ANALYZING POTENTIAL OF GRAPHENE AS ADDITIVE IN NANOLUBRICANT FOR AN IC ENGINE

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ABSTRACT

This thesis focus on the performance of graphene based nanolubricant in a 4-Stroke IC engine of a 125cc motorcycle engine. The nanolubricant was formulated using graphene Grade C particles and a 10W40 SF grade synthetic engine oil meeting API standards. The addition of 0.01wt% graphene particles to the 10W40 SF grade nanolubricant resulted in enhancing the thermal conductivity (κ) upto 23% with increasing temperature. Moreover this increased thermal conductivity reduced the lubricant temperature in the engine & enhanced the heat transfer rate enabling greater performance, fuel consumption & wear n tear of engine components as compared to base oil.

INTRODUCTION

1.1Nanotechnology:

Nano word basically from the Greek referring to as “one billionth of a meter”. Richard P. Feyman (Nobel Laureate in Phyhsics, 1965) was the one which introduced the concept of nanotechnology about 50 years ago. He suggested that in the atoms can be arranged as the way we want them to be.

Nanotechnology is generally considered to be a size below 0.1µm or 100nm (which is one billionth of a meter, 10-9m). Nanotechnology is basically the study of materials at atomic scales as on atomic level the quantum-scale effects play an important role. Nanotechnology is then the design, the manipulation, the building, the production and application, by controlling the shape and size, the properties-responses and functionality of structures, and devices and systems of the order or less than 100 nm [1, 2].

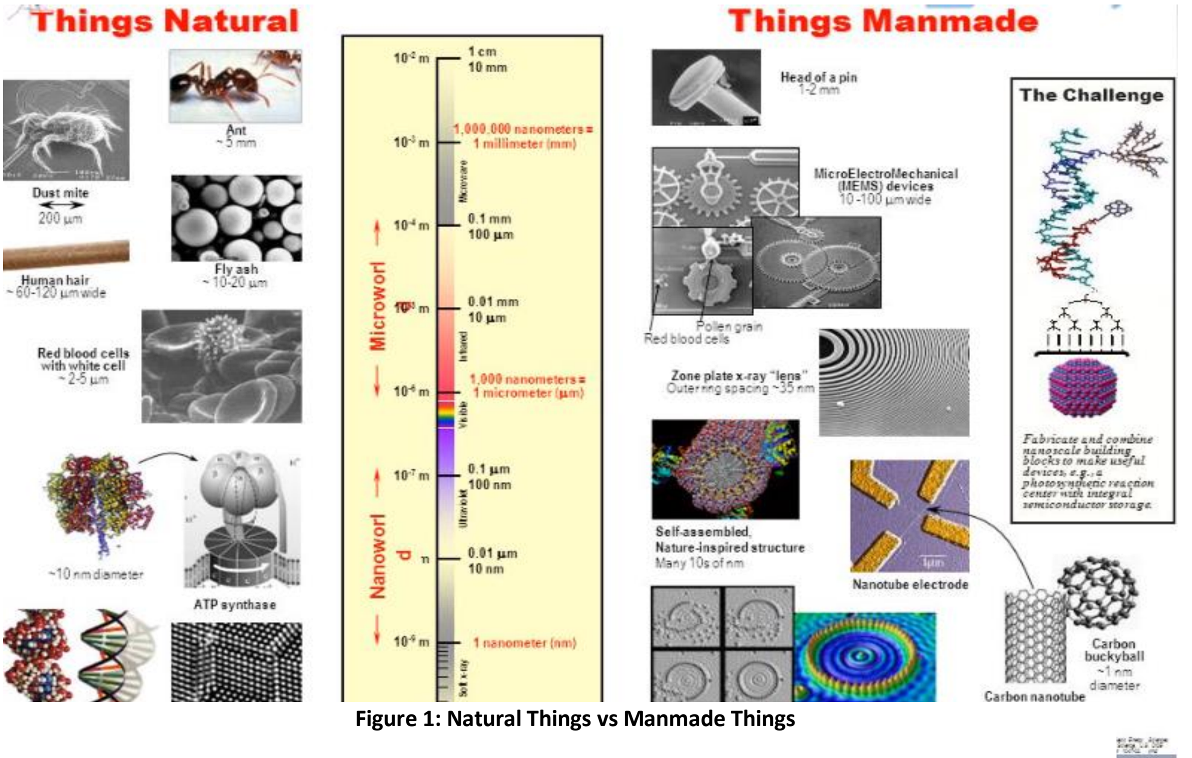


Figure 1: Natural Things vs Manmade Things

1.2 Important Milestones

- **1959** • Feynman gives lecture titled "There's Plenty of Room at the Bottom" describing molecular machines building with atomic precision
- **1974** • Taniguchi uses term "nano-technology" in paper on ion-sputter machining
- **1977** • Drexler originates molecular nanotechnology concepts at MIT.
- **1981** • Drexler gives the first technical paper on molecular engineering to build with atomic precision; Scanning Tunneling Microscope invented.
- **1986** • First book published- "Engines of Creation: The Coming Era of Nanotechnology" by Eric Drexler; Atomic Force Microscope invented, First organization formed- the Foresight Institute.
- **1987** • First protein engineered, First university symposium
- **1991** • Japan''s MITI announces bottom-up "atom factory," IBM endorses bottom-up path, Japan's MITI commits $200 million, Carbon nanotube discovered
- **1992** • First textbook published, First Congressional testimony
- **1995** • First think tank report, First industry analysis of military applications
- **1997** • First company founded: Zyvex, First design of nanorobotic system
- **1998** • First NSF forum, held in conjunction with Foresight Conference, First DNA-based nanomechanical device
- **1999** • First Nanomedicine book published, First safety guidelines, Congressional hearings on proposed National Nanotechnology Initiative
- **2000** • President Clinton announces U.S. National Nanotechnology Initiative, First state research initiative: $100 million in California
- **2001** • First report on nanotech industry, U.S. announces first center for military applications
- **2002** • First nanotech industry conference, Regional nanotech efforts multiply
- **2003** • Congressional hearings on societal implications, Call for balancing NNI research portfolio, Drexler/Smalley debate is published in Chemical & Engineering News
- **2004** • First policy conference on advanced nanotech, First center for nanomechanical systems
- **2005** • At Nanoethics meeting, Roco announces nanomachine/nanosystem project count has reached 300

1.3 IC Engine & Its Heat Losses

Internal combustion (IC) engine is majorly divided into two sub categories.

