Major Project Report 2014-2015

On

Study the effects on rheological properties of nanofluids

Under the guidance of

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(Physics Department)

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This is to certify that the work contained in this minor project report titled **"<u>Study the effects on rheological properties of nanofluids</u>"** is being carried out by

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Acknowledgement

We would like to express our gratitude to our mentor **Dr.Gagan Anand,** our activity coordinator **Dr. S.V. Garimella,** H.O.D of Mechanical department and all the other faculty member of Physics Department (U.P.E.S) who gave us the golden opportunity to work on this project titled "**<u>Study the effects on the rheological properties of nanofluids</u>".**

We would also like to thank our friends who helped us a lot in finalizing this project within the stipulated time frame.

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ABSTRACT

Nanolubricants have been the topic of discussion lately. Not only from researcher's point of view but also for industrialists and businessmen, owing to its easy and versatile applications so far. As for the transportation sector, nanolubricants hold great potential to improve automotive, heavy duty engine cooling rate, wear, friction by increasing efficiency, lowering weight and reducing complexity of thermal management systems.

On adding carbon additives like CNT, graphene, fullerenes, to conventional lubricants like engine oil, not only enhances the properties of fluid (viscosity, thermal conductivity, elasticity) but also reduces friction to great extent. This is because the additives are nanoparticles i.e. having dimensions in nano scale which offers much better properties than any bulk material. The surface-to-volume ratio of these nanoparticles is so high that even their small concentration dispersed in lubricant enhances its quality.

Many researchers have earlier used nanoparticles with base oils to improve anti wear and friction properties. These include- Philip who studied effect of graphite and carbon nanofibers as additives on the performance efficiency of gear pump driven hydraulic circuit using ethanol solution.

They claim that both graphite and carbon nanofibers dispersions in ethanol within a concentration range of 195-1500 ppm can maintain hydraulic circuits with increase pump efficiency without modifying the viscosity of the ethanol. Zhang has reported 17 and 14% reduction in frictional coefficient and wear, respectively, with oleic acid-modified graphene as lubricant additive. The studied tribological properties of reduced graphene oxide (RGO) sheets on silicon substrate synthesized via covalent assembly.

The practical applications are on road! In U.S.A, car manufacture GM and Ford are running their own research programs on nanofluids.

The main objectives of the study include:

- To assess the properties of base oils and choose the best sample
- Preparation of a series of nanofluids using (Carbon Nano Tubes)
- Evaluate prepared sample for different concentration and prepare a comparative study for maximum optimization
- To review properties of the product for potential applications.

INTRODUCTION

Materials with a nanometer-sized microstructure are called nanocrystalline materials. The synthesis, characterization and processing of such nanocrystalline materials are part of an emerging and rapidly growing field referred to as nanotechnology. Research & development in this field emphasizes scientific discoveries in generation of materials with controlled micro structural characteristics, research on the processing with engineered properties and technological functions, and introduction of new device concepts and manufacturing methods. Recent advances in techniques for the deposition and processing of thin films have enabled the design and manipulation of materials with unique properties that are often unachievable in bulk materials. The materials and/or devices involved may be divided into the following three categories.

The first category comprises materials and/or devices with reduced dimensions in the form of isolated, substrate-supported or embedded nanometer-sized particles, thin wires or thin films. CVD, PVD, inert gas condensation, various aerosol techniques, precipitation from the vapor, from supersaturated liquids or solids (both crystalline and amorphous) are techniques most frequently used to generate this type of microstructure.

The second category comprises materials and/or devices in which the nanometer-sized microstructure is limited to a thin (nanometer-sized) surface region of a bulk material. PVD, CVD, ion implantation and laser beam treatments are the most widely applied procedures to modify the chemical composition and/or atomic structure of solid surfaces on a nanometer scale.

Nanofluids have high boiling point, it can be used to improve normal coolant temperature.Kole et al.prepared car engine coolant (Al2O3 nanofluid) using standard car engine coolant (HPKOOLGUARD) as the base fluid and studied thermal conductivity and viscosity of the coolant.

The prepared nanofluid, containing only3.5% volume fraction of Al2O3, displayed a fairly high amount of thermal conductivity than base fluid and a maximum enhancement of 10.41% was observed at room temperature. Tzeng et al, applied nanofluids to cooling of automotive transmission oil by dispersing CuO and Al2O3nanoparticles into engine oil. The researchers of Argonne National Laboratory have assessed the applications of nanofluids for transportation. The use of high thermal conductive nanofluid in radiators can lead to a reduction in frontal area of the radiator up to 10%.The fuel saving is upto 5% due to a reduction in aerodynamic drag.

Thus, reducing the size and weight of a fuel tank. Xie et al. [25,26] prepared and measured the thermal conductivities of 26 nm and 0.6 μm SiC suspensions in deionized water and EG using a transient hot-wire method. Different from experimental results of Lee at al. [10], they found that the nanofluids with the same solid particles in different base fluids had the same improvement in the effective thermal conductivity.

Assael et al. [39,40] experimentally studied the enhancement of the thermal conductivity of carbon-multiwall nanotubes (C-MWNT)–water suspensions with 0.1 wt% sodium dodecylsulfate (SDS) as a dispersant. They found that the maximum thermal conductivity enhancement was 38% for a 0.6 vol% suspension.

Results showed that the additional SDS would interact with C-MWNT in that the outer surface was affected. Later, Assael et al. [41] repeated the similar measurements using carbon-multiwall nanotubes (C-MWNTs) and carbon doublewalled nanotubes (C-DWNTs), but using hexadecyltrimethyl ammonium bromide (CTAB) and nanosphere AQ as dispersantsinstead. The maximum thermal conductivity enhancement obtained
was 34% for a 0.6 vol% C-MWNT–water solution.

Nanofluids also show remarkable results when it comes to tribology.Single walled CNTs doped with base oil when tested for friction coefficient was found to be 0.069 which is lower than friction coefficient of base oil i.e 0.09-0.10(Fukushima et al). Xu et al. (1996) investigated tribological properties of the two-phase lubricant of paraffin oil and diamond nanoparticles, and the results showed that, under boundary lubricating conditions, this kind of two-phase lubricant possesses excellent load-carrying capacity, anti-wear and friction-reduction properties.

