ACCOUSTICAL AND THERMODYNAMICAL STUDY OF GRAPHENE OXIDE- N-METHYL-2-PYRROLIDONE NANOSUSPENSION

ALOK JAIN & K.C. JUGLAN

Department of Physics, School of Chemical Engineering and Physical Sciences LPU, Phagwara, 144401, Punjab, India

ABSTRACT

Graphene Oxide (GO) shows some excellent properties like very high electron mobility, excellent thermal conductivity, and most robust material, etc. All these properties make the GO a unique material. GO was produced in this study with the help of Hummer's method. This prepared GO was used to create a nanosuspension with N-Methyl-2-Pyrrolidone (NMP). NMP is an excellent solvent which extensively used in industry to dissolve many polymers. Another use of the NMP is in the paint industry; pharmacy industries use NMP in both oral and transdermal delivery routes. Here in this study, we use NMP as a base fluid for the suspension of GO nanoparticles with the help of an excellent ultrasonication technique. DLS checks the stability of the prepared nanosuspension. This prepared nanosuspension used to study various thermoacoustic parameters. The interferometer has calculated the velocity of the samples; the pycnometer estimated the density of the GO-NMP nanosuspension, and the rotational viscometer used to calculate the viscosity of the nanosuspension. All these studies are carried out at the temperature range from 298 to 313 K. These experimental values used to calculate the derived costs like adiabatic compressibility, attenuation, relaxation time, Bulk modulus, etc. in this paper; we have calculated the various acoustical properties of the GO-NMP nanosuspension.

KEYWORDS: Graphene Oxide; FESEM; XRD; EDS; UV-Visible; Ultrasonic Velocity; Density; Viscosity; Bulk Modulus; Nanosuspension; Adiabatic compressibility

Received: Jun 08, 2020; **Accepted:** Jun 28, 2020; **Published:** Aug 19, 2020; **Paper Id.:** IJMPERDJUN2020813

INTRODUCTION

When we disperse nanoparticles in the solvent under the controlled condition, the suspension mixture prepared is called the nanosuspension. Many definitions of nanosuspensions; nanofluids are available in the literature; in this study, we are considering the size of the solute particles are in the range of 100 to 500nm than the suspension is called nanosuspension [1]. A lot of examples of nanosuspension are available in the literature most of the example available is based on nanoparticles of carbon like carbon nanotubes, nanoparticles of metals and metal oxides, ceramics, etc. all these nanoparticles shows some remarkable properties when compared to their micrometer counterpart. It is discussed in the literature that most of the impressive features of the nanoparticles are because of the larger surface area. The addition of nanoparticles with the larger surface enhances the overall properties of the fluid in which we are mixing it [2-5]. Since the size of the nanoparticles is very small, they can interact with the molecules of the solvent. When we apply heat, the molecules of the liquid will start random zigzag motion. Due to this motion, molecules collide with the nanoparticle of the suspension. During this process, heat is transferred to the nanoparticles, and they start moving at a rapid pace in the suspension. This rapid movement in the suspension helps to give higher thermal conductivities in the case of nanofluids. Therefore, it is a perfect opportunity to study the nanosuspension of these available solute and solvent.

Ultrasonication is a recognized method for studying these crisscross motions of particles and diffusing accumulated nanoparticles for aqueous nanosuspension preparation [6-7]. Since as per literature, it has been observed that when we add ordinary particles with micron-size, it causes changes in ultrasonic velocity and ultrasonic attenuation. So, the size of particles also plays an essential role in the study of nanosuspension. The demand of the ultrasonication in the research also increases the curiosity of the research groups to study the effect of passing the ultrasonic waves through the nanosuspensions. Many researchers are studying the ultrasonic velocity, density, and viscosity of nanosuspensions. Since we know the surface to volume percentage of the nanoparticles is very high, they can significantly improve the thermoacoustic properties of the nanosuspension. Hence it is essential to discuss the impact of the density of the solid particles on the properties of pure liquids to predict the final properties of the nanosuspensions.