1. Spark Ignition (SI) Engine.
2. Compression Ignition (CI) Engine.

In this thesis the research in on SI engine which will be referred to as IC engine. The automotive industry with the help of modern technology is trying its best to make as efficient engine as possible to reduce the fuel cost as it's the fuel required to make the engine run. The major problem in the engine are the losses which occurs and causes the decrease in useful energy.

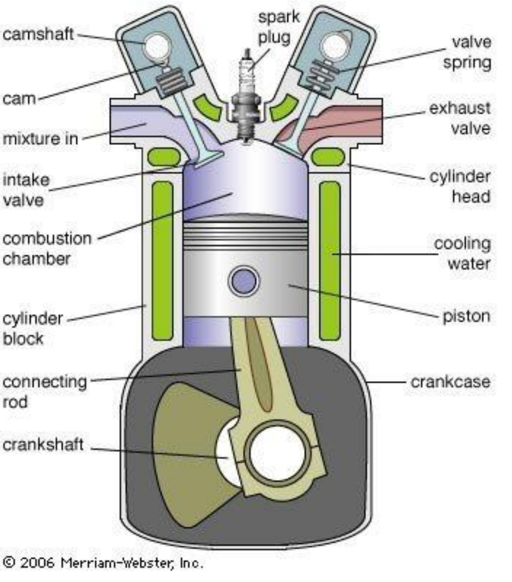


Figure 2: Structure of a Crankshaft

Theoretically a CI engine has about 50% efficiency. Even the energy losses contribute in this 50% efficiency and they are as shown.

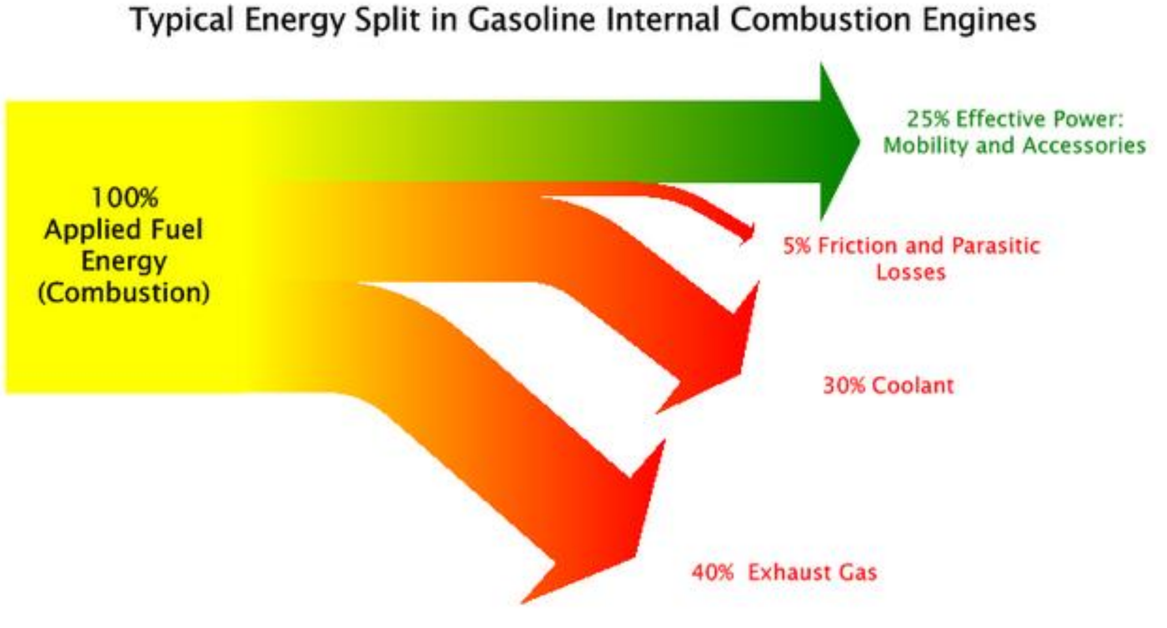


Figure 3: Energy Conversion in IC Engine

Even 1% reduction of any loss can contribute largely in terms of engine life, fuel efficiency, cost, environmental impact, etc. Using modern technology to do so is possible.

1.4 Problem Statement

In automotive accounts there is significant reduction in useful power due to frictional losses. About 15% of the total energy is consumed to overcome frictional losses in moving parts. Lubricants are provided to minimize these frictional losses. Mainly these frictional losses are generated at piston rings, transmissions & bearings. These oil applications comprise of around 50% of the global market. To accomplish this task efficiently & effectively several additives are added in these oils such as anti-wears, anti-oxidants, friction modifiers, dispersants, corrosion inhibitors, etc.

With the growing demand of automation, the demand of lubricants has also increased. But these conventional additives are not proving to be reliable in these modern ages. As these fail at higher temperatures & higher pressure & being unable to meet the industrial demand of now-a-days. In addition to this most of these additives are expensive and toxic in nature which limit their use. Therefore keeping in mind the uprising industrial & commercial demand, we need to find alternate additives, which prove to be user friendly, in expensive.

Recent research & development reported that metallic nanoparticles added to lubricant oils (nanolubricants) can act as anti-wear additives under extreme pressure [1]. These metallic nanoparticles are non-corrosive and can work at very high temperatures. Therefore, they are very promising for establishing a new era of nanolubricants for the future.

This research focuses on to analyze the potential of such metallic additives in such a boundary layer lubrication, such as carried out in an internal combustion engine.

1.5 Research Objectives

This research project attempts to explore the effective potential of graphene nanomaterial as an additive in terms of heat transfer, effect of RPM of heat transfer, clogging etc in an IC engine realizing the potential of graphene. Following below would be the main objectives.

1. Nano Lubricant Stability
2. Effect of Different RPMs on Heat Transfer Rate
3. Fuel consumption using nanolubricant.

1.6 Expected Results

The below results are to be expected from this research work.

1. Enhanced Lubricating property of Oil.
2. Fuel Efficiency.

LITERATURE SURVEY

2.1 Heat Transfer In Nano Fluids

Efficient heat transfer behavior of nanofluids depends upon a number of factors which include density changes, viscosity changes, change in specific heat, thermal conductivity effectiveness. The heat transfer coefficient is the best way to determine the net benefit of nanofluids so that they could be used as heat transfer fluids. The thermal conductivity can be studied quite reasonably, whereas on the contrary when nanoparticles are dispersed in fluids they show a complexity in their morphology and orientation, therefore to counter such complexity some correlations are devised for heat transfer coefficient.