According to Verma et al. (2007), MoS2 in its nanoparticulate form has exceptional tribological properties, which can reduce friction under extreme pressure conditions. Wu et al. (2006) examined the tribological properties of lubricating oils with CuO, TiO2, and diamond nanoparticles additives.

The experimental results show that nanoparticles, especially CuO, added to standard oils exhibit good friction-reduction and anti-wear properties.(Taylor and Francis et al) In this work, the influence of temperature and concentration on the viscosity index of oil-multiwalled carbon nanotube (MWCNT) nanofluids has been investigated theoretically and experimentally. Data were collected for temperatures ranging from ambient to 100°C and for concentrations ranging from 0.01 to 0.2 wt.% of MWCNT. The results show that viscosity is enhanced with increasing the MWCNT concentration and decreasing temperature.

Experimental results emphasize that the maximum enhancement of the viscosity index is 14.11% for MWCNT-oil nanofluid. Stability examinations of the nanofluids have been performed by a UV-vis spectrophotometer.

It has been found that the Einstein formula and those derived from the linear fluid theory are valid for relatively low particle volume fractions of MWCNT, and for higher MWCNT concentrations the discrepancy between these formulas and experimental data is significant, indicating that the linear fluid theory is no longer appropriate to represent the real behavior of these nanofluids.

LUBRICANTS

A lubricant is a substance introduced to reduce friction between surfaces in mutual contact, which ultimately reduces the heat generated when the surfaces move. It may also have the function of transmitting forces, transporting foreign particles, or heating or cooling the surfaces. The property of reducing friction is known as lubricity.A good lubricant generally possesses the following characteristics:
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Typically lubricants contain 90% base oil (most often petroleum fractions, called mineral oils) and less than 10% additives. Vegetable oils or synthetic liquids such as hydrogenated polyolefins, esters, silicones, fluorocarbons and many others are sometimes used as base oils. Additives deliver reduced friction and wear, increased viscosity, improved viscosity index, resistance to corrosion and oxidation, aging or contamination,etc.

Non-liquid lubricants include grease, powders (dry graphite, PTFE, molybdenum disulfide, tungsten disulfide, etc.), PTFE tape used in plumbing, air cushion and others. Dry lubricants such as graphite, molybdenum disulfide and tungsten disulfide also offer lubrication at temperatures (up to 350 °C) higher than liquid and oil-based lubricants are able to operate.

A large number of additives are used to impart performance characteristics to the lubricants.

Antioxidants,Detergents,Anti-wear,Metal-deactivators,Corrosion-inhibitors,
Rust-inhibitors,Friction-modifiers,ExtremePressure,Anti-foaming-agents
Viscosityindex-improversDemulsifying/Emulsifying Stickiness improver, Note that many of the basic chemical compounds used as detergents (example: calcium sulfonate) serve the purpose of the first seven items in the list as well. Usually it is not economically or technically feasible to use a single do-it-all additive compound. Oils for hypoid gear lubrication will contain high content of EP additives. Grease lubricants may contain large amount of solid particle friction modifiers, such as graphite, molybdenum sulfide.
One of the single largest applications for lubricants, in the form of motor oil, is protecting the internal combustion engines in motor vehicles and powered

equipment.

Lubricants such as 2-cycle oil are added to fuels like gasoline which has low lubricity. Sulfur impurities in fuels also provide some lubrication properties, which has to be taken in account when switching to a low-sulfur diesel; biodiesel is a popular diesel fuel additive providing additional lubricity.

Another approach to reducing friction and wear is to use bearings such as ball bearings, roller bearings or air bearings, which in turn require internal lubrication themselves, or to use sound, in the case of acoustic lubrication

Lubricants are typically used to separate moving parts in a system. This has the benefit of reducing friction and surface fatigue, together with reduced heat generation, operating noise and vibrations. Lubricants achieve this in several ways. The most common is by forming a physical barrier i.e., a thin layer of lubricant separates the moving parts. This is analogous to hydroplaning, the loss of friction observed when a car tire is separated from the road surface by moving through standing water. This is termed hydrodynamic lubrication. In cases of high surface pressures or temperatures, the fluid film is much thinner and some of the forces are transmitted between the surfaces through the lubricants.

Typically the lubricant-to-surface friction is much less than surface-to-surface friction in a system without any lubrication. Thus use of a lubricant reduces the overall system friction. Reduced friction has the benefit of reducing heat generation and reduced formation of wear particles as well as improved efficiency. Lubricants may contain additives known as friction modifiers that chemically bind to metal surfaces to reduce surface friction even when there is insufficient bulk lubricant present for hydrodynamic lubrication, e.g. protecting the valve train.

Both gas and liquid lubricants can transfer heat. However, liquid lubricants are much more effective on account of their high specific heat capacity. Typically the liquid lubricant is constantly circulated to and from a cooler part of the system, although lubricants may be used to warm as well as to cool when a regulated temperature is required. This circulating flow also determines the amount of heat that is carried away in any given unit of time. High flow systems can carry away a lot of heat and have the additional benefit of reducing the thermal stress on the lubricant. Thus lower cost liquid lubricants may be used. The primary drawback is that high flows typically require larger sumps and bigger cooling units. A secondary drawback is that a high flow system that relies on the flow rate to protect the lubricant from thermal stress is susceptible to catastrophic failure during sudden system shut downs. An automotive oil-cooled turbocharger is a typical example. Turbochargers get red hot during operation and the oil that is cooling them only survives as its residence time in the system is very short i.e. high flow rate. If the system is shut down suddenly (pulling into a service area after a high speed drive and stopping the engine) the oil that is in the turbo charger immediately oxidizes and will clog the oil ways with deposits. Over time these deposits can completely block the oil ways, reducing the cooling with the result that the turbo charger experiences total failure typically with seized bearings. Non-flowing lubricants such as greases & pastes are not effective at heat transfer although they do contribute by reducing the generation of heat.

