance peak observed in carbon-based nanofluids [12, 13]. The peak absorbance value from the UV-vis spectra indicates the dispersion state of the nanofluid. A higher peak absorbance value suggests better dispersion of nanoparticles within the fluid. As compared to Day 1, a decrease in absorbance values was noted across the samples by Day 30. This reduction is typically linked to decreased dispersion quality, attributed to the settling of nanoparticles over time. This phenomenon is primarily attributed to the gravitational settling and van der Waals attraction between nanoparticles, which causes them to aggregate thus lowering the absorbance value [14].

A relative peak absorbance values between Day 30 and Day 1 are plotted to provide better clarity regarding the dispersion stability. The relative peak absorbance is the ratio between the peak absorbance values of Day 30 (A_{30}) to Day 1 (A_1). This value reflects the dispersion stability of nanofluid, where higher relative absorbance indicates greater dispersion stability. Figure 3 depicts the relative peak absorbance of different GNP-MWCNT size combinations. It is evident that the GNP5-MWCNTlong configuration produces the highest dispersion stability followed by GNP25-MWCNTlong, GNP5-

MWCNTshort and GNP25-MWCNTshort. Shorter MWCNTs tend to cluster due to weaker dispersion forces and higher surface energy, which hinder their uniform distribution [15]. Besides, compared to GNP5, GNP25 has larger contact area that can cause greater attractive interactions between nanoparticles that will lead to agglomeration [16-17].

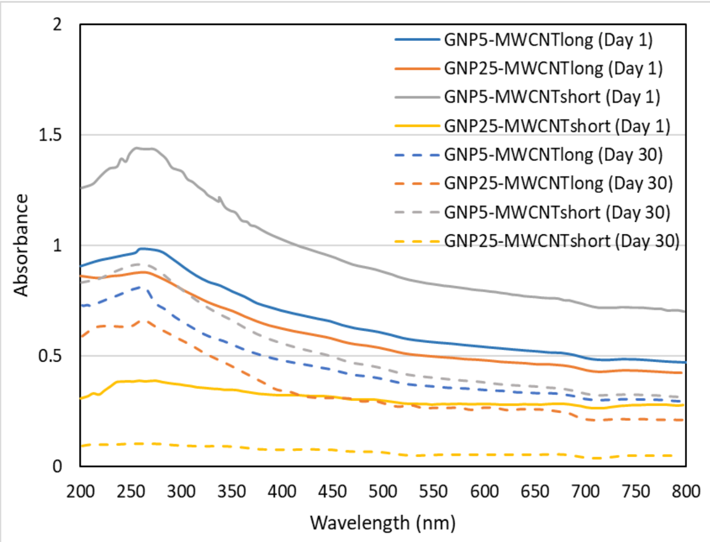


Figure 2: UV-vis absorption spectra of nanofluid samples during Day 1 and Day 30.

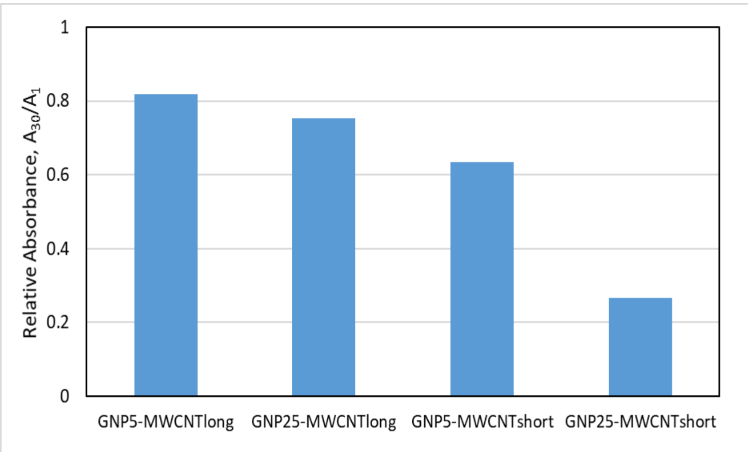
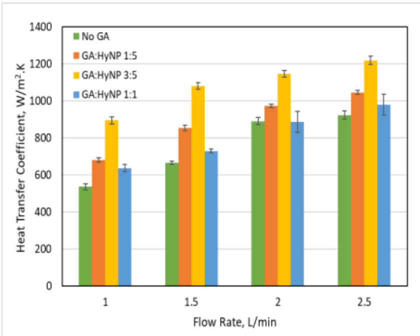


Figure 3: Relative peak absorbance (Day 30-to-Day 1) of nanofluids with various GNP-MWCNT size combinations.

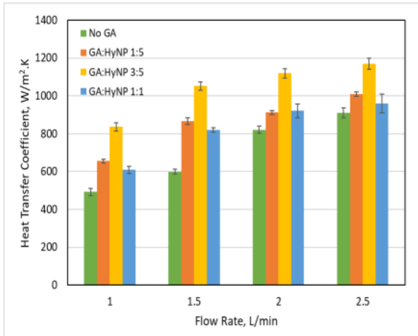
3.2 Heat Transfer Performance

Figure 4 illustrates the HTC for different configurations of GNP-MWCNT with varying GA content by using the correlations given in Eqs. (1) to (5). The HTC values were found to be the lowest when GA was absent in the samples. As the GA content increased, the HTC also increased, reaching a maximum at a GA-to-nanoparticle volumetric ratio of 3:5. However, further increasing the GA-to-nanoparticle ratio to 1:1 led to a decrease in HTC values. This trend was consistent across all configurations.