There exist a relation between the flow per unit area of heat and the thermodynamic driving force for heat flow known as the heat flux. The proportionality constant, which balances the equation, is heat transfer. As the heat transfer coefficient changes with respect to the nature of the nature of the fluid, the type of flow regime and the mode of heat transfer therefore there are a number of methods for calculating the heat transfer coefficient as per need. The effectiveness of heat transfer in a system can be enhanced by a number of factors, which includes the thermal conductivity enhancement of the fluid, conditions at the boundary, or by changing in flow geometry.

Pure liquids use for heat transfer is the thing of the past now. The upcoming generation of nano fluids hold the future of heat transfer fluids as they offer new possibilities of improving performance of heat transfer. Conventional fluids lacks the superior properties these nanofluids have to offer along with metallic micro-sized particles containing fluids [3]. Listed below are some contributing factors for enhanced heat transfer performance [4]:

1. Increase in the heat capacity of the fluid along with the surface area required for the heat transfer.
2. Thermal conductivity effectiveness increases due to the presence of suspended nanoparticles.
3. The surface area is intensified in the result of interaction and collision of particles the flow passage area also increases as a result.
4. Suspended particles become the cause of fluctuation in mixing and increases turbulence, which enhances the heat transfer.
5. Transverse temperature gradient of the fluid is flatten by the dispersion of nanoparticles.

2.2 Nano Materials Methods of Synthesis

There are two approaches to the synthesis of nanomaterials.

1. Bottom Up Approach
2. Top Down Approach

Bottom Up Approach	Top Down Approach
• In the bottom-up approach, molecular components arrange themselves into more complex assembly's atom-by-atom, molecule-by-molecule, cluster-by cluster from the bottom (e.g., growth of a crystal). • Bottom-up approaches, in contrast, arrange molecular components	• In the top-down approach, nanoscale devices are created by using larger, externally-controlled devices to direct their assembly. The top-down approach often uses the traditional workshop or microfabrication methods in which externally controlled tools are used to cut, mill and shape materials

themselves into some useful conformation using the concept of molecular self-assembly. Synthesis of nanoparticles by colloid dispersions is an example of the bottom-up approach. • The bottom-up approach has been well-known to the chemists for a long time. This approach plays a very important role in preparing nanomaterials having very small size where the top-down process cannot deal with the very tiny objects. • The bottom-up approach generally produces nanostructures with fewer defects as compared to the nanostructures produced by the top-down approach. The main driving force behind the bottom-up approach is the reduction in Gibbs free energy. Therefore, the materials produced are close to their equilibrium state.	into the desired shape and order. Attrition and milling for making nanoparticles are typical top-down processes. • In top-down techniques such as lithography,significant crystallographic defects can be introduced to the processed patterns. For example, nanowires made by lithography are not smooth and can contain a lot of impurities and structural defects on its surface. Since the surface area per unit volume is very large for the nanomaterials, these defects can affect the surface properties, e.g., surface imperfections may cause reduced conductivity and excessive generation of heat would result. • Despite the defects, the top-down approach plays an important role in the synthesis and fabrication of nanomaterials. The present state of nanoscience can be viewed as an amalgamation of bottom-up chemistry and top-down engineering techniques.

2.3 Base Oil

The road vehicles which includes bikes, four wheel cars or heavy vehicles including transportation trucks and buses uses internal combustion engine which requires lubrication as uses motor oil for that purpose. The purpose of this lubricating oil to separate the adjacent moving parts so that no direct contact occurs between them, as to protect the engine by reducing wear & tear and frictional heat losses. The mechanism involves the conventional heat transfer through the engine by means of air flow on the oil pan surface, oil cooler and through the buildup of oil gases evacuated by the Positive Crankcase Ventilation (PCV) system. Motor oils today are mainly blended from base oils composed of various hydrocarbons (mineral, poly-alpha-olefins (PAO), etc. [5], and are thus organic compounds consisting entirely of carbon and hydrogen.

Motor oil composition contains a number of chemicals with varying properties. One of the key parameters of oils include the flash point temperature. It is that temperature where the burning process of the oil is initiated. The chemicals that burn at lowest temperature are its indicators. Flash point is directly related to the stability of the oil. The greater the flash point refers to greater stability at elevated temperature whereas on the contrary a lower number will cause oil burn in engine. The pour point is the temperature at which the oil stops flowing like a liquid. The lower this number is, the better protected the engine is when it's cold. The thickness of the oil, that is the resistance the oil offers to motion, is called the viscosity. The viscosity depends on all the various chemicals in the oil and how they react to each other and to heat. Importantly, as the oil heats up, it thins out, that is the viscosity goes down. The better the oil is at retaining its viscosity at high temperatures, the higher the viscosity index. All of these properties depend on all the chemicals in the oil.

2.4 Graphene:

Graphene is known to be the wonder material of the 21st century. It unlocked a new era of research in many fields like electronics, membranes, medical, automotive, military etc. Its discussion is a whole other matter, therefore some of the facts, properties & applications are given below just to grasp the idea of graphene importance.

- The first **2-dimensional** material ever discovered.
- **One-atom thick** of carbon atoms arranged in a hexagonal lattice.
- Found in graphite, coal, and created in other fashions.
- **Hard to manufacture** in large quantities, just about all graphene produced is used for R&D within companies and universities.
- **The strongest, lightest, and most conductive** material known to man.

