Enhancement of Stability and Thermal Conductivity of Nanofluids Using Chinese Ink As a Surfactant

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Abstract. Stability of nanofluids is a basic requirement for cooling applications since it is directly related to properties of nanofluids. The objective of the present study is to compare different types of nanoparticles in water-based fluids. Nanosilica, graphene and functionalize multi-walled carbon nanotubes (F-MWCNT) were dispersed in water-based fluids, and Chinese ink was used as a surfactant. Ultrasonication via two-step method was used to produce the nanofluids. The Chinese ink has been used to reduce surface tension in fluid and minimize the sedimentation problems of nanofluids. Thermal conductivity of the nanofluids was measured by thermal property analyser. The stability of nanofluids was observed through visual observation and zeta potential measurement methods. F-MWCNT with Chinese ink exhibit 79% thermal conductivity enhancement compared to the base fluid. Graphene and F-MWCNT possess zeta potential value which are more than 47 mV (negative) compared to the other tested samples. In conclusion, F-MWCNT nanofluid has a potential to be used in cooling applications due to the highest thermal conductivity and nanoparticle stability.

1. Introduction

Nowadays, the development of high-performance thermal systems of the base fluid for heat transfer enhancement has become popular in applications: electronic cooling, heat exchanger, heat pipe car radiators, coolant in welding and machining, solar heating and etc. [1]. Conventional coolants such as water, ethylene glycol (EG), engine oil, and toluene do not have adequate cooling capacity due to their low thermal conductivity [2]. In order to increase the thermal conductivity of the base fluid, different of millimeter- or micro-meter-sized particles have been added in the fluid especially for electronic cooling applications. Lee et al. [3] proposed the use of nanofluid as an ideal candidate for heat transfer enhancement.

In general, there are two methods to prepare nanofluids; one-step and two-step methods [4]. The single-step preparation process indicates the synthesis of nanofluids prepared by simultaneous synthesis of nanoparticles and dispersion in base fluids. Using this method, the agglomeration of nanoparticles can be minimized and increased the stability of the fluids [5]. However, the presence of residual reactants in the nanofluids due to incomplete reaction or stabilization has been an inherent drawback of the procedure [6]. In the two-step method, the nanoparticles are first produced by physical or chemical processes and then dispersed in base fluids by magnetic stirring [7], ball milling, high-shear mixing, homogenizing [8] or ultrasonic agitation [7, 9] with or without surfactant addition. Two-step method is a most economic method to produce nanofluids in large scale for industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. Simple techniques such as ultrasonic agitation or the addition of surfactants to the fluids
have been proposed by some researchers to minimize particle aggregation and improve the stability of nanoparticles suspension in fluids.

Surfactants or dispersants are used to stabilize the water based nanofluids. This is due to the natural instability of material in polar solvents such as water. Surfactants act as chemical compounds that can reduce the surface tension of fluid and assist the dispersibility of particles in fluid. Various types of surfactants that are commonly used such as salt and oleic acid [10], dodecyltrimethylammonium bromide (DTAB) [11], sodium dodecylsulfate (SDS) [12], polyvinylpyrrolidone (PVP) [13], hexadecyltrimethylammoniumbromide (HCTAB) [14], gum arabic [15], etc.

The stability of nanofluids is a basic requirement for cooling applications since it is directly related to thermal conductivity, viscosity and other thermo-physical properties of nanofluids [16]. Therefore, the optimization of the specific heat capacity with respect to concentration of nanoparticles and surfactant addition is required to ensure faster cooling rate. In this study, silica, graphene and F-MWCNT nanofluids were prepared by two-step method. Effect of chinese ink as a surfactant on the thermal properties and stability of the nanofluids was investigated. However, to the best of our knowledge, the use of commercial chinese ink as a surfactant in nanofluids is rarely explored.

2. Methodology

Silica was supplied by Merck with a specified molecular weight average of 60.8. Graphene nanoplatelets (grade M) with 6 to 8 nanometers thickness and 5 micron of average particles size was purchased from XG Sciences, Inc. The functionalize multi-walled carbon nanotubes (F-MWCNT) with 97% purity synthesised via catalytic chemical vapour deposition (CCVD) was supplied by USAINS, Universiti Sains Malaysia, Penang. Surfactant kin's ink -liquid black (chinese ink) was purchased from Winsin Trading SDN.BHD.