Lubricant circulation systems have the benefit of carrying away internally generated debris and external contaminants that get introduced into the system to a filter where they can be removed. Lubricants for machines that regularly generate debris or contaminants such as automotive engines typically contain detergent and dispersant additives to assist in debris and contaminant transport to the filter and removal. Over time the filter will get clogged and require cleaning or replacement, hence the recommendation to change a car's oil filter at the same time as changing the oil. It is apparent that in a circulatory system the oil will only be as clean as the filter can make it, thus it is unfortunate that there are no industry standards by which consumers can readily assess the filtering ability of various automotive filters. Poor filtration significantly reduces the life of the machine (engine) as well as making the system-inefficient.

Lubricants known as hydraulic fluid are used as the working fluid in hydrostatic power transmission. Hydraulic fluids comprise a large portion of all lubricants produced in the world.

Lubricants prevent wear by keeping the moving parts apart. Lubricants may also contain anti-wear or extreme pressure additives to boost their performance against wear-fatigue.

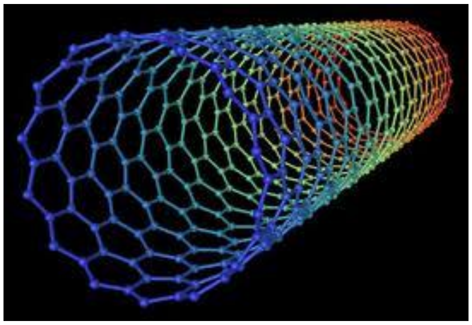
Good quality lubricants are typically formulated with additives that form chemical bonds with surfaces, or exclude moisture, to prevent corrosion and rust. It reduces corrosion between two metallic surface and avoids contact between these surfaces. Lubricants will occupy the clearance between moving parts through the capillary force, thus sealing the clearance. This effect can be used to seal pistons and shafts.

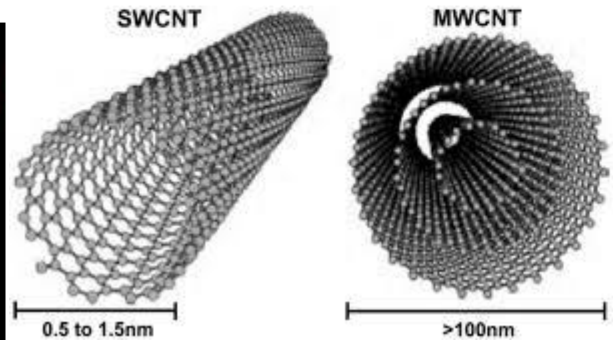
CARBON NANOTUBES

Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, significantly larger than for any other material. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials. For instance, nanotubes form a tiny portion of the material(s) in some (primarily carbon fiber) baseball bats, golf clubs, car parts or damascus steel.

Nanotubes are members of the fullerene structural family. Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. These sheets are rolled at specific and discrete ("chiral") angles, and the combination of the rolling angle and radius decides the nanotube properties; for example, whether the individual nanotube shell is a metal or semiconductor. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Individual nanotubes naturally align themselves into "ropes" held together by van der Waals forces, more specifically, pi-stacking.

Applied quantum chemistry, specifically, orbital hybridization best describes chemical bonding in nanotubes. The chemical bonding of nanotubes is composed entirely of sp^2 bonds, similar to those of graphite. These bonds, which are stronger than the sp^3 bondsfound in alkanes and diamond, provide nanotubes with their unique strength.





Multi-walled

Multi-walled nanotubes (MWNTs) consist of multiple rolled layers (concentric tubes) of graphene. There are two models that can be used to describe the structures of multi-walled nanotubes. In the *Russian Doll*model, sheets of graphite are arranged in concentric cylinders, e.g., a (0,8) single-walled nanotube (SWNT) within a larger (0,17) single-walled nanotube. In the *Parchment* model, a single sheet of graphite is rolled in around itself, resembling a scroll of parchment or a rolled newspaper. The interlayer distance in multi-walled nanotubes is close to the distance between graphene layers in graphite, approximately 3.4 Å. The Russian Doll structure is observed more commonly. Its individual shells can be described as SWNTs, which can be metallic or semiconducting. Because of statistical probability and restrictions on the relative diameters of the individual tubes, one of the shells, and thus the whole MWNT, is usually a zero-gap metal.

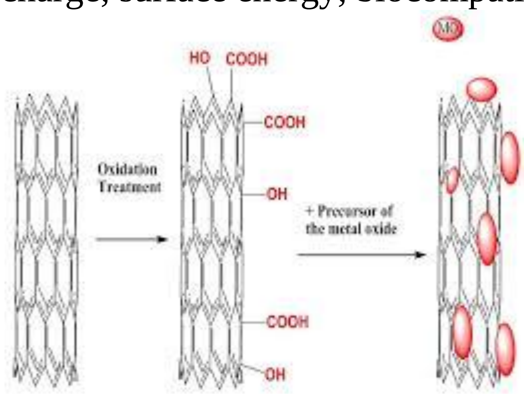
Double-walled carbon nanotubes (DWNTs) form a special class of nanotubes because their morphology and properties are similar to those of SWNTs but their resistance to chemicals is significantly improved. This is especially important when functionalization is required (this means grafting of chemical functions at the covalent functionalization will break some C=C double bonds, leaving "holes" in the structure on the nanotube and, thus, modifying both its mechanical and electrical properties. In the case of DWNTs, only the outer wall is modified. DWNT synthesis on the gram-scale was first proposed in 2007 by the CCVD technique, from the selective reduction of oxide solutions in methane and hydrogen.

SURFACE MODIFICATION/FUNCTIONALIZATION

Surface modification is the act of modifying the surface of a material by bringing physical, chemical or biological characteristics different from the ones originally found on the surface of a material.