Some of its properties are shown below

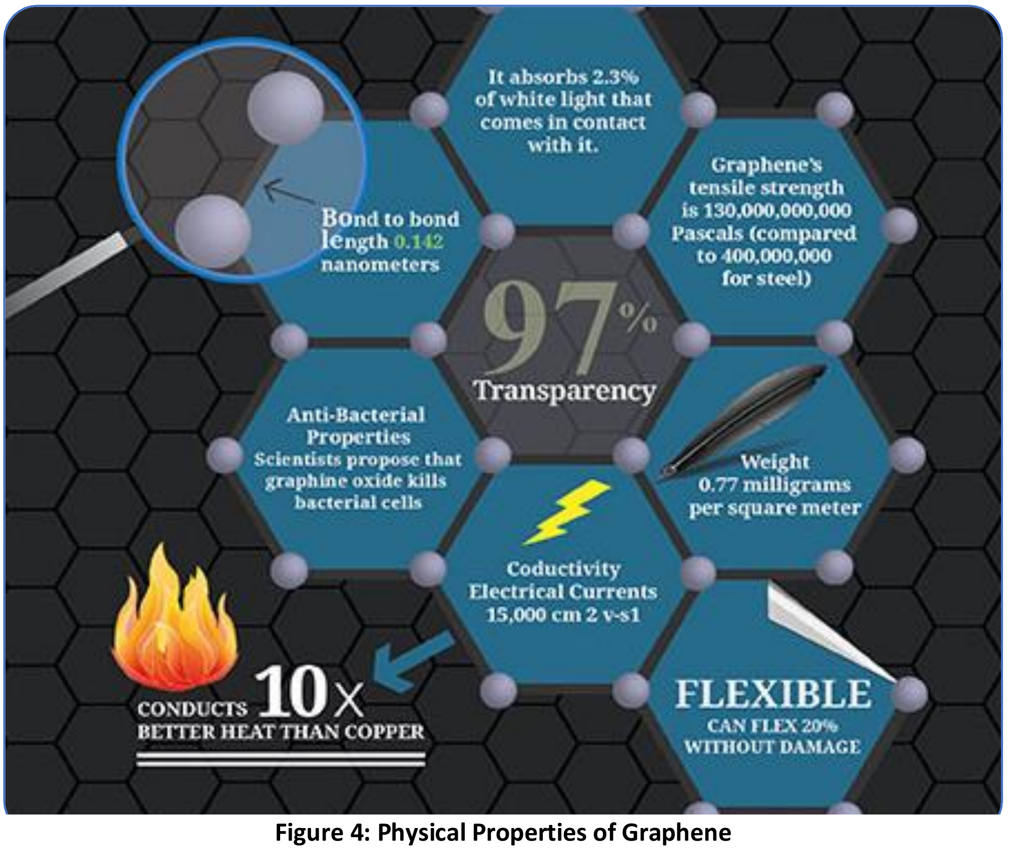


Figure 4: Physical Properties of Graphene

The applications of graphene depend on the method of its fabrication. Which can be seen in the below diagram.

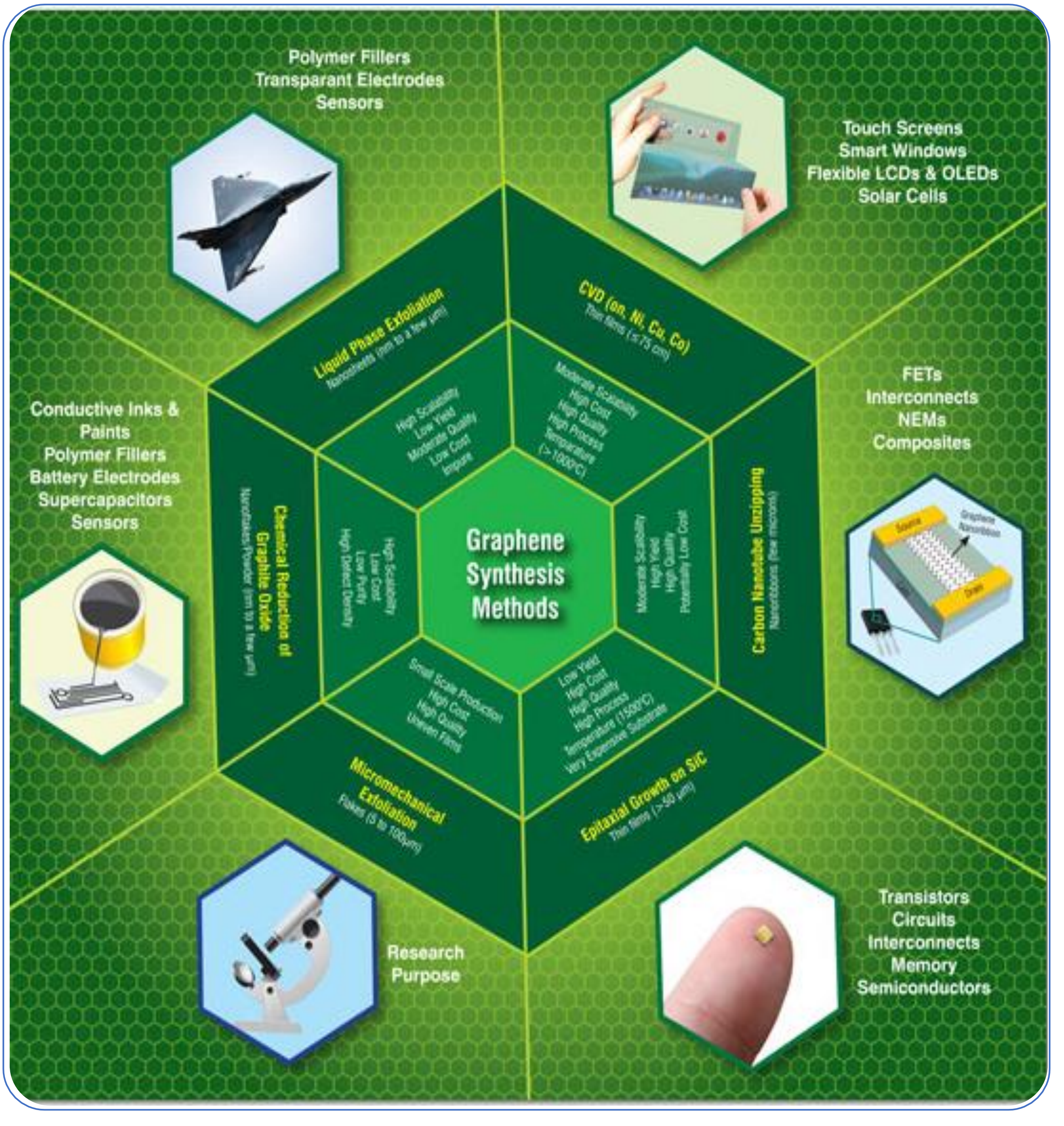


Figure 5: Graphene Application Based on Synthesis Method

With respect to field the graphene has a wide application in the industry.