Three different nanoparticles such silica, graphene and F-MWCNT were prepared by using two-step method. In this method, the nanoparticles were added into chinese ink-distilled water solution to produce 0.1 v% of nanofluids. The distilled water acts as the base fluid of the suspension. Then, the nanofluid was dispersed using ultrasonic for 20 minutes in order to break down the agglomeration of nanoparticles. The prepared nanofluids have been kept under visual surveillance for 30 days so as to investigate the stability of the samples.

The thermal conductivity of nanofluids was carried out by using KD2 Pro thermal property analyzer (Decagon Devices Inc., USA). This instrument uses the concept of transient line heat source to determine the nanofluids thermal conductivity. This measurement was done at room temperature (about 24 °C). Zeta potential measurement was performed using Zetasizer Nano instruments, model: Malvern Instrument, UK. From each sample, 1ml of solution was extracted from the medium suspension and filled into folded capillary zeta cell. Three measurements were performed for each sample.

3. Results and Discussion

The effect of chinese ink as surfactant on the visual stability of different nanoparticle can be clearly seen in figure 1. All the nanofluids without using surfactant showed good stability on the first day of experiment and the stability was monitored over the period of 30 days (refer figure 1 (a)). The sedimentation slowly happened on the second day for all nanofluids without surfactant. Apparently, it can be seen that the visual observation the all nanofluids with surfactant shows good stability up to 30 days (refer figure 1(b)). These results prove that the chinese ink functioning as an effective surfactant to improve nanoparticles stability in base fluid. Wang et al., [17] reported that carbon black particles and animal glue which is collagen are presented in the chinese ink. Hence during the preparation of the suspension, the carbon black particles of the ink and the MWCNTs are coated by the collagen through van der Waals attraction, hydrogen bonds and surface tension, forming core-shell colloidal structures. An electrical double layer formed on the surface of the colloid prevents agglomeration while Brownian motion promotes stabilization of MWCNT particles in the suspension.
Since the huge sedimentation is evident by visual observation for the nanofluids without surfactant, thermal conductivity and zeta potential analysis were not been carried out for the nanofluids. Figure 2 shows the thermal conductivity characteristics of silica, graphene and F-MWCNT water based nanofluid samples added with Chinese ink, after 30 days. The base fluid (distilled water) and Chinese ink solution show thermal conductivity values of 0.537 Wm\(^{-1}\)K\(^{-1}\), and 0.253 Wm\(^{-1}\)K\(^{-1}\) which are lower than those thermal conductivity of nanofluids with surfactant. According to Leong et al. [18], the interfacial layers of water molecules surrounding the nanoparticles are believed to contribute to the thermal conductivity enhancements. The usage of Chinese ink can decreases the thermal resistance between nanoparticles and base fluid, and thus, increasing the thermal conductivity of nanofluids.

From figure 2, F-MWCNT with Chinese ink shows the highest thermal conductivity (2.591 W/m.K) compared to those of base fluid and others nanofluids. According to Lindsay et al. [19], Chinese ink modified the F-MWCNT surface from hydrophobic to hydrophilic. Hence the F-MWCNT nanoparticles tend to repulse each other due to the surface modification.

Zeta potential analysis has been carried out to determine the stability nanofluids by measuring the attraction force and repulsive force between the nanoparticles suspending in the liquid. Figure 3 shows that the addition of Chinese ink based fluid water in all nanoparticles exhibited zeta potential value which is more than 40 mV (negative). In general, a value of ± 25 mV (positive or negative) can be taken as the arbitrary value that separates low-charged surfaces from highly charged surfaces. The nanofluids with zeta potential from ±40 to ±60 mV are believed to be good stability, while more than ±60 mV have excellent stability [3]. The graphene nanofluids with zeta potential value of -51.4 mV is
the most stable among the tested nanofluids, followed by the F-MWCNT (-47.9 mV). The stability of nanofluids is because of the protective role of chinese ink as it prevents the agglomeration of nanoparticles due to steric effect. Higher absolute zeta potential value indicates that the electrostatic repulsion force is higher than van der Waals force (attraction forces) which leads to better stability of the samples.

Figure 3: Zeta potential analysis of the prepared samples containing surfactant on day 30

4. Conclusions
In this present study, the effect of surfactant on the stability of different types of nanoparticles-chinese ink has been experimentally investigated. The addition of chinese ink as surfactants promote better stability of nanoparticles in base fluids. The highest thermal conductivity is shown by the F-MWCNT nanofluid with improvement of 79% compared to the based fluid. All of nanofluids sample with chinese ink show a good colloidal stability based on the absolute values of zeta potential which zeta potential value which are more than 40 mV (negative).

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