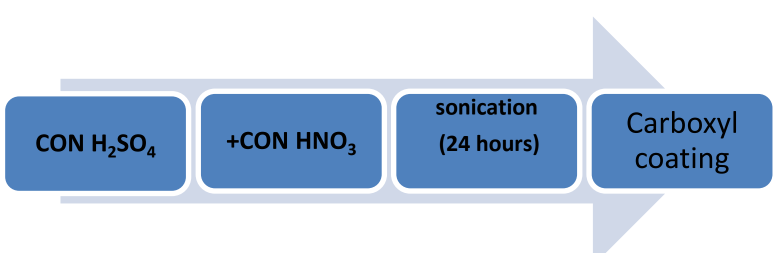
This modification is usually made to solid materials, but it is possible to find examples of the modification to the surface of specific liquids.

The modification can be done by different methods with a view to altering a wide range of characteristics of the surface, such as: roughness, hydrophilicity, surface charge, surface energy, biocompatibility and reactivity.



In the experiments performed.

Sample additives (CNT's) were functionalized using carboxyl groups.



BACKGROUND/LITERATURE REVIEW

The studies provide a technical background to the contents of the project. The physical properties as well as the chemical properties along with the effects of addition of additives is discussed

Commercially, these days many engine oils are available for motor vehicles and machinery. To know which engine oil suits the needs better, one should be aware of its properties like-lubrication system of applied machinery, conditions of machinery, cost of lubricant,viscosity,density,adiabatatic compressibility ,torque,shear rate, flash point,pour point, friction coefficient,boilingpoint,meltingpoint,corrosionresistive,etc.

Rheology is the study of flow of matter: typically in liquids, sometimes in soft solids also under conditions they flow and do not deform elastically.Rheology plays an important role in the flow behaviour of liquids during preparation as well as during processing. It also predicts structural properties and characteristics.

Rheology not only tells about the current behaviour of a fluid but also that after a certain year, how it tends to behave [1].The most important parameter of lubricants is viscosity, as it also affects the tribological properties.

RHEOLOGY

- In Greek ‘Rheo’ – flow
- The study of flow of matter

RHEOLOGICAL PROPERTIES

- Viscosity – measure of the internal friction of a fluid
- Torque
- Shear stress

- Visco-elasticity

LUBRICANTS

- Base oils/fluids
- To provide lubrication primarily
- Therefore have the most significance on viscosity

ADDITIVES

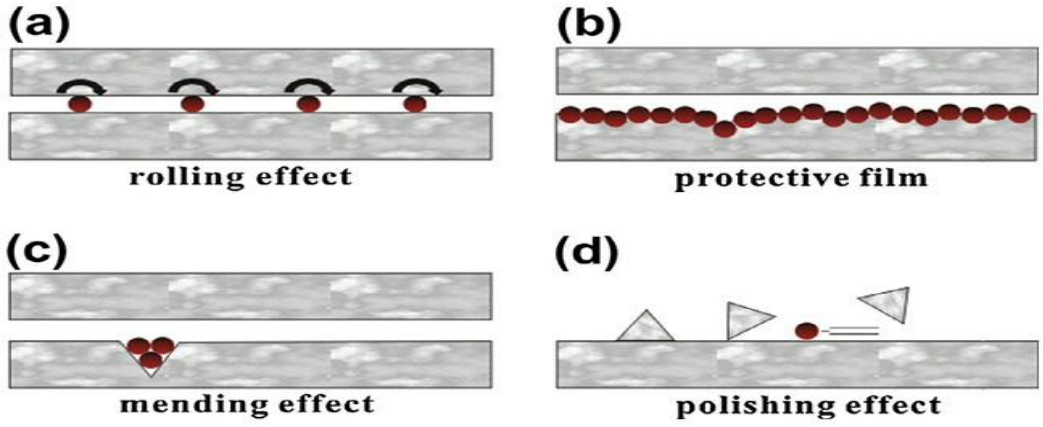
- 10 percent of total composition
- Antioxidants
- Dispersants

Thus,from the above data, list of materials of interest to nanofluids synthesis are-

Material	Thermal conductivity (W/m-K)	Reference
Aluminum oxide (Al_2O_3)	36	Incropera and DeWitt (2001)
Carbon nanotube (CNT)	3000	Che et al. (2000)
Diamond (C)	2300	Incropera and DeWitt (2001)
Zinc oxide (ZnO)	100	Florescu et al. (2000))

Engine lubricant is critical to experiment with the very lifeblood of the engine. The reliable running of any transport would not be possible without this.The engine oil goe through extreme condition during its flow.The tailored blend of nano additives and engine oil results in high amount of cleansing and protection of engine while maximizing the power of vehicle.

Eswaraiah et al studied the tribological behaviuor of engine oil with grapheme as an additive.They claimed the improvement of friction coefficient,anti wear and extreme pressure properties of nanofluids can be attributed to the nanobearing mechanism of grapheme in engine oil and the ultimate mechanical strength of graphene.



Rheology plays a vital role when it comes to the application of nanolubricants.High viscosity oil takes more power to pump. Multiwalled CNT nanofluid viscosity measurement was done using shear rheometer,Haake model RS1.

The measurement were performed for shear rate 0-600 sec-1 from temperature 298-318 K.At low shear rates 0-100 CNTs showed pseudo plastic behavior.

At higher rate dilatant behavior is observed.Pseudo plastic behavior is alsocalled"Shear-thinning"where increased shear rate results in decreased viscosity.

On adding carbon additives like CNT, graphene, fullerenes, to conventional lubricants like engine oil, not only enhances the properties of fluid (viscosity, thermal conductivity, elasticity) but also reduces friction to great extent. This is because the additives are nanoparticles i.e. having dimensions in nano scale which offers much better properties than any bulk material. The surface-to-volume ratio of these nanoparticles is so high that even their small concentration dispersed in lubricant enhances its quality.

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EXPERIMENT

METHODOLOGY ADOPTED:

- Interferometer tests
- Rheometer tests

Multigrade engine oils C20W40,S20W40 and M20W40are considered as sample oils as shown in Figure 1.Viscosity measurement with rise in temperature was done using Rheometer MCR302(Figure 2),SN000000,ID 80963516 from Anton Paar Gurgaon. Measuring system PP25F/PESN25F125 (d=0.4mm) with accessory TUI=P-PTD200-SN 81183777 was used. It measures rheological properties like viscosity,torque,shear stress with respect to temperature with the help of rotational and oscillatory tests based on a dynamic

EC motor.