In the last decade, graphene was one of the essential materials which we able to discover and study. After its discovery in 2004, a series of properties have been considered and reported by many research groups. Firstly, the manufacturing process of the graphene is itself a topic of research; many research groups are working to find a clean and green way to produce graphene. As far as the properties of graphene are concerned, it has been reported that this material is having high mobility of electron, impermeable to gasses, most potent content available, very high thermal conductivity, etc. Graphene offers a lot of opportunities in the field of research and development, but still, there are some gaps available like production of the graphene at the industry scale is not possible, the creation of the graphene involves toxic gasses, there are very less available solvents in which graphene can be suspended[8-11].

In this paper, we are studying the thermoacoustic properties of the prepared GO-NMP nanosuspension at different temperatures as well as different concentrations of GO. Different thermodynamically, physical, and fluid-particle interaction studies have done and related. Various acoustical parameters like ultrasonic velocity, density, viscosity were calculated at a temperature range of 298 to 313 K and explained.

MATERIAL AND METHOD

Reagent and Chemicals

Graphite powder, sodium nitrate procured from Sigma Aldrich, KMnO_4 , HCL , H_2SO_4 and Ammonia has taken from CDH. H_2O_2 has obtained from fisher scientific. NMP has been procured from sigma Aldrich. All chemicals employed during this research were of AR quality and utilized without additional purification. Throughout the whole experiment, double distilled water used.

Methods

As mentioned earlier, GO was prepared by the novel Hummers method. In this method, 4g of carbon powder was mixed with 8 g of sodium nitrate. On the other side, a flask of 1 liter was taken and placed on the magnetic agitator. An ice bath has been formed all around the flask, and a thermometer is set inside the flask to measure the temperature. Now 160 ml of sulphuric acid was added to the flask with a mixture of carbon powder and sodium nitrate. Keeping the check on the temperature and makes sure that it should be close to zero. As soon as the temperature of the mixture reaches zero and carbon is fully dissolved in the sulphuric acid, we can move to the next step. Now we add potassium permanganate in the mixture very slowly because the reaction of the potassium permanganate with the mixture is exothermic. The rate of adding the potassium permanganate in the mixture should be so slow that the temperature of the reaction should not go above 90 °C. We have done continuous stirring for 3 hours. After 3 hours, the ice bath was removed, and the flask was

moved to a water bath where 40 °C temperature was maintained. This increase in temperature boosts the oxidation process in the reaction mixture. After half an hour, the flask is again transferred to a magnetic stirrer without an ice bath, now again keeps the mixture on a magnetic stirrer until the shade of the combination adjusts from black to yellowish-brown, keep a rotation of the magnetic stirrer to the lowest. After 24 hours, the 30 % hydrogen peroxide was added to the mixture, which stops the further oxidation of the mixture. Further water was added to the mixture very slowly. More water was added to the mixture, and the mixture divided into two parts for easy handling. Leaving the mixture overnight helps to remove the excess water from the final product. Furthermore, water was used for washing, and the mixture was washed with hydrochloric acid two times. The hydrochloric wash will remove the excess metal ions from the final product and will increase the purity of the sample after that sample was again washed and kept for 3 hours of continuous ultrasonication. Then the filtered result was dried up in a vacuum at the temperature of 40 °C. After drying, brown color powder of the GO was obtained. This GO powder was used to make nanosuspension of the different concentrations with the help of ultrasonication. [7], [12-14].

Characterization of GO and GO-NMP Nanosuspension

In this study for the SEM analysis, we have used Nova Nano FESEM 450 with the attached EDS for the micrograph studies. For the preliminary investigation of the sample, the FTIR spectrum has been calculated with the help of Shimadzu 8400S spectrometer, appearing in the scope of 400 to 400 cm^{-1} . XRD has been calculated with the help of Panalytical Xpert Pro. The final testing of the sample has been done with the Raman spectrometer model Airix STR 500 at wavelength 1.54 Å. The average size of the particle size in the formulated nanosuspension in conjunction with Malvern Zetaster Nano Z290. The velocity of the ultrasonic wave inside the liquid sample, together with the use of Mittal Interferometer M-81 with a static frequency of 2 MHz, the density of the prepared nanosuspension has been calculated by a pycnometer. In this study, the viscosity of the sample has been calculated with rotatory viscometer model Labman LMDV-200.