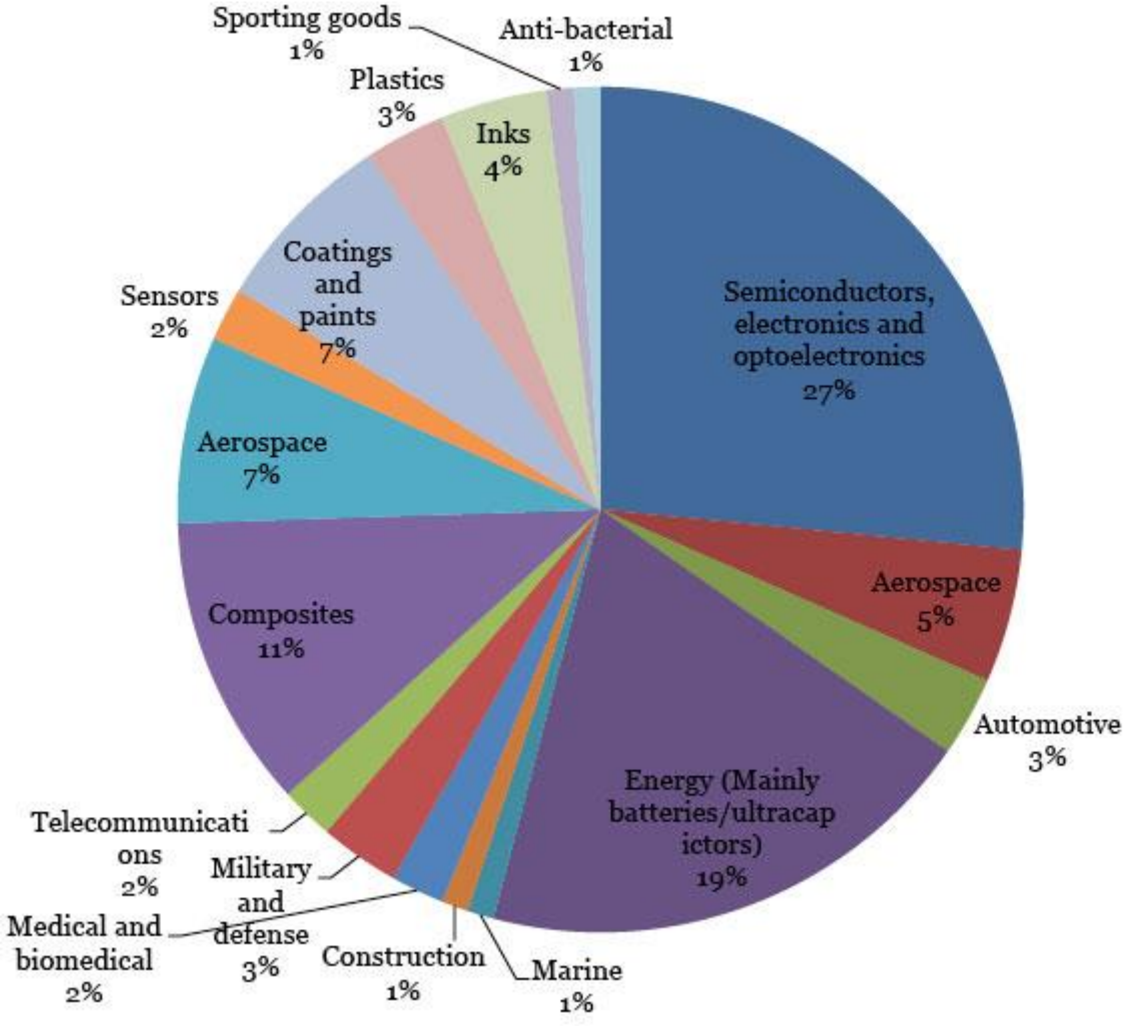


Figure 6: Graphene Industrial Application Distribution

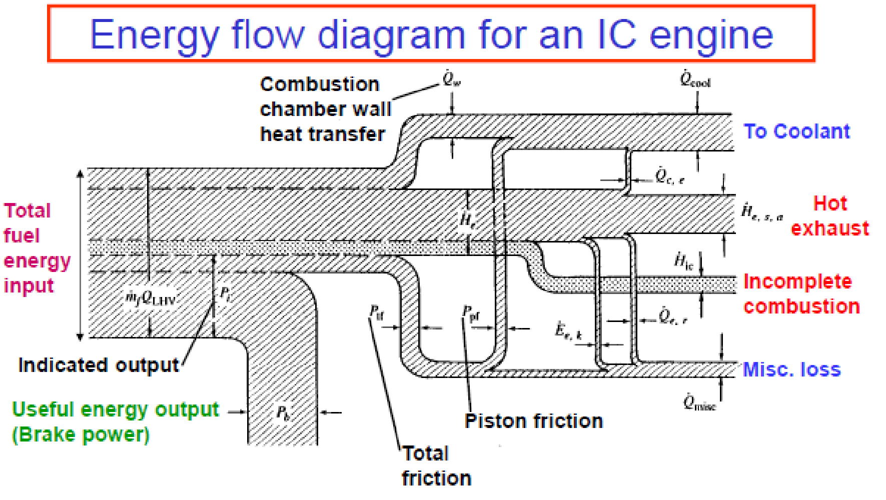
2.5 Graphene as Additive

Many reports found that the pure and modified graphene flakes can reduce the coefficient of friction and reduce anti-wear ability of oils [6,7,8]. 0.075wt% chemically modified graphene platelets were found to improve the wear resistance and load-carrying capacity of the machine [9]. Another study used 1.0% grapheneoxide (GO) nano sheets obtained by modified Hummers and Offeman methods with poly-alph-olefin [10]. It was found that the wear scar diameter was reduced from 1.0mm to 0.52mm, besides the wear rate being low in the presence of graphene oxide. When single layer sheets of graphene oxide were used as additive in water-based lubricants, the coefficient of friction reduced significantly [8]. Interestingly another study explained the anti -friction behavior of graphene flakes (solid lubricant) using an increased affinity for metal carbon bond formation [11]. The study found that the friction coefficient decreases by a factor of approx. 10 in an Ag/Ag contact. Tribological studies of now unanimously agree that graphene can enhance a lubricant performance [3,4], yet the mechanism behind such enhancement is yet to be discovered in situ conditions. Boundary layer conditions exist in surfaces of piston rings and cylinder liners.