In an oscillatory rheometer,the moving part of the measuring system oscillates,creating vibrations which are transferred to the sample.This provides information on the viscoelastic behaviuor of the substancs.The oscillation is usually carried out at low deformations to stay in the elastic range.The advantage of using oscillatory tests over rotational tests is that the sample does not gets destroyed.

2.1 Measurement of Viscosity, with temperature. The above setup is used to measure the viscosity (η) for all three samples with temperature varying from 20°C-80°C at constant shear rate of 1000 (1/s) as mentioned in table 1.

2.2 Measurement of torque (τ) and shear stress (σ) with temperature. The setup mentioned in 2 is used for the above measurements for three samples as given in the table 2.

2.3 Measurement of Viscosity vs. Shear Rate at different temperature. The table 3 shows Viscosity and shear rate variation with changing temperature.

2.4 Measurement of adiabatic compressibility (β) and ultrasonic sound velocity with temperature. Table 4 shows adiabatic constants and ultrasonic sound velocity measured using Ultrasonic interferometer working at a frequency of 2 KHz (Mittal enterprises, New Delhi, Model-5F-05), accuracy ±0.1m/s for three oils in temperature range of 20-80C.Ultrasonic interferometer works on ultrasonic waves of known frequency generated by quartz crystal which are reflected by magnetic plates to determine the velocity (v) based on accurate wavelength (λ) using-

$$V= \lambda/f;$$

Where f=frequency

In an ultrasonic interferometer,the ultrasonic waves are produced by the piezoelectric method.The wavelength of the sound in an experimental liquid medium is measured,and from this one can calculate its velocity through that medium.The apparatus consists of an ultrasonic cell,which is a double walled brass cell with chromium plated surfaces having a capacity of 10ml.The double wall allows water circulation around the experimental medium to maintain it at a known constant temperature.

techniques. The atomizers differ in resulting droplet size, rate of atomization, and the initial velocity of the droplets.

The initial leaving velocity of the droplet is an important parameter as it determines the rate at which the droplets reach the substrate surface, the heating rate of the droplet, and the amount of time the droplet remains in the spray pyrolysis environment.

TESTING METHODS

- Chemical assessment to check whether CNT has been modified at the surface

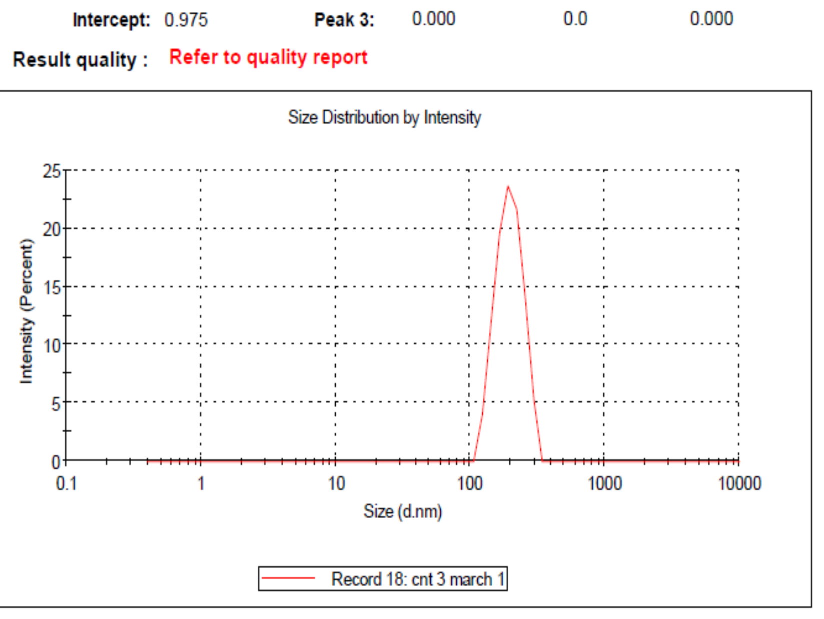
Using Fourier Transform Infrared Spectroscopy

- Particle size analysis using Zeta Sizer.