DATA TABLE

Table 1: GO-NMP Nanosuspension

Concentration (mg/ml)	Temperature(T) (K)	Average Velocity(U) (m/s) $U = \lambda \times f$	Density(ρ) (Kg/m^3)	Viscosity(η) (Pa-s)	Adiabatic Compressibility(β) (1/Pa) $\beta = 1/ (U^2 \times \rho)$
0	299	1547.69	1028.316	0.001661	4.06E-10
0.2	299	1556.69	1046.763	0.001794	3.94E-10
0.4	299	1567.69	1053.713	0.001839	3.86E-10
0.6	299	1576.46	1061.288	0.001989	3.79E-10
0.8	299	1583.46	1064.063	0.002134	3.75E-10
1	299	1592.38	1066.813	0.002277	3.70E-10
0	304	1526.15	1023.823	0.001523	4.19E-10
0.2	304	1535.69	1042.713	0.001643	4.07E-10
0.4	304	1545.92	1049.688	0.00175	3.99E-10
0.6	304	1552.15	1057.213	0.001865	3.93E-10
0.8	304	1559.15	1060.438	0.002	3.88E-10
1	304	1570	1061.904	0.002128	3.82E-10
0	309	1504.69	1019.33	0.001413	4.33E-10
0.2	309	1514.69	1038.538	0.00155	4.20E-10
0.4	309	1521.69	1046.663	0.001635	4.13E-10
0.6	309	1529.62	1053.163	0.001717	4.06E-10
0.8	309	1539.69	1055.513	0.001844	4.00E-10
1	309	1549.77	1057.263	0.001966	3.94E-10
0	314	1483.00	1014.72	0.001259	4.48E-10

Table 1: Contd.,

0.2	314	1489.23	1035.338	0.001375	4.36E-10
0.4	314	1497.23	1042.263	0.00153	4.28E-10
0.6	314	1507.08	1049.063	0.001649	4.20E-10
0.8	314	1515.23	1052.263	0.001743	4.14E-10
1	314	1526.15	1054.438	0.001887	4.07E-10

Table 2: GO-NMP Nanosuspension

Concentration (mg/ml)	Temperature (T) (K)	Acoustical impedance (Z) (Pa. s/m ³) $Z = \rho \times U$	Attenuation (α/f^2) (m ⁻¹) $\alpha/f^2 = 8\pi^2\eta/3\rho U^3$	Bulk Modulus (K) (Pa) $K = \rho U^2$	Relaxation Time (τ) (s) $\tau = 4\beta\eta/3$	Intermolecular Free Length (L_f) ($L_f = K_T \times \beta^{1/2}$)
0	299	1591516.763	1.14556E-14	2463178252	8.99E-13	4.17E-10
0.2	299	1629487.132	1.19433E-14	2536610083	9.43E-13	4.05E-10
0.4	299	1651896.981	1.1909E-14	2589666190	9.47E-13	3.97E-10
0.6	299	1673078.925	1.25794E-14	2637544576	1.01E-12	3.90E-10
0.8	299	1684902.043	1.32835E-14	2667977582	1.07E-12	3.85E-10
1	299	1698775.813	1.38963E-14	2705104471	1.12E-12	3.80E-10
0	304	1562511.409	1.10016E-14	2384632797	8.51E-13	4.35E-10
0.2	304	1601285.565	1.14405E-14	2459081925	8.91E-13	4.22E-10
0.4	304	1622736.13	1.18639E-14	2508625231	9.30E-13	4.14E-10
0.6	304	1640956.448	1.24025E-14	2547016862	9.76E-13	4.07E-10
0.8	304	1653385.207	1.3085E-14	2577881904	1.03E-12	4.02E-10
1	304	1667189.542	1.36121E-14	2617487580	1.08E-12	3.96E-10
0	309	1533778.16	1.07009E-14	2307864200	8.17E-13	4.54E-10
0.2	309	1573064.763	1.12931E-14	2382709095	8.67E-13	4.39E-10
0.4	309	1592698.275	1.16563E-14	2423596714	8.99E-13	4.32E-10
0.6	309	1610933.563	1.19779E-14	2464108761	9.29E-13	4.25E-10
0.8	309	1625164.477	1.25865E-14	2502253244	9.83E-13	4.18E-10
1	309	1638512.891	1.31357E-14	2539316863	1.03E-12	4.12E-10
0	314	1504829.76	9.99993E-15	2231662534	7.52E-13	4.73E-10
0.2	314	1541856.462	1.05725E-14	2296180084	7.98E-13	4.59E-10
0.4	314	1560507.485	1.14968E-14	2336439822	8.73E-13	4.52E-10
0.6	314	1581017.885	1.20714E-14	2382715569	9.23E-13	4.43E-10
0.8	314	1594420.517	1.25195E-14	2415915027	9.62E-13	4.37E-10
1	314	1609233.846	1.32351E-14	2455938424	1.02E-12	4.30E-10

