COST EFFECTIVE METHOD TO ANALYZE LUBRICATION OIL

Thottage Nuwan Aravinda Rathnayake

(159492 B)

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Department of Material Science and Engineering

University of Moratuwa
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DECLARATION

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The above candidate has carried out research for the Masters Dissertation under my supervision.

Name of the supervisor: Dr. Shantha Amarasinghe

Signature of the supervisor: Date:

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Abstract

The lubricating oil analysis is the most common method to identify the condition of any machinery. There are various ways to analyze lubricating oil, and those methods are based on an individual examination of lubricant properties such as Viscosity, Total Base Number (TBN), Total Acidic Number (TAN), Water Content, Impurities (element analysis), etc. However, to carry out these analyses, sophisticated pieces of equipment are required. They are costly and need specific environmental conditions. Furthermore, as the tests are done in a laboratory, away from the machine, carefully collected lubricating oil samples must be transported to them. The whole process, from collecting samples to obtained results, takes a considerable amount of time. Therefore, this process will hamper the maintenance program's efficiency since the machine has to be kept in idle until receiving the results. Hence, it is of utmost importance to have a cost-effective and faster results-giving method to analyze lubricating oil at the place where the machines are installed. Then the operator himself can check the condition of lubricating oil to ensure the safe and smooth operation of the machine.

A comprehensive literature survey was carried out to understand the current trends in lubricating oil analysis. Most of the tests described in the literature are based upon Physical, Chemical, Electro-magnetic and Optical methods. The proposed design is based on an optical technique that deals with the Refractive Index (RI) since it is an indicator of the physical as well as the chemical property characteristic of a substance. The critical angle of a material is directly related to RI. Therefore, monitoring the critical angle changes leads to an understanding of the quality of the lube-oil. During the design stage, special attention was paid to the cost of the fabrication and user-friendliness of the device.

The performance of a proposed lube-oil analyzer was assessed using Shell Gardenia 40 (lubricating oil used in high-speed marine engines of Fast Attack Craft) lubricant. The lubricant used for different operating hours were analyzed. This analysis unveiled that, though Original Equipment Manufacturer (OEM) emphasize changing the lubricating oil after 500 hours, lube-oil quality has not deteriorated below the specified levels at this stage. This shows that the lifetime of lube-oil can be further extended, and frequent quality testing of lube-oil can save large sums of money without putting the machine life into any danger.

The results obtained from the proposed device was compared with the tests carried out according to the American Society for Testing and Materials (ASTM) standards. Moreover, forced diluted lube-oil samples were analyzed using the proposed device. Both tests confirm the effectiveness of the proposed device.

Keywords: Lubricating oil analysis, Refractive Index, Cost-effective lubricating oil analyzer

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LIST OF ABBREVIATIONS

AES	Atomic Emission Spectroscopy
ASTM	American Society for Testing and Materials
CBPM	Condition Based Preventive Maintenance
FAC	Fast Attack Craft
ODI	Oil Draining Interval
OEM	Original Equipment Manufacturer
port	Left hand side of the ships bow when facing the bow
PPM	Plan Preventive Maintenance
ppm	Parts per million
RI	Refractive Index
stbd	Right hand side of the ships bow when facing the bow
TAN	Total Acid Number
TBN	Total Base Number
VI	Viscosity Index

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The relative movement of rubbing parts creates resistance. This resistance is called friction between the rubbing surfaces [1], and it causes a lot of wear and tear. It could also convert a part of energy of motion into heat. Lubricants are used to reduce this resistance and the other adverse effects caused by it. Lubricant is defined as any element which is used to minimize the friction of any rubbing surfaces.

Lubrication oil is essential for any machine to reduce the friction between surfaces where the two surfaces of the same kind of material or different kinds of materials are mutually rubbing.

At present, Sri Lanka Navy practices Plan Preventive Maintenance (PPM) or schedule maintenance procedures to maintain machinery condition. The manufacturer of the machine will indicate a schedule (specific time period) to change the lubrication oil without considering the usability of the used oil. Hence, in the practical scenario, the oil changing interval is carried out in according with the directives produced by the Original Equipment manufacturer (OEM). As an example, the lubrication oil changing details for MTU 12V 396 TE 94 high speed marine diesel engine used in Sri Lanka Navy is given below;

Number of engines available	- 36
Lubricant used	- Shell Gardenia 40
Lubrication oil capacity (per engine)	- 210 Ltrs
Amount per Ltr	- Rs 727.00
OEM given Oil Draining Interval (ODI)	- Every 500 operating hours
Total cost to change the lubrication oil	- Rs 152,670.00

The Condition Based Preventive Maintenance (CBPM) method used to monitor the performances of the machine and decide the maintenance schedule. As blood samples are used in diagnostics, lubrication oil analysis of a machine can be used to detect or predict the machine failures. The quality of lubrication oil plays an important part here as it can provide information on a failure at least ten times earlier than other indicators.

