

An experimental study of thermal performance of GN and MWCNTs-based aqueous nanofluids with surfactants SDS and SDBS

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Abstract: High thermal conductivity enhancement of nanofluid is a promising topic for the recent research fields. And in this regard, GN and MWCNTs based nanofluids with their outstanding properties are examined vastly. Beside this, SDBS and SDS have been concerned for composing better nanofluids. This paper tries to suggest not a solution but a solution approach and deduce a new conclusion by testing thermal conductivity and heat transfer coefficient enhancement ratio of nanofluids with surfactants SDS and SDBS.

1. Introduction

The researches of nano-science field demonstrated the advantages of nanofluids compared with those fluids containing millimeter or micrometer size particles [1]. Nanofluid with a high thermal conductivity enhancement may be potentially applicable in heat sink applications as coolant [2]. And the concept of nanofluid was first introduced by Choi [3] who quantitatively analyzed some potential benefits of nanofluids [4]. Within last few years, many research projects were conducted in order to produce more stable suspensions [1], [5] with well dispersion as well as well homogenization. Some surfactants, such as SDS, SDBS, and so on, are under experiment for using as dispersant for these nanofluids [6] as well as PCA in grinding process [7]. Ultrasonication is used for dispersing nanoparticles in base fluids and grinding method is applied for increasing specific surface area [8] which helps to decrease the sphericity of particles and as a result of this, thermal conductivity is increased [4].

Again, transparent conductive films (TCFs), widely used in transistors [9] as well as in solar cells, are fabricated by indium tin oxide [10]. But the rising cost of indium, high temperature processing in production and brittleness of ITO [11], [12] have introduced some emerging alternatives, such as CNTs [13], GN [14], metal or metal nanowires [15] and hybrids of these [16].

Graphene (GN) with two dimensional extended honeycomb network of sp^2 hybridized carbon atoms [17], high electron mobility [18], excellent mechanical, chemical and thermal properties [19] possesses twice specific surface area compared with SWCNTs [11]. However, CNTs (carbon nano tubes) carry some properties such as one of the lightest [20], strongest [21], stiffest [21], electrically [22] and thermally [23] conductive nanoparticles. But, graphene with insolubility and the intrinsic tendency to

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agglomerate [24] as well as MWCNTs with insolubility in water due to hydrophobic surface [8] are under research with great challenge to overcome these major obstacles.

Although, ultrasonication is mainly used to disperse nanoparticles in base fluid, there is still agglomeration problem after ultrasonication (Section 3.1). And with the increasing rpm, there is adhere of powder, especially GN, to grinding media (vial and balls) which increases in grinding process (Section 3.2). This paper chooses wet grinding and ultrasonication in order to minimize these problems during making nanofluid. The reason for wet grinding is to decrease the sticking problem and the possibility of decomposition of surfactants which produces contamination. Again, surfactant controls the welding and fracturing [7] during grinding process and during ultrasonication, it is used as dispersant [1]. So, in order to get the both advantages, surfactants are added with nanoparticles from starting of the process.

In this paper, we do not suggest a solution but a solution approach and try to deduce a new conclusion by giving evidence. This paper tries to show what happens during preparing nanofluid during ultrasonication as well as the effect of SDS and SDBS in making nanofluids (Section 3.1) and in grinding process (Section 3.2). In this paper, the curves of thermal conductivity are analyzed by percent enhancement (Section 3.4) and heat transfer coefficient enhancement ratio (Section 3.5) is done for better decision making. Here, it should be noted that the results of this paper are only for comparison and do not suggest the optimum condition for this process.

2. Experimental Setup

2.1 Materials

Raw MWCNTs with a ~20nm diameter, ~5 μ m length (Carbon Nanomaterial Technology Co., Ltd, South Korea) and graphene nanopowder with 8nm (average flake thickness) flakes, average particle size ~550 nm, specific surface area 100 m²/g, and 99.9% purity (graphene supermarket) are used in this experimental study. Sodium dodecyl benzene sulfonate (SDBS, C₁₈ H₂₉ NaO₃ S) with hard type, 348.48 molecular weight (Tokyo Chemical Industry Co., Ltd) and Sodium dodecyl sulfate (SDS, CH₃ (CH₂)₁₁ OSO₃ Na) with 288.38 molecular weight (Junsei Chemical Co., Ltd) surfactants are used as dispersant as well as controller of welding and fracturing during grinding process. Distilled water (DW) is used as base fluid for making nanofluids.

2.2 Grinding process

A planetary ball mill machine (HPM-700) (Haji Engineering, Korea) is used for grinding process where MWCNT and GN individually as well as with different surfactants and with various weight ratios are ground for one hour with 500rpm rotation speed.