RESULT AND DISCUSSIONS

Figure 1(a) shows the FESEM image of the prepared GO sample at 20000X magnification. The stacking of the carbon layers can be seen in the image very clearly. The side layers of the carbon sheets are visible, which confirms the conversion of the carbon powder into graphene oxide. In figure 2, elemental analysis of the prepared sample is given; this EDS is taken with FESEM with EDS attachment, which uses backscattered electrons. The carbon content present in the sample is 74.33 %, and oxygen is 24.46%. The amount of oxygen present in the sample shows good oxidation of the prepared sample. This confirms the conversion of carbon powder into graphene oxide. [15], [16]

FTIR of the prepared sample is given in figure 3. Peaks at 1116.8 confirm the presence of a carbon-oxygen stretching bond, which again strengthens the existence of oxygen inside the sample. The peaks at 1618.3 confirm the bonding between carbon and carbon, the peak in the range of 1400 to 1700 confirms the presence of graphene in the sample under study as per literature. 2445.5 corresponds to the presence of carbon dioxide in the sample [17-19].

The study of the XRD spectrum shows a peak at 8.934, as per figure 4. We know XRD works on the principle of Braggs law. As per this law, if the separation between two planes is large, then the angle corresponding to the material will be less. In our sample, the peak comes at a shallow angle, which shows the separation of the layer with a larger distance. This large distance may be due to the presence of a big oxygen atom in between the layers of carbon. [22-22]. Raman spectrum is shown in figure 5. two peaks are clearly visible in the Raman spectra; the first peak is at 1352.3, and the second peak is at 1595.2. as per the literature, the first zenith resembles the imperfection appear in the graphene network, and the second peak corresponds to the good structure of the graphene network. the ratio of the intensity of defect peak and good structure peak is $I_D/I_G = 0.84$, which shows the presence of a good graphene network in the sample preparation. [23-25]

Figure 1: (a) FESEM Image of GO

Figure 2: EDS of GO

Figure 3: FTIR of GO

Figure 4: XRD of GO

Figure 5: Raman Spectra of GO

Figure 6: Particle size of GO in NMP

As discussed earlier, nanosuspension has been prepared with intensive ultrasonication. So the presence of the GO can be shown with the help of UV-Vis, but in this study, we are using NMP as the solvent, which has a UV cut off wavelength 285 cm^{-1} but we know the peak of the GO comes near 230 cm^{-1} but here which cannot be measured. So, we are not discussing UV-Vis spectra in this study [26-27]. The size of the particles and their distribution has been calculated with the help of the Dynamic light scattering method. The results of DLS have been plotted in figure 6. It is visible from the figure that the size of the particle in the solvent is between 130 to 155 nm. [16], [28-29]. Since the particle size is above 100 nm, we call our sample as nanosuspension, not nanofluid.