As at high temperatures (>200 C) and pressures (>5000 psi) conventional additives fails therefore bringing the need of extreme pressure (EP) & anti-wear additives. One impact of these additives is that they are expensive and have hazardous effect on the environment. Technical limitations of EP additives such as high reactivity & corrosivity in the presence of water, limited activity at high temperatures, ineffectiveness at slow speeds and low temperatures etc. [10] All above reasons compels the need to find suitable alternates which are environment friendly & economical. Recent reports show that lubricant oils (nanolubricant) shows anti-wear abilities under extreme pressures with the additions of metallic nanoparticles in the [12]. These metallic particles are non-corrosive and can work under high pressure and temperatures. Therefore, they build a promising base for the establishment of a new era of AW and EP additives. Clogging problem is an issue when dealt with additives but due to small size of nanoparticles this problem is resolved being, undegradable or modified with temperature provides them to be at a greater advantage then other additive.

2.6 Heat Transfer Impact on Engine

Heat transfer is parasitic that contributes to the loss in fuel conversion efficiency. Heat transfer is a surface phenomenon.



Energy flow diagram for IC engine. $(\dot{m}_f Q_{LHV})$ = fuel flow rate × lower heating value, $\dot{Q}_w$ = heat-transfer rate to combustion chamber wall, $\dot{H}_e$ = exhaust gas enthalpy flux, P_b = brake power, P_{tf} = total friction power, P_i = indicated power, P_{pf} = piston friction power, $\dot{Q}_{cool}$ = heat-rejection rate to coolant, $\dot{Q}_{c,e}$ = heat-transfer rate to coolant in exhaust ports, $\dot{H}_{e,s,a}$ = exhaust sensible enthalpy flux entering atmosphere, $\dot{H}_{e,ic}$ = exhaust chemical enthalpy flux due to incomplete combustion, $\dot{Q}_{e,r}$ = heat flux radiated from exhaust system, $\dot{E}_{e,k}$ = exhaust kinetic energy flux, $\dot{Q}_{misc}$ = sum of remaining energy fluxes and transfers.

Figure 7: Energy flow of an IC Engine

The heat transfer in the engine impact many factors. Some of them are,

- **Efficiency and Power**: Heat transfer in the inlet decrease volumetric efficiency. In the cylinder, heat losses to the wall is a loss of availability.
- **Exhaust temperature:** Heat losses to exhaust influence the turbocharger performance. In- cylinder and exhaust system heat transfer has impact on catalyst light up.
- **Friction:** Heat transfer governs liner, piston/ ring, and oil temperatures. It also affects piston and bore distortion. All these effects influence friction. Thermal loading determined fan, oil and water cooler capacities and pumping power.

- **Component design**: The operating temperatures of critical engine components affects their durability; e.g. via mechanical stress, lubricant behavior.
- **Mixture preparation in SI engines**: Heat transfer to the fuel significantly affect fuel evaporation and cold start calibration
- **Cold start of diesel engines:** The compression ratio of diesel engines is often governed by cold start requirement
- **SI engine octane requirement:** Heat transfer influences inlet mixture temperature, chamber, cylinder head, liner, piston and valve temperatures, and therefore end-gas temperatures, which affect knock. Heat transfer also affects buildup of in-cylinder deposit which affects knock.

2.7 Importance of Lubrication System:

Lubricating system is a mechanical system of lubricating internal combustion engines in which a pump forces oil into the engine bearings. It is of vital importance, as the purpose of lubrication is,

- To **reduce the friction** between moving parts.
- To **increase the efficiency.**
- To **minimize the vibrations.**
- To **reduce the corrosion** and carbon deposits.
- To **reduce the heat** of moving parts.
- To **minimize power loss** due to friction.
- To **reduce the noise** created by moving parts.
- To **provide cooling** to the engine.

EXPERIMENTAL STRATEGY & METHODOLOGY

3.1 Introduction

This project was completed over the time span of 11 months and costed around 1.8 hundred thousand rupees (108,000 Rs) excluding the cost of graphene, which was provided by the university.

The experiment was divided into three parts,

1. Base Fluid (Nanolubricant) preparation.
2. Test Rig preparation.
3. Recordings.

the first two parts was worked on simultaneously and required delicate steps to ensure promising results of the experiment.

3.2 Experimental Strategy:

3.2.1 Sample Preparation:

Materials

Graphene: Graphene (G) which was purchased from XG Sciences, Inc. USA and the type is xGenP® Graphene Nanoplates – Grade C. Typically, particles of Grade C are the aggregates of sub-micron platelets. The platelets have average particle diameter of less than 2 micron and thickness of particles are of few nanometers (generally, 1-20 nm) depending upon the average surface area. The average surface area of G Nanoplatelets is 500 m^2/g. It is of very fine black granules or in powdered form in the physical appearance. Its bulk density and relative gravity are 0.2-0.4 g/cm^3 and 2.0-2.25 g/cm^3 respectively.

Base Oil: The base oil which selected was ***Shell Advance 4T Ultra 10W-40*** which is a multi-grade oil having physical properties as given below in table.

Properties			Method	Shell Advance 4T Ultra
SAE Viscosity grade			SAE J300	10W-40
Kinematic Viscosity	@40^{0}C	mm^2/s	ASTM D445	90.2
Kinematic Viscosity	@100^{0}C	mm^2/s	ASTM D445	14.2
Viscosity Index			ASTM D2270	163
Density	@15^{0}C	kg/m^3	ASTM D4052	858
Flash Point (COC)		^{0}C	ASTM D92	230
Pour Point		^{0}C	ASTM D97	-33

Table 1: Physical Properties of Shell Advance 4T Ultra 10W-40

Base Fluid Preparation: The sample preparation began with taking 250ml of the sample and the amount of graphene required to prepare the sample. Then the graphene was added to the sample which was subjected to heated water bath sonication for an appropriate time to give a homogenous solution. The sonication provided the sample to avoid cluster formation of the nanoparticles at the bottom for a number of days, which gave ample time for sample to be stable for experimentation period. Although the sonication time plays a vital role for the homogeneity of the solution but that itself is another study to be explored.

Figure 8: Water Bath Heating of Sample

The sample after preparation in different ratios of 0.01%,0.05% by weight of oil with graphene. Therefor a total of three samples were tested labeled as S1, S2, S3 having 0,0.01,0.05 graphene by weight percent.

These sample were compiled in their original bottles and was then labeled for later identification. A small sample of these different mixture were taken for analysis.