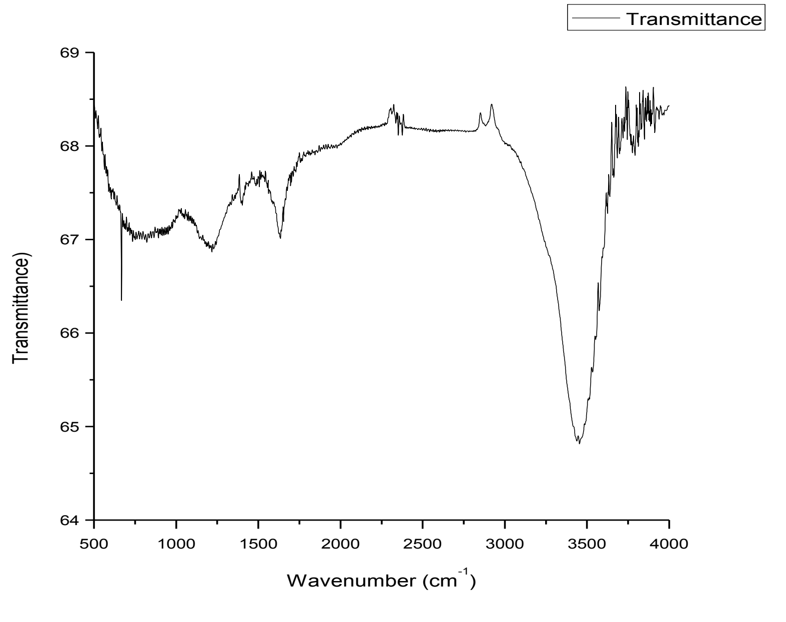
OBSERVATIONS

1. Particle size

Zeta Sizer~198nm



2. Surface Modification (Carboxyl group)



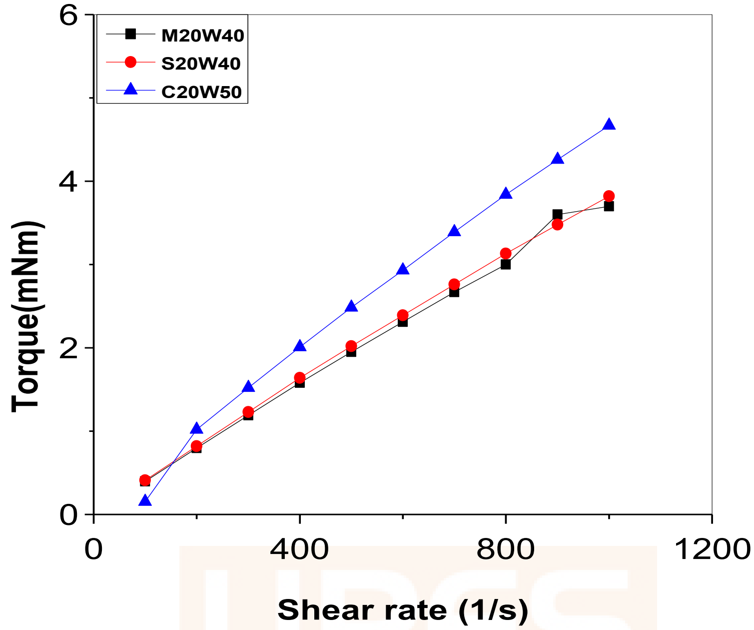
3. Interferometer test.

Temp	20	30	40	50	60	70	80
veloc[m]	1366	1438	1383	1369	1322	1282	1267
vel[0.02]	4000	8000	8000	14000	10000	6000	4000
vel[0.03]	14000	10000	8000	6000	4000	4000	4000
vel[0.04]	4000	4000	4000	4000	4000	4000	4000
β[m]	0.6	0.61112	0.66098	0.67458	0.7224	0.76923	0.7874
β[0.02]	6.967	1.741	1.741	5.687	1.114	3.096	6.967
β[0.03]	5.687	1.741	1.741	3.096	6.967	6.967	6.967
β[0.04]	6.967	6.967	6.967	6.967	6.967	6.967	6.967