To understand the intermolecular and intraparticle interaction among the solute molecule and solvent, it is essential to study the ultrasonic parameters of the nanosuspension. The ultrasonic velocity of all prepared samples has been calculated at the temperature 298, 303, 308, and 313K. Approximately 20 reading has been taken for each concentration to avoid any experimental error. In figure 7(a), it is clearly visible that the ultrasonic velocity increases with the increase of concentration of the particles inside the solvent. This behaviour is in line with the increase of intramolecular interaction over intermolecular interaction, which means particles are attracted to the solvent. The growth of the number of particles present with increasing concentration also contributes to the outward layer, which additionally increases the speed inside

the sample. An increase in the temperature decreases the ultrasonic velocity in the sample; that is might be because the zigzag motion of the solvent molecules increases with the rise in the heat, which hinders the passage of ultrasonic waves through the sample [30-31]. From figure 7 (b), the density of the liquid increases with the addition of GO particles in the NMP. The values increase from range 1010 kg/m^3 to 1050 Kg/m^3 . As seen in the image, as soon as GO powder is added to the liquid, there is a sudden jump in the density. After this, there is a slight increase in the density of nanosuspension. The rise in the density is because of increased intramolecular collaboration than intermolecular collaboration. The density of the nanosuspension decrease with the rise in the heat of the nanosuspension, as shown in figure 7(b). The reason can be intermolecular interaction improve with a rise in the temperature [32-33]. In figure 7(c), it can be seen clearly that the viscosity of the GO-NMP nanosuspension rises with a rise in the particle concentrations. The rise in the viscosity with particle loading can be due to the increase in the particle-solvent interaction, which increases the viscosity. On the other hand, the viscosity of the GO-NMP nanosuspension declines with an upsurge in the temperature. The fundamental reason behind this decrease is the rise in the zigzag movement of the NMP solvent molecules increases with increasing temperature [2], [31].

Figure 7: (a) Velocity of sound in GO-NMP nanosuspension (b) density of GO-NMP nanosuspension (c) viscosity of GO-NMP nanosuspension (d) Adiabatic compressibility of GO-NMP nanosuspension (e) Acoustical impedance of GO-NMP nanosuspension (f) Attenuation of the ultrasonic wave in GO-NMP nanosuspension (g) Bulk Modulus of GO-NMP nanosuspension (h) Relaxation time for GO-NMP nanosuspension (i) Intermolecular free length in GO-NMP nanosuspension.

Figure 7(d) shows the continuous decline in the adiabatic compressibility with the increase in the particle loading of the GO particle in the NMP. This decrease is because of increased particle and solute molecule interaction. Adiabatic compressibility increases with an increase in the temperature that might be because of increasing intermolecular interaction between solvent molecules. [34-35]. Figure 7(e) shows the continuous increase in the acoustical impedance with the increase in the GO particles in the NMP solvent. The increase in the impedance value suggests the increased interaction between molecules of the solvent and solute, which also affects the structural change. The acoustic impedance decreases because the Zigzag movement of the solvent increases with the rise in the heat, and the solvent molecule interacts with