The variation in HTC values with different GA content can be attributed to the state of dispersion of nanoparticles in the nanofluid [18, 19]. Increasing the GA-to-nanoparticle ratio will improve the dispersion of the nanoparticle, which could enhance the thermal conductivity and heat transfer capability of the nanofluid [16, 20]. This will be effective up to a certain GA content, beyond which the HTC starts to decrease. This reduction of HTC with further increase in GA content is typically attributed to the increase in the viscosity of the nanofluid [21]. These findings underscore the critical importance of maintaining an optimal nanoparticle-surfactant ratio for enhancing the heat transfer properties of nanofluids.



(a)



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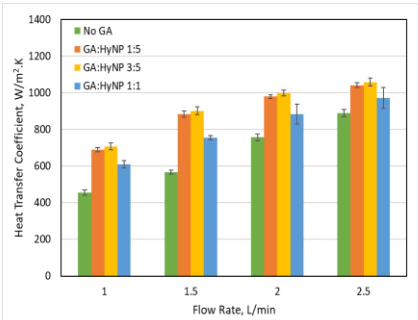

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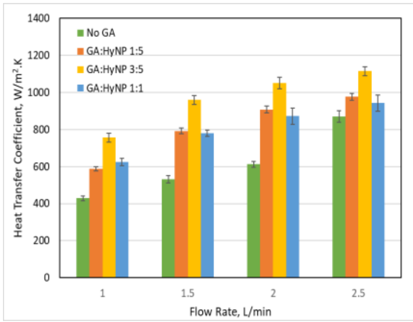

(d)

Figure 4: HTC of hybrid nanofluids of (a) GNP5-MWCNTlong, (b) GNP25-MWCNTlong, (c) GNP5-MWCNTshort, and (d) GNP25-MWCNTshort at different surfactant concentrations under various flow rates.

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Figure 5 presents the HTC values of hybrid nanofluid samples for different size combinations of GNP-MWCNT at a GA-to-nanoparticle volumetric ratio of 3:5 under varying flow rates. The data reveals a positive correlation between the flow rate and HTC across all nanoparticle combinations, consistent with the principles of forced convection. This correlation is attributed to the increased fluid velocity that enhances convective heat transfer.

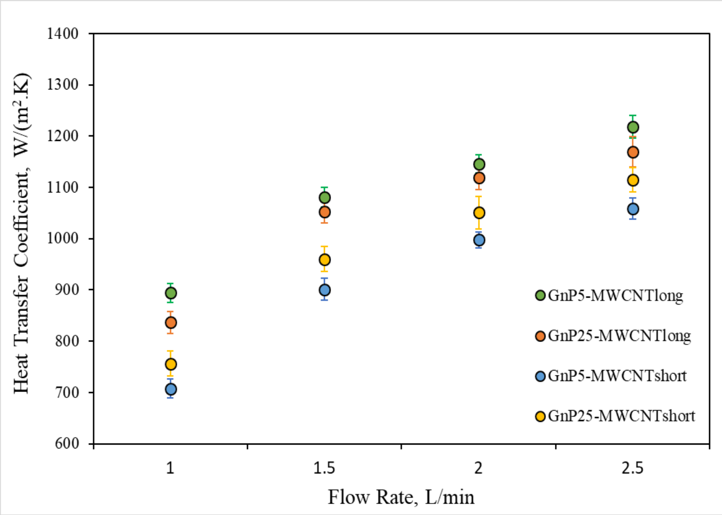

Figure 5: HTC of different size combinations of GNP-MWCNT hybrid nanofluid with GA at surfactant-to-nanoparticle ratio of 3:5.

Notably, the GNP5-MWCNTlong nanofluid consistently exhibits higher HTC values across various flow rates, indicating superior heat transfer performance. This can be directly linked to the enhanced dispersion stability of GNP5-MWCNTlong compared to the other GNP-MWCNT combinations as observed in the dispersion stability tests shown in Figures 2 and 3. Moreover, the smaller size of GNP (5µm) provides a larger surface area per unit volume, which can promote more efficient interaction with the base fluid, thereby enhancing heat transfer [22]. Additionally, long MWCNTs provide better contact points and pathways within the fluid, resulting in improved heat conduction compared to their shorter counterparts [23]. Hence, this GNP5-MWCNTlong combination enhances the synergistic effect, thereby maximizing heat transfer effectiveness.

4.0 CONCLUSION

In this study, the effect of GA surfactant concentration and size of GNP and MWCNT on the heat transfer performance of GNP-MWCNT hybrid nanofluids were experimentally investigated. The optimal GA-to-nanoparticle volumetric ratio was found to be 3:5, which yielded the highest HTC. Notably, the GNP5-MWCNTlong configuration demonstrated superior heat transfer performance across various flow rates of the nanofluid in a concentric tube heat exchanger. This is directly linked to its enhanced dispersion stability compared to the other tested GNP-MWCNT size combinations. These findings underscore the critical importance of utilizing optimal nanoparticle-surfactant ratio and selecting appropriate nanoparticle size combinations to maximize heat transfer performance of nanofluids.

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