2.3 Ultrasonication

Ultrasonic mixing system (Model 1510E-DTH, 47 kHz) is used for making nanofluid of MWCNT and GN in a base fluid distilled water. At first, 5 minute DEGAS then 20 minutes or 40 minutes SONIC time is used for making nanofluid.

In 50ml distilled water surfactant is added and Ultrasonication is performed for 5 minutes. Then, nanoparticles are dissolved in this base fluid and 20 minutes (for sample 7 also 40 minutes) ultrasonication is done for making nanofluid. The surfactants are SDS and SDBS which are added separately. And the nanoparticles are GN and MWCNTs.

2.4 Nanofluids preparation by wet grinding as well as Ultrasonication

By using the planetary ball mill machine and Ultrasonic mixing system as mentioned in section 2.2 and 2.3 respectively, the nanofluids of certain weight ratios (mentioned in section 3) are made. At first, nanoparticles and surfactant are hand mixed and then ground by planetary ball mill machine with 500 rpm for 1 hour. After that, distilled water is added and Ultrasonication is performed for 5 minutes and

20 or 40 minutes for degassing and ultrasonication respectively. Surfactants are added individually and same is for nanoparticles.

2.5 Testing apparatus

In order to get continuous determination of the thermal conductivity as well as heat transfer coefficient enhancement ratio, the LAMDA system measuring instrument is used. Precisely calculation of the thermal conductivity by a theoretical approach is almost impossible [4], so experimental approach is mandatory. And for this, the in-stationary transient hot wire method i.e. LAMDA system is used. At first, hot wire apparatus is calibrated by measuring distilled water (DW) which has known thermal conductivity. The difference between the standard value and the experimental value has been shown in fig.1. And the error is within 1.5% with respect to the standard value.

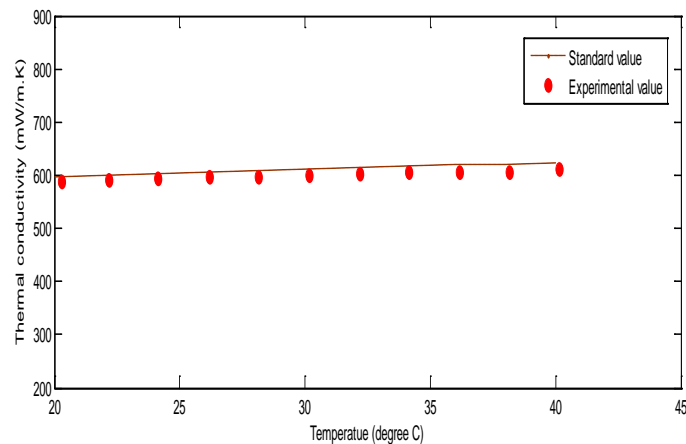


Figure1. Graph of the standard value and the experimental value of distilled water.

3. Results and discussion

3.1 Result of Ultrasonication

From fig. 2 and fig. 3, it can be easily seen that after four days of settlement, low added SDBS to GN solutions have shown better dispersed than other weight ratios. Between 2/1 and 3/1 ratios of GN/SDBS solutions, later one is better.

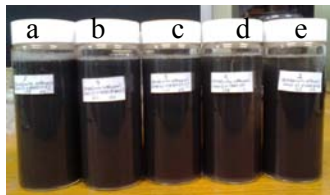


Figure 2. Ultrasonication of GN and SDBS with different weight ratios a) 1/3 b) 3/1 c) 1/1 d) 1/2 e) 2/1

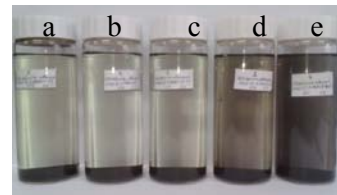


Figure 3. After 4 day settlement of Ultrasonication of GN and SDBS with different weight ratios a) 1/3 b) 1/2 c) 1/1 d) 2/1 e) 3/1

By comparing between fig. 4 and fig. 5, it has been seen that, after 3 day settlement, the three samples (1/1, 2/1 and 3/1 ratios) of GN/SDS solution are better than the other two solutions of 1/2 and 1/3 ratios. Among 1/1, 2/1 and 3/1 ratios, 2/1 as well as 3/1 have been more dispersed.