nanoparticles, which creates a gap between the molecules, which helps the ultrasonic waves to pass through the liquid easily. [36-37]. Figure 7(f) shows the attenuation of the ultrasonic wave inside the GO-NMP nanosuspension. With the rise in the particle loading in the fluid, attenuation of the ultrasonic wave decreases. This may be due to network formation by GO particles, which reduces the intensity of the ultrasonic wave to reach from one end to the other. Attenuation declines with the rise in the heat of the sample. This might be due to the increase in the particle and solute interaction as this interaction increases the gap between molecules increases, which helps to pass the ultrasonic wave easily [38-39]. Bulk modulus is the fluid's opposition to the stress being applied. In figure 7(g), it can be seen clearly that the value of bulk modulus rises with the increase in the particle loading in the solvent. Interaction between the particle and fluid increases as the concentration of the GO-NMP nanosuspension increases. The value of the bulk modulus decreases with the rise in the heat of the nanosuspension. The resistance of the nanosuspension decreases to the externally applied stress at a higher temperature because the interaction between particle and solute increases creates the gap between molecules, which helps in decreasing bulk modulus [40-41]. The relaxation time of the GO-NMP sample increases with the increase in the particle concentration in the GO-NMP nanosuspension. Since the interaction between the solvent molecules and solute increases. The reordering time for the solute molecules increases. When the heat of the GO-NMP nanosuspension rises, the zigzag movement of the solvent molecule increases, which helps to reorder the molecules quickly because of fast motion [41-42]. The intermolecular length of the sample rises with a rise in the particle loading in the GO-NMP nanosuspension. It shows the interaction between particle and solvent molecules increases. The increase in the intermolecular length with the rise in the heat is because the zigzag movement of the solvent molecules rises, and this movement increases the solute and solvent molecule interaction [36-37].

CONCLUSIONS

GO was prepared using the Hummers method. The characterization of the sample proves the formation of the graphene oxide and nanosuspension formulation. Top-Down approaches have been used to disperse the GO nanoparticles in the NMP. Ultrasonication of the samples helps to distribute GO particles evenly in the NMP. From the above discussion, it can be concluded that the intermolecular interaction between GO and NMP molecules dominates than GO-GO interaction or NMP-NMP interaction. The velocity, density, viscosity, acoustical impedance, attenuation increase with a rise in the particle loading of the GO in the nanosuspension. On the other hand, adiabatic compressibility and intermolecular free length decline with a rise in particle loading. Ultrasonic velocity, density viscosity, acoustical impedance, attenuation, bulk modulus declines with the rise in the heat. On the other hand, adiabatic compressibility and intermolecular free length decline with the rise in the temperature. There is no complex structure formation indicated in the present study.

ACKNOWLEDGMENTS

The writer would like to thank the Department of Physics for having the requisite laboratory facilities at Lovely Professional University. The writer is also grateful for the support in characterizing by MNIT Jaipur.

REFERENCES

1. Chingunpituk J 2007 *Nanosuspension Technology for Drug Delivery Walailak J Sci Tech* 4 139–53
2. Nabeel Rashin M and Hemalatha J 2014 *A novel ultrasonic approach to determine thermal conductivity in CuO-ethylene glycol nanofluids, J. Mol. Liq.* 197 257–62