3.2.2 Test Rig Preparation

The test rig was a 2015 model Atlas Honda Motorcycle. Its specs were as follows,

Engine	4-Stroke Single Cylinder Air Cooled	**Displacement**	125 cc
Bore & Stroke	56.5 x 49.5 mm	**Compression Ratio**	9.0:1
Clutch	N/A	**Transmission**	4-speed
Starting	Kick start	**Frame**	Diamond Type Steel
Dimension (Lxwxh)	1911	**Ground Clearance**	140 mm
Petrol Capacity	9.2 L	**Tyre at Front**	2.50 - 18
Tyre at Back	3.00 - 17	**Dry Weight**	99 KG

Figure 9: Specs of Atlas Honda CG-125

The motorcycle was almost new and only 93km driven therefore the engine was almost new so there was minimum contamination inside the engine. All the sensors of bike were recalibrated with default setting to ensure there proper working and accuracy. The bike engine was then opened with the help of a local mechanic & was then properly cleaned with ethanol to ensure the crankshaft and piston rings were oil free so that the sample results could be as accurate as possible. After cleaning the engine parts were left for 4hrs to evaporate any ethanol residue present on the engine parts. Then the engine was assembled again and was ready for experimentation.

Figure 10: Experimental Plateform

The bike was kept in a workshop to reduce external effects on the experiment

The Piston were cleaned thoroughly.

Figure 11: Outer Casing of Piston

Figure 12: Piston Cleaning

The piston had some oil stains on it, which were removed with help of ethanol.

3.3 Recordings

The 3 samples (S_1,S_2,S_3) were tested on three different RPM's (1500,2000,2500) to see the effect of RPM on the nano lubricant. Therefore, making a total of 9 samples of three different concentrations to be tested at RPM's of 1500,2000,2500 respectively. Firstly, the sample marked as S_1(which has no graphene in it) was taken and the followed as,

- The sample was poured in the oil chamber along with placement of K-type needle thermocouple for temperature measurement.
- The initial temperature of the oil in the chamber was measured.
- After ignition the RPM was adjusted as per requirement using tachometer.
- The IC engine was given 5-10min time for initial run and RPM adjustment after which the bike run idly for 60min.
- The temperature was measured after every 15 min for the 60min run.
- The petrol was then taken out after each reading and the quantity was measured.
- The bike was given a rest period of 22hrs after every trial to ensure that each part of engine attains ambient temperature.
- The samples were drained before rest period
- The thermocouple was calibrated after every trial for accurate readings.

The above-mentioned steps were repeated for each sample so that each sample passes through the same physical conditions as its predecessor as realistically possible. A total of 9 samples were tested and each sample had a 15min reading interval which gave a total of 36 readings for the temperature.

Figure 13: Oil Ambient Temperature

Figure 14: Oil Temperature during Operation

RESULTS & ANALYSIS

4.1. Suspension Stability

As this suspension is a dispersed suspension, therefore agglomeration and sedimentation generation are easy due to clustering of nanoparticles and Brownian motion in nanoparticles. The interfacial surface forces between base fluid and nanoparticles is divided into momentary and continuous forces.

Continuous forces account for the buoyancy, repulsion force, steric hindrance and electrostatic repulsion forces. The Brownian force which is caused by the irregular motion of base fluid molecules is mainly the momentary force [15]. Other mass forces including gravity can be neglected because of the small size effect of nanoparticles in the disperse system. However, the movement of nanoparticles mainly depend upon interfacial surface force, nanofluid dispersion stability which is affected by the Van der Waals force and electrostatic repulsion force. This force will show different behavior with the addition of a dispersant in the suspension [16].

The stability of the sample is very crucial. As we know that solid particles in any liquid follows sedimentation unless properly dispersed in the solution. The nanoparticles agglomerate (formation of clusters) with other particles and eventually settling down at the bottom as shown.

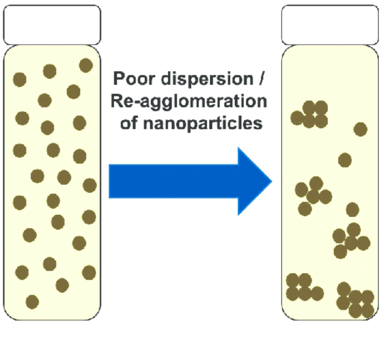


Figure 15: Dispersion Vs Agglomeration

If this agglomeration continuous the whole stability of the solution will be compromised, and all will be lost. Therefore, we had to make sure the samples we formulated were stable enough. To check their stability, we took the samples and placed them in an environment closed from external botheration and observed them.

The suspensions were observed for any signs of sedimentation at the bottom of the vessels. The table below shows the analysis,

Sample	DAY1	DAY2	DAY3	DAY4	DAY5
S_1	N/A	N/A	N/A	N/A	N/A
S_2	No sedimentation	No sedimentation	No sedimentation	No sedimentation	Settling was observed
S_3	No sedimentation	No sedimentation	Settling was observed	Suspension begin to get clear	Almost clear sample was observed.

Note: S_1 was Not Applicable as it contained no graphene

Table 2: Sedimentation Analysis of Samples

Although a nominal sonication time with an appropriate temperature was given, but it shows that this sonication time was not enough for the suspension to sustain its stability for more than 4-5 days. Research has shown that by increasing the sonication time the stability can be increased [14]. Determining the appropriate time for sonication and how it effects the stability is itself another study.

4.2 Temperature Analysis

The purpose of the lubricant is to avoid direct contact of piston cylinder with the chamber walls to reduce abrasion along with to emit the heat of the piston outside to keep it cool and prevent overheating. As due to high RPM the piston gets heat up, the heat from the piston is taken by the lubricant and is transferred to the oil chamber from where the heat is transferred to the chamber casing. The direct contact of air with the fins of the chamber casing from the outside provide cooling to the lubricant and thus the lubricant remains cool so that the engine parts don't overheat, thus decreasing the efficiency of the engine. The greater the heat transfer coefficient the better.

As the heat transfer coefficient of oil increases it will enable efficient transfer of lubricant heat to the chamber casing thus keeping the temperature cooler than before to increase the over engine performance.

The relation of heat transfer and thermal conductivity coefficient is given by,

$$\boldsymbol{h = \kappa / l}$$

Where,

H= Heat Transfer

l = Length of the material

κ = Thermal Conductivity of the Fluid

The difference is that H is a property of an object or system, whereas κ is the property of material. As κ is directly proportional to heat transfer therefore as the thermal conductivity of the fluid increases the heat transfer also increases which in our case will keep the lubricant cool and ensure it retains its lubricant properties do not exhaust soon.