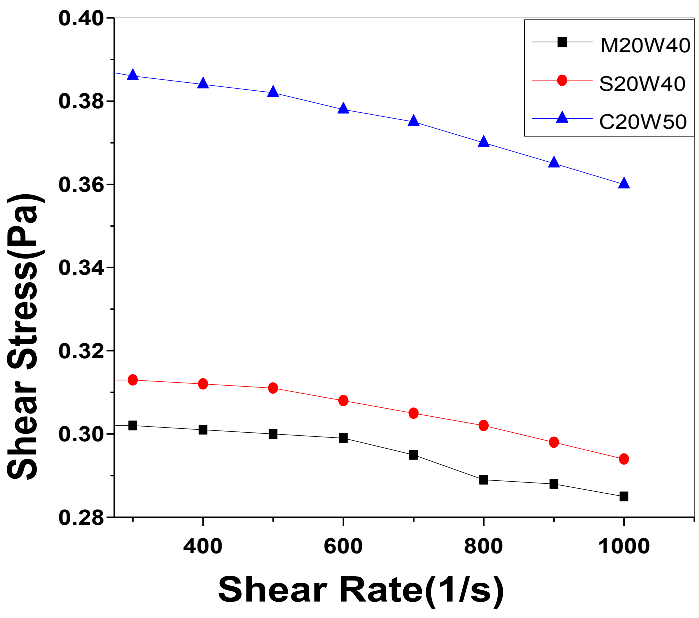
4. Rheometer tests

4.1. BASE OIL

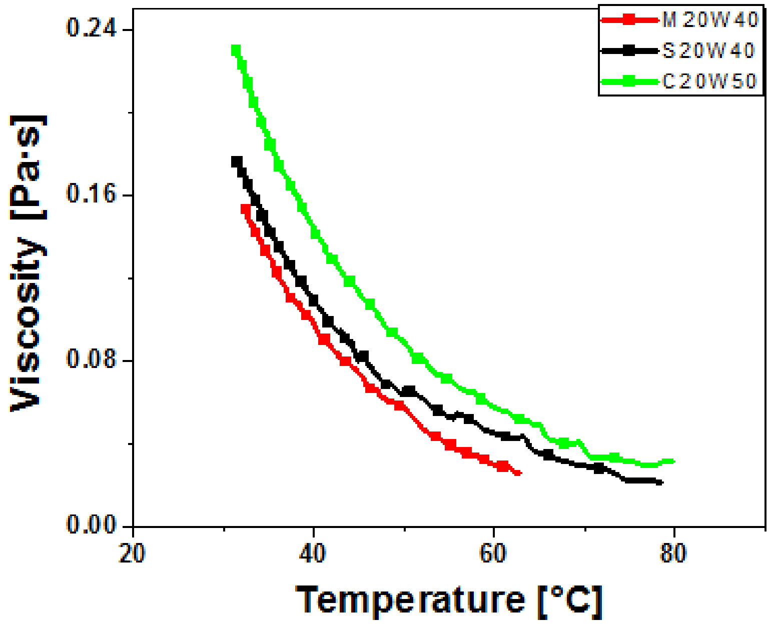
4.1.1. Torque v/s Shear Rate



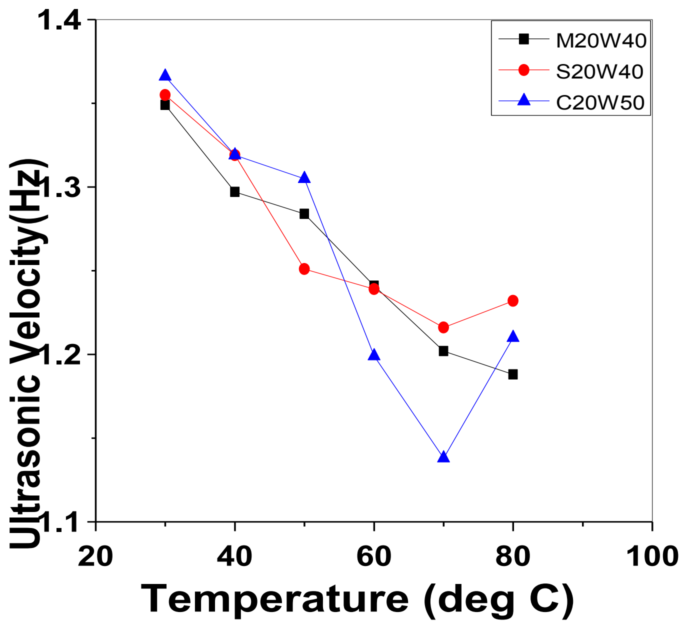
4.1.2. Shear stress v/s Shear rate



4.1.3. Viscosity v/s Temperature

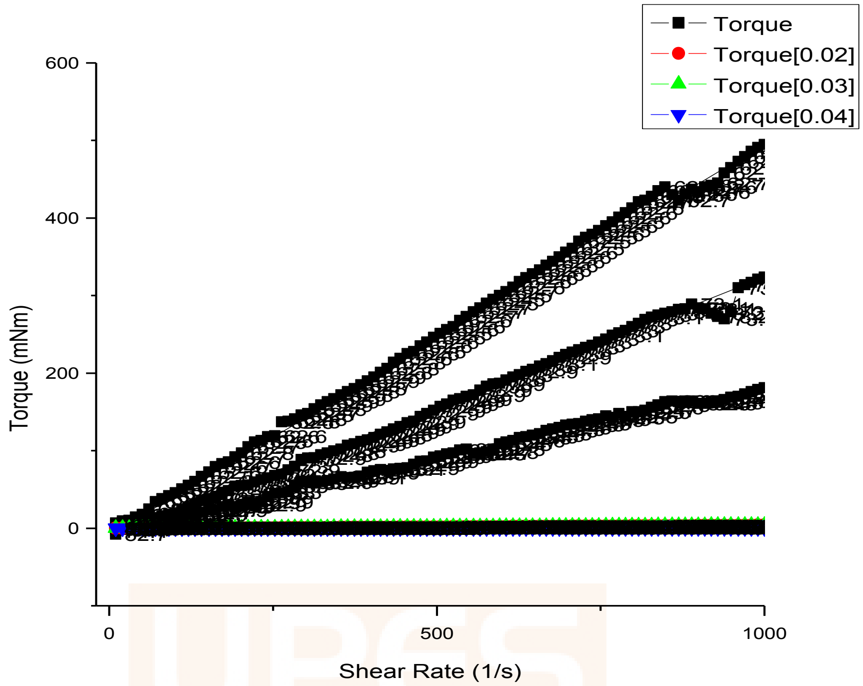


4.1.4. Velocity v/s Temperature

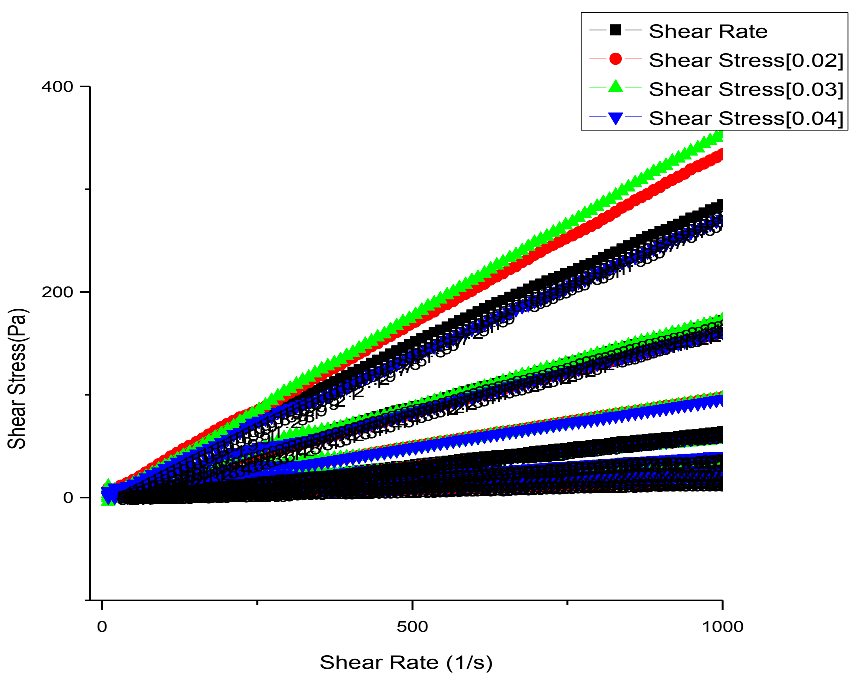


4.2. NANOFLUID SERIES

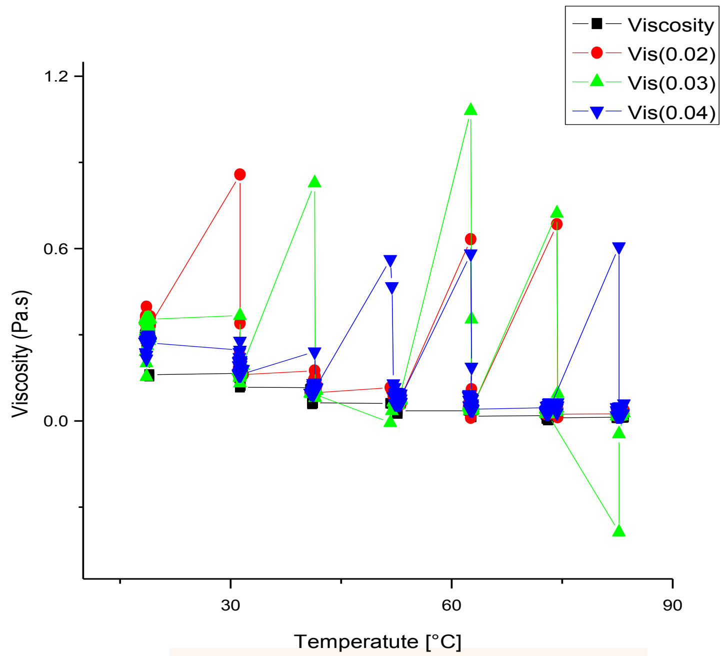
4.2.1. Torque v/s Shear Rate



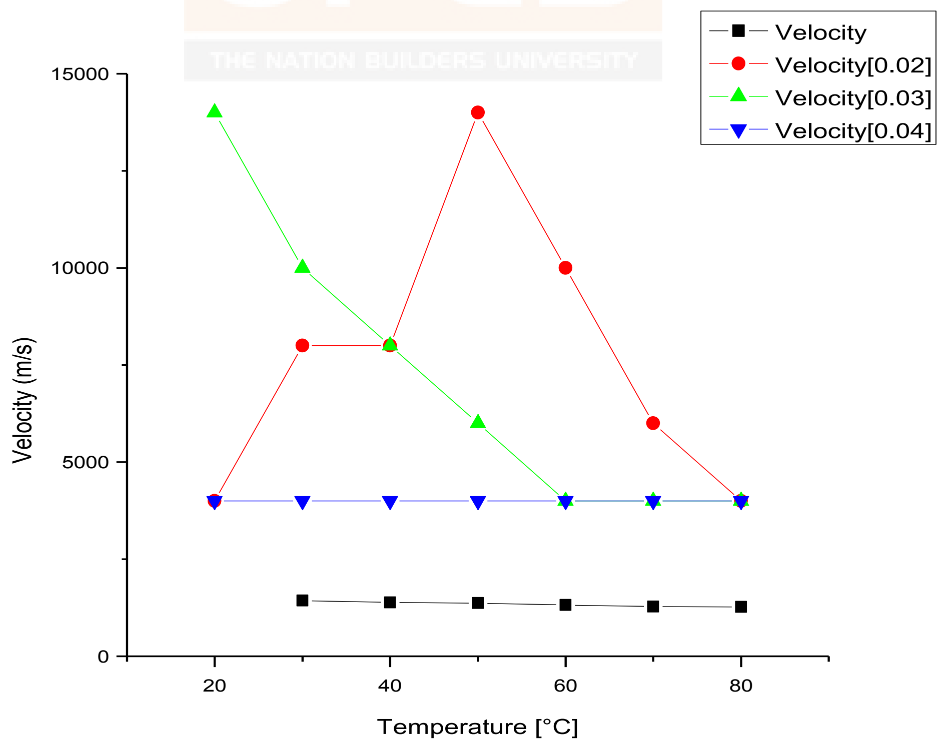
4.2. Shear stress v/s Shear rate



4.3. Viscosity v/s Temperature



4.4. Velocity v/s Temperature



DISCUSSION

- GRAPH 1 [Torque vs. Shear rate]-

Torque is needed to overcome the resistance offered by a fluid.

It is directly proportional to shear deformation rate because with increasing shear rate, fluid becomes less viscous .Therefore it becomes easier to rotate the spindle by the fluid resulting in an increase in torque. Thus showing linear relationship between torque and shear rate.

The graph confirms thixotropic behaviour in lubricants. i.e lubricants become less viscous when agitated/shaken

- GRAPH 2 [Shear stress vs. shear rate]-

Shear stress decreases with increasing shear rate because as the shear force is continuously applied on the lubricant, the microspheres organize themselves into hexagonally packed structures that slide over each other more easily (i.e exhibit lesser shear stress on fluid)

This process is often termed as-"shear thinning", shown by pseudoplastic fluids. It results in decreased viscosity.Thus,flow of fluid becomes easy without much stress(hence decreased shear stress).

Its application is in-fast moving engine parts lubrication. As the oil settles again under low shear rate, protecting the engine from wear. Suggesting excessive shear thinning is bad. Hence too steep graph is unacceptable.

- GRAPH 3 [Viscosity vs. temp]-

According to the relation-

$$\mu=\mu_{\circ}E\ \mu/ert$$

Where μ=liquid viscosity

$\mu_{\circ}$=viscosity at some reference temperature

E=temperature coefficient for viscosity

E μ has a physical significance of activation energy so mobility (1/ μ) of liquid molecules is temperature- activated process.