3. Kharat P B, More S D, Somvanshi S B, and Jadhav KM 2019 Exploration of thermoacoustic behaviour of water-based nickel ferrite nanofluids by ultrasonic velocity method *J. Mater. Sci. Mater. Electron.* 30 6564–74
4. Leena M and Srinivasan S 2015 Synthesis and ultrasonic investigations of titanium oxide nanofluids *J. Mol. Liq.* 206 103–9
5. Xu C, Shi X, Ji A, Shi L, Zhou C and Cui Y 2015 Fabrication and characteristics of reduced graphene oxide produced with different green reductants *PLoS One* 10
6. Jain A, Kaur P, and Juglan KC 2020 Synthesis and Ultrasonic Investigation of Reduced Graphene Oxide Nanosuspension with Water *J. Phys. Conf. Ser.* 1531 0–16
7. Wang Y, Peng Z, and Jiang W 2016 Controlled synthesis of Fe₃O₄@SnO₂/RGO nanocomposite for microwave absorption enhancement *Ceram. Int.* 42 10682–9
8. Dilip Kumar Singh P K I and Giri P K 2011 Improved Chemical Synthesis of Graphene Using a Safer Solvothermal Route *Int. J. Nanosci.* 10 1–4
9. Jiang H, Zhang Q and Shi L 2015 Journal of the Taiwan Institute of Chemical Engineers Effective thermal conductivity of carbon nanotube-based nanofluid *J. Taiwan Inst. Chem. Eng.* 55 76–81
10. Rambabu, V., J. Ramarao, and S. Ravibabu. "Enhancement of Heat transfer in Shell and Tube heat exchanger by using nano fluid." *International Journal of Mechanical and Production Engineering Research and Development*, 7 (5) (2017): 191-198.
11. Pei S and Cheng H M 2012 The reduction of graphene oxide *Carbon N. Y.* 50 3210–28
12. Greve C and Jorgensen L 2016 Therapeutic Delivery *Ther. Deliv* 7 117–38
13. Kumar, M. Ajay. "Thermal Characterization of Hybrid Nano Fluids." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) Special Issue, Jun 2018*, 215-222
14. Paulchamy B, Arthi G and Bd L 2015 A Simple Approach to Stepwise Synthesis of Graphene Oxide 6 2–5
15. Yang S, Deng B, Ge R, Zhang L, Wang H, Zhang Z, Zhu W and Wang G 2014 Electrodeposition of porous graphene networks on nickel foams as supercapacitor electrodes with high capacitance and remarkable cyclic stability *Nanoscale Res. Lett.* 9 1–11
16. Naficy S, Jalili R, Aboutalebi S H, Gorkin R A, Konstantinov K, Innis P C, Spinks G M, Poulin P, and Wallace G G 2014 Graphene oxide dispersions: Tuning rheology to enable fabrication *Mater. Horizons* 1 326–31
17. Kumar, Hema, et al. "Design and Simulation of Double Wishbone (Sla) Suspension Geometry." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 9.5, Oct 2019, 679–688
18. Xiong G, Meng C, Reifengerger R G, Irazoqui P P and Fisher T S 2014 Graphitic Petal Micro-Supercapacitor Electrodes for Ultra-High Power Density Energy Technol. 2 897–905
19. Lee Y, Choi J, Lee K J and Stott N E 2008 Large-scale synthesis of copper nanoparticles by a chemically controlled reduction for applications of inkjet-printed electronics 415604
20. Eftekhari A, Li L and Yang Y 2017 Polyaniline supercapacitors *J. Power Sources* 347 86–107
21. Xiong G, Meng C, Reifengerger R G, Irazoqui P P and Fisher T S 2014 A review of graphene-based electrochemical micro-supercapacitors *Electroanalysis* 26 30–51
22. Kosti, Siddhartha. "Effect of Heat-Flux Boundary on Buoyancy-Driven Flow in a Two-Dimensional Square-Enclosure Utilizing Cu-H₂O Nano-Fluid." *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)* 4.6 (2014): 23-36p.