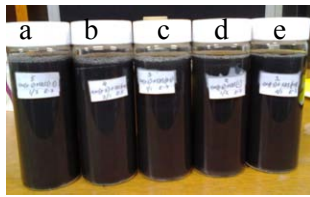


Figure4. Ultrasonication of GN and SDS with different weight ratios a) 1/3 b) 3/1 c) 1/1 d) 1/2 e) 2/1

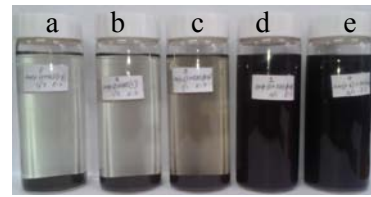


Figure5. After 3 day settlement of Ultrasonication of GN and SDS with different weight ratios a) 1/3 b) 1/2 c) 1/1 d) 2/1 e) 3/1

3.2 Result of grinding

Fig. 6 has illustrated the adherence problem after grinding of MWCNT as well as GN nanoparticles. This grinding process has been done at 500 rpm. After this experiment, it has been seen that the adherence problem of ground GN is more than that of MWCNT. But, by wet grinding this problem has been somewhat reduced.

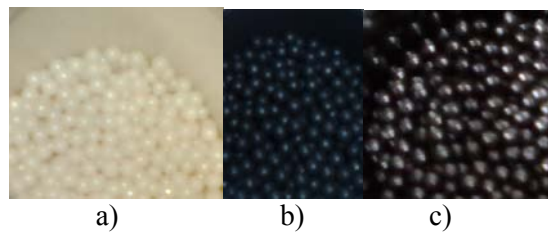


Figure6. Grinding container and ball a) before grinding b) dry grinding with MWCNT c) dry grinding with GN

3.3 Result of wet grinding and ultrasonication with surfactants

It has been seen that grinding of MWCNTs-surfactant and GN-surfactant have no adhere problem and their nanofluids have no agglomeration (the figures have not been shown).

3.4 Thermal conductivity

The effect of nano particles on the thermal conductivity can be explained from the two aspects: the particles increase the thermal conductivity of nanofluid and the chaotic movement of the particles strengthens energy transport process [4]. The thermal conductivity which is the property of a material to conduct heat has been measured by LAMDA system and the related graph has been shown in fig. 7. It has been seen in fig. 7 that both MWCNTs-SDS and MWCNTs-SDBS have increasing trends and similar to [22], later one has shown better thermal conductivity though in our experiment and both trends are below the thermal conductivity of distilled water.

However, for GN nanofluid, it has been seen that GN-SDBS (sample 2) nanofluid trend has gone downward and also below the trend of distilled water. Whereas, GN-SDS nanofluids (sample 4 and 6) have shown significantly good thermal conductivity and 2/1 ratio solution has given better results than 1/1 ratio (sample 4).

In fig. 8, both sample 6 and sample 7 with different ultrasonication times (20 minutes and 40 minutes respectively) have showed thermal conductivity above that of distilled water. And similar to Section: 3.1, it can be said that in our experiment increasing the Ultrasonication time has not showed effective value. Though sample 2 has positive percent enhancement at 25⁰ C, it is more negative at 35⁰ C. Sample 3 has a negative percent enhancement for both 25⁰ C and 35⁰ C. At 35⁰ C, it is almost 4 times. At 25⁰ C, sample 4, sample 6 and sample 7 have positive enhancements (4.202 %, 5.546 %, and 4.706 % respectively) and among them sample 6 has showed better value. Similarly, at 35⁰ C sample 6 also has showed better value than other two.

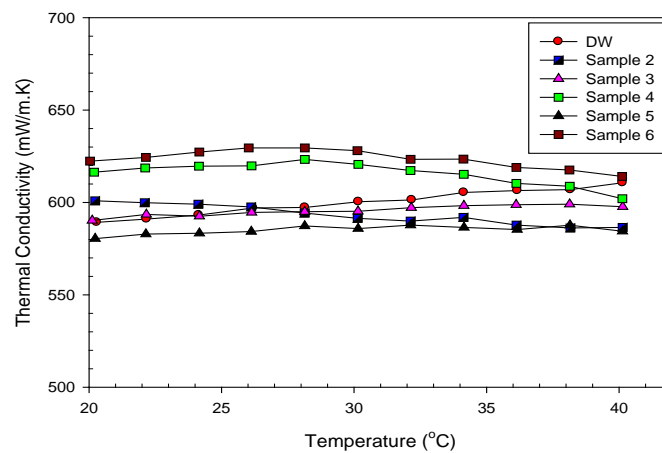


Figure7. Thermal conductivity vs. temperature curve of

Sample 1: Distilled water (DW), used as reference

Sample2: GN (0.5 wt %), SDBS (0.5 wt %), wet grinding, 20 min. Ultrasonication

Sample3: MWCNTs (0.5 wt %), SDBS (0.5 wt %), wet grinding, 20 min. Ultrasonication