At increasing temperature, particles get excited and start oscillating which makes particles speed up and spread out. Due to moving apart of particles, it gets easier for them to move past each other. Thus, decreasing the viscosity. This increases the volume and fluid expands.

- GRAPH 4 [Ultrasonic velocity vs. Temperature]-

Ultrasound velocity is sensitive to packing volume.

At high temperature, viscosity decreases therefore decreasing the density and increasing the volume. This leads to increase in penetration of ultrasonic sound waves through lubricant at high temperature.

Denser packing of molecules results in increase in ultrasonic velocity.

Therefore, the fluid should be moderately dense avoiding the extreme nature.

As the temperature of the oil increased, the particles making up the oil gained more energy and vibrated faster. As the temperature rose, the force of attraction between the particles became weaker, leaving larger spaces between them. This decreased the resistance that the oil had to flowing, resulting in a decreased viscosity.

CONCLUSION

Based on the observations of the conducted experiments it is correct to derive the following inference.

1. Base oil (M20W40)

a) M20W40 shows least variation of viscosity with temperature, thus depicting consistent behaviour with temperature variations.

b) S20W40 and M20W40 show relatively lower curve for stress versus strain, suggesting more fluidity which is verified by lower viscosity.

c) M20W40 and S20W40 shows decreasing torque with increasing shear rate

d) Ultrasonic velocity accounts for rigidity of a fluid. From the above graph, M20W40 shows minimum variation throughout. Thus, resulting in less compressibility

2. Nanofluid Series (w/w% ; 0.02,0.03 and 0.04)

Sample consisting w/w% (0.04) is the most optimum sample as observed from the results.

a) Adiabatic Compressibility
   - Higher ultrasonic sound velocity is preferable and observed
   - Ultrasonic velocity is proportional to stiffness
   - Less adiabatic compressibility is preferable and observed

b) Viscosity
   - Sample shows slow and steady rise with increasing temperature

c) Torque
   - Decrease in torque is observed therefore suggesting in simultaneous shear thinning thereby improving viscosity

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