23. Htut Z, Kim M, Lee E, Lee G, Baek S H, and Shim S E 2017 Biodegradable polymer-modified graphene/polyaniline electrodes for supercapacitors *Synth. Met.*227 61–70
24. Trung NB, Tam T Van, Kim H R, Hur S H, Kim E J and Choi W M 2014 Three-dimensional hollow balls of graphene-polyaniline hybrids for supercapacitor applications *Chem. Eng. J.*255 89–96
25. Zong M, Huang Y, Wu H, Zhao Y, Wang S, Zhang N, and Zhang W 2013 Facile synthesis of RGO/Fe₃O₄/Ag composite with high microwave absorption capacity *Mater. Lett.*111 188–91
26. Gui D, Liu C, Chen F, and Liu J 2014 Preparation of polyaniline/graphene oxide nanocomposite for the application of supercapacitor *Appl. Surf. Sci.*307 172–7
27. Saeed E, Piñeiro M M, Hermida-Merino C and Pastoriza-Gallego M J 2019 Determination of transport properties of glycol-based nanofluids derived from surface-functionalized graphene *Nanomaterials*9
28. Liu G, Jiang W, Sun D, Wang Y, and Li F 2014 One-pot synthesis of urchinlike Ni nanoparticles/RGO composites with extraordinary electromagnetic absorption properties *Appl. Surf. Sci.*314 523–9
29. Cheng Y, Li H, Fang C, Wang K, Chen J, Su J, and Zheng F 2019 Green Synthesis of Fluorescent Ag-Anionic Polyacrylamide Nanoparticles Gels Solution with High Stability via a Simple Template Method *Results Phys.* 102636
30. Li D, Müller M B, Gilje S, Kaner R B, and Wallace G G 2008 Processable aqueous dispersions of graphene nanosheets *Nat. Nanotechnol.*3 101–5
31. Hummers W S and Offeman R E 1958 Preparation of Graphitic Oxide *J. Am. Chem. Soc.*80 1339
32. Ma J . J, et al. 2015 Large area few-layer graphene/graphite films as transparent thin conducting electrodes *J. Mol. Liq.*3 1–4
33. Bao H, Pan Y, Ping Y, Sahoo N G, Wu T, Li L, Li J, and Gan L H 2011 Chitosan-functionalized graphene oxide as a nanocarrier for drug and gene delivery *Small*7 1569–78
34. Hemalatha J, Prabhakaran T, and Pratibha Nalini R 2011 A comparative study on particle-fluid interactions in micro and nanofluids of aluminium oxide *Microfluid. Nanofluidics*10 263–70
35. Khushboo, Devi A, Malik P, and Kumar H 2016 Thermodynamic and acoustical study of zinc oxide-nematic liquid crystals mixtures *J. Mol. Liq.*214 145–8
36. Nain A K and Lather M 2016 Study of solute-solute and solute-solvent interactions of homologous series of some α -amino acids in aqueous-D-xylose solutions at different temperatures by using physicochemical methods *J. Chem. Thermodyn.*102 22–38
37. Mauricio M R, Velasco D S, Guilherme M R, Kunita M H, Neto A M, Bento A-C and Rubira A F 2014 Zinc oxide composites prepared by in situ process: UV barrier and luminescence properties *Mater. Lett.*125 75–7
38. Pandey J D, Dubey G P, Shukla B P and Dubey S N 1991 Prediction of ultrasonic velocity and intermolecular free-length and their correlation with interaction in binary liquid mixtures *Pramana*37 497–503
39. Kenry, Yeo J C, Yu J, Shang M, Loh K P, and Lim C T 2016 Highly Flexible Graphene Oxide Nanosuspension Liquid-Based Microfluidic Tactile Sensor *Small*12 1593–604
40. There P S 2013 Study of Molecular Interactions of 3, 4- Dihydroxy-5-Nitrobenzaldehyde in Ethanol Using Ultrasonic Interferometer *6* 111–6
41. Ashima, Juglan K C, and Kumar H 2020 Volumetric and ultrasonic investigation of polyethylene glycols (PEG-200 and PEG-600) in aqueous solutions of sodium methylparaben at various temperatures *J. Chem. Thermodyn.*140 105916

42. Thakur A, Juglan K C, Kumar H, and Kaur K 2019 Investigation on the molecular interaction of glycols in methanol solutions of methylparaben (methyl 4 – hydroxybenzoate) at different temperatures through thermo-acoustical analysis *J. Mol. Liq.* 288 111014
43. [Pardeike J, Strohmeier D M, Schrödl N, Voura C, Gruber M, Khinast J G, and Zimmer A 2011 Nanosuspensions as advanced printing ink for accurate dosing of poorly soluble drugs in personalized medicines *Int. J. Pharm.* 420 93–100
44. Ayachit N H, Vasan S T, Sannaningannavar F M, and Deshpande D K 2007 Thermodynamic and acoustical parameters of some nematic liquid crystals *J. Mol. Liq.* 133 134–8
45. Tumberphale U B, Kawale R S, Pawar N P, and Kalamse V G 2015 Ultrasonic Behaviour of Binary Mixture of Ethanol in Ethylene Diamine at 3 Mhz Frequency *Int. J. Phys. Math. Sci.* 5 25–31
46. Mahapatra A P 2016 Acoustic and Ultrasonic Studies of Dextran in 2 (M) Glycine-Variation with Frequencies and Concentrations 12 71–9"