Sample4: GN (0.5 wt %), SDS (0.5 wt %), wet grinding, 20 min. Ultrasonication

Sample5: MWCNTs (0.5 wt %), SDS (0.5 wt %), wet grinding, 20 min. Ultrasonication

Sample6: GN (0.5 wt %), SDS (0.25 wt %), wet grinding, 20 min. Ultrasonication

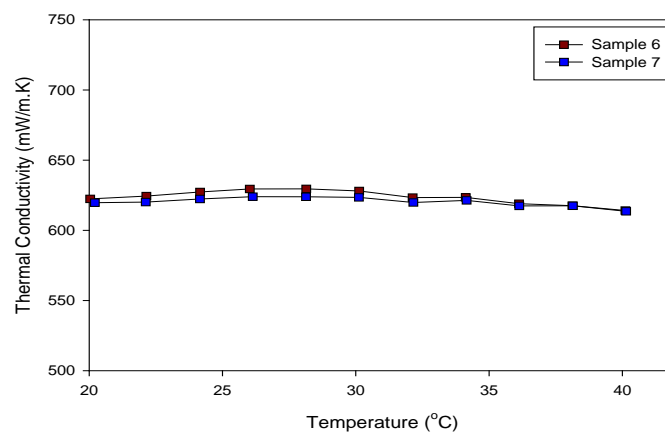


Figure8. Thermal conductivity Vs. temperature curve of

Sample 6: GN (0.5 wt %), SDS (0.25 wt %), wet grinding, 20 min. Ultrasonication

Sample 7: GN (0.5 wt %), SDS (0.25 wt %), wet grinding, 40 min. Ultrasonication

3.5 Heat transfer coefficient enhancement ratio

Heat transfer coefficient is the calculation of heat transfer, typically by convection or phase transition between fluid and a solid and its SI units is watts per square meter Kelvin ($\text{W/m}^2\cdot\text{K}$). Sadik et al. [27] for constant wall temperature boundary condition and by considering convective heat transfer of laminar nanofluid flow inside a straight circular tube showed that average heat transfer coefficient enhancement ratio is increased by enhancing in volumetric heat capacity and thermal conductivity of nanofluid and there is a pronounced effect of thermal conductivity on heat transfer enhancement.

Heat transfer coefficient enhancement ratio is defined as the ratio of the heat transfer coefficient of the nanofluid to that of the base fluid [27]. From fig. 9, it has been easily seen that sample 6 has higher

heat transfer coefficient enhancement ratio from 20°C to 35°C (about) than sample 7 and with the increasing temperature it has decreased.

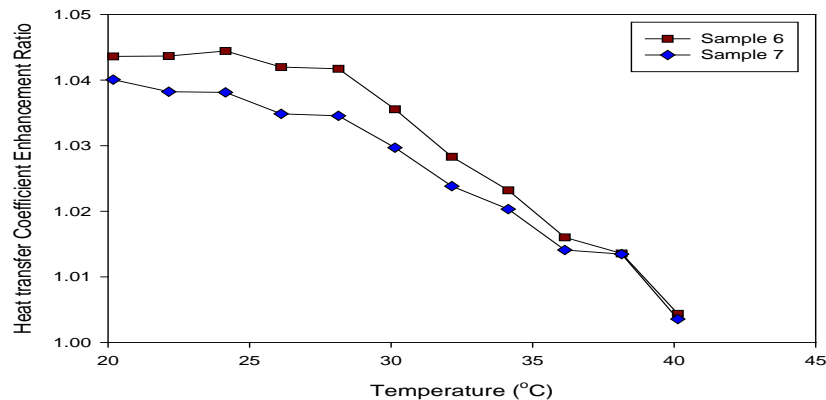


Figure9. Heat transfer coefficient enhancement ratio

4. Conclusion

This experimental approach was done on the basis of thermal conductivity as well as heat transfer coefficient enhancement ratio. After analysis and comparison of these points of view, the key conclusions can be digested as follows:

- Surfactants (SDS, SDBS) are useful for both grinding and dispersing processes.
- In this experiment, the one of the causes of applying wet grinding was to minimize the possibility of contamination by decomposition of surfactants and this was considered theoretically. The presence of surfactant induced contamination in grinding process can be disclosed by the analysis of X-ray diffraction (XRD) spectra where either shifting in peak positions or the appearance of new diffraction peaks will indicate the contamination [20]. The decreasing trends of thermal conductivity were due to the sedimentation of nanoparticles in a base fluid (DW) with time.
- Beside the thermal conductivity, heat transfer coefficient enhancement ratio was calculated and both revealed that GN-SDS with 2/1 ratio, 1 hour with 500 rpm of wet grinding, 20 minute ultrasonication was the better nanofluid in this experiment.

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