Both Graphene (G) sample and Non-Graphene (NG) sample showed us the following results when tested,

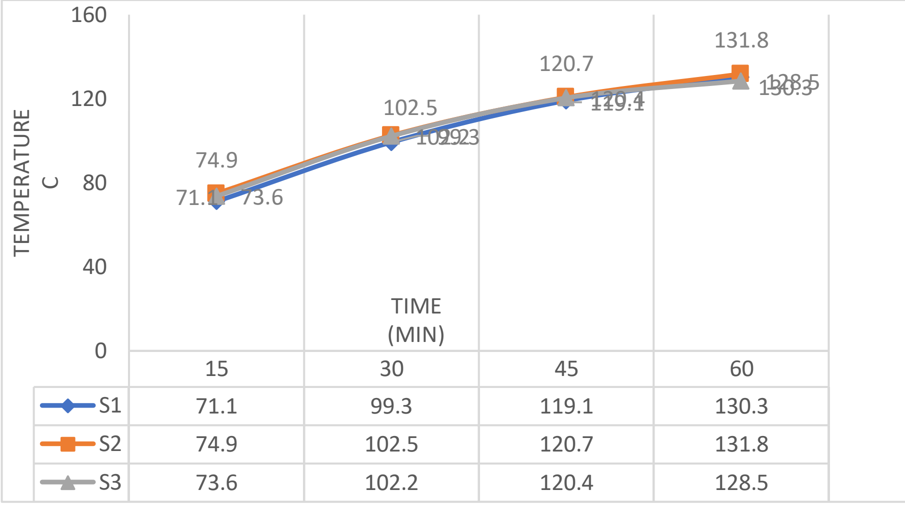


Figure 16: Temperature of Oil vs Time at 1500RPM

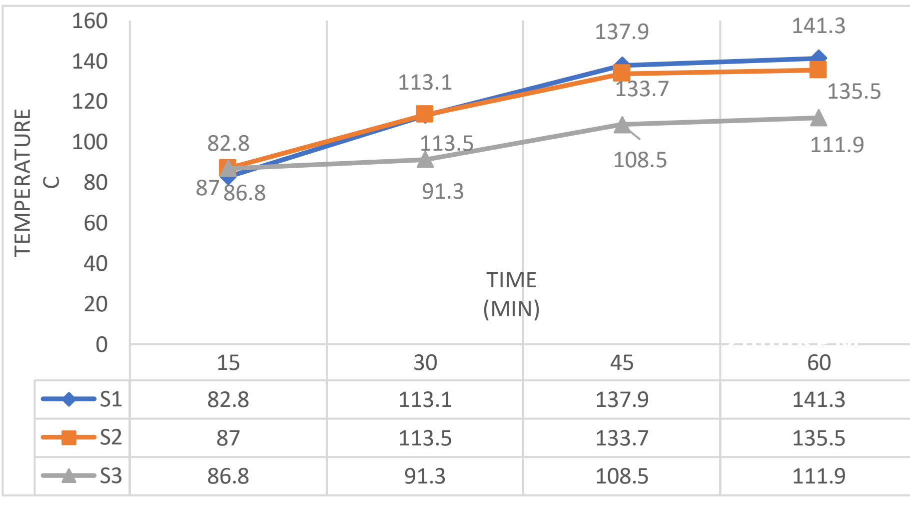


Figure 17: Temperature of Oil vs Time at 200RPM

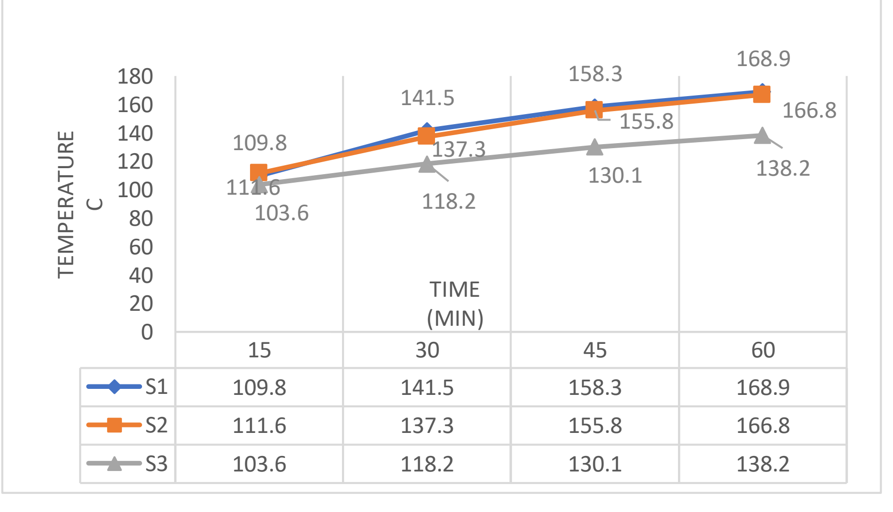


Figure 18: Temperature of Oil vs Time at 2500RP

Following results were compiled from this experimentation,

- A 23% increase in heat transfer coefficient was observed with 0.01wt% addition
- At lower RPM there is not much difference in performance between G & NG sample, but after longer run minor increased rate of heat transfer is observed.
- At 2000RPM Sample S2 shows significant changes with passage of time while S3 shows a drastic decrease in 21C of oil temperature at 80C in comparison with S1.
- At 2500 RPM sample S2 shows no significant change in temperature whereas sample S2 maintains its lower oil temperature

The results showed that the graphene lubricant is more effective at heat transfer as compared to non-graphene lubricant even at higher RPM’s.

CONCLUSIONS

The results and analysis showed that the temperature of the oil was reduced with the addition of graphene particles. This was due to the greater heat transfer coefficient of the oil. The graphene particles aided the oil to transfer heat to the wall of the engine more efficiently which in return reduced the oil temperature thus enabling it to hold its oily properties and keep the engine parts from rubbing against each other and keeping the engine cool which increased its efficiency as the parts didn't over heated and a direct surface to surface contact of the crankshaft with the inner chamber cylinder walls was avoided which elongated the engine's life. The results showed that with just a addition of little graphene particles the heat transfer coefficient can increase up-to 23%. As the heat transfer coefficient increase, the fuel efficiency of the system was also affected and an increase in fuel efficiency was also seen.

RECOMMENDATIONS

Below are some of the points that can take this research a few steps further.

- The stability of the nano-lubricant using different sonication times, water bath temperatures or with the help of dispersants.
- As this research was conducted with bike running in idle mode while being static. The stability or performance of nano-lubricant can be calculated more practically by including certain parameters such as dynamic load, ambient temperature change, shifting of gears, etc.

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