A unit cost of a particular lubrication oil depends upon the properties of the oil. The cost involvement for changing lubrication oil according to PPM is considerably high since the feasibility of the reusing ability of the lubrication oil is not analyzed. If the condition of the used oil is within the acceptable limit, the operational duration of lubrication oil can be extended and it decreases the frequency of oil changing intervals which will reduce the maintenance cost [2].

The contemporary methodology of analysis of the lubrication oil using laboratory-based methods take considerable time. The current practice is based on specific property analysis of lubricating oil such as viscosity, impurities available (carbon content, dilution, water content, and material particles) etc. These lab-based investigation methods require special conditions such as controlled environments (temperatures, humidity, etc.) and proper sampling methods.

Hence, the requirement of a cost-effective lubrication oil analysis method which will not require controlled environmental conditions can enhance the cost-effectiveness of maintenance. This in turns facilitate decision making with lesser delays.

1.2 Objectives of the study

Objective 01

To identify the functions of lubricants in a lubrication oil system and the main properties of a lubricant through literature survey.

Objective 02

To design and fabricate a cost-effective lubrication oil analyser to check the condition of lubricating oil.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents the necessity of using lubricants in a machinery and the main properties of lubricants when selecting it to a lubrication oil system. Further, the theories behind the friction between a moving/ sliding surface are discussed with the recent literature with reference to lubricants/ lubrication oil systems.

The process of extracting the compounds available in crude petroleum is known as petroleum refining. Crude oil, which exists as a liquid in the earth's crust is also called petroleum with a complex mixture of carbon and hydrogen. Lubricants are a substance that produced during the process of crude oil refining. Fig 2.1 illustrates the refining process of crude oil and the output substances during the process [3].

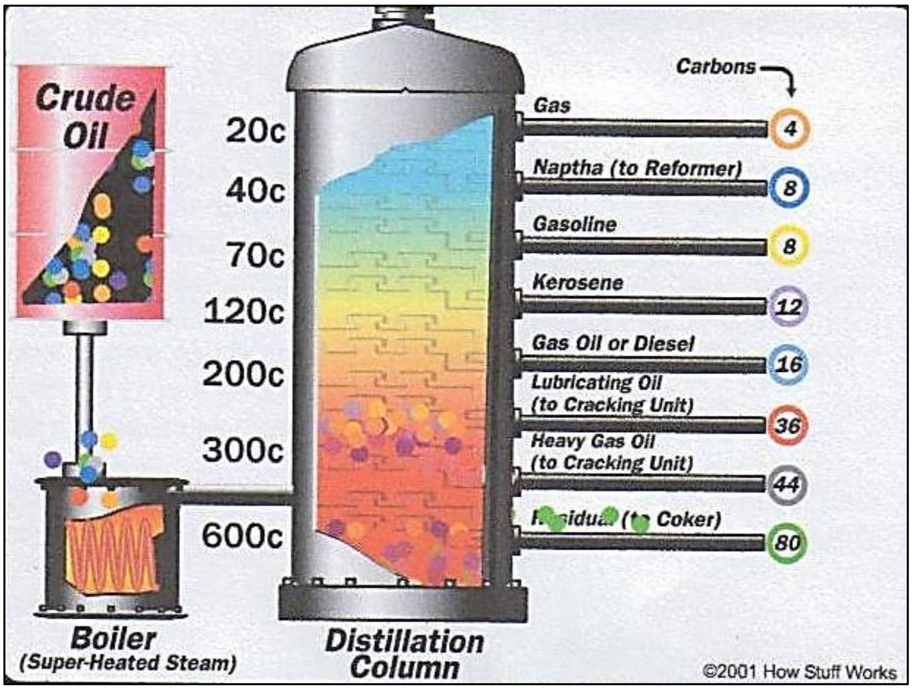

Fig 2.1: Crude oil refining process

The lubrication oils which are used for machines can be basically categorized under two headings. They are Mineral and synthetic lubrication oils. The mineral oils are produced during the process of the crude oil refining as an output product. Synthetic oils are manufactured polyalphaolefins which are hydrocarbon-based polyglycols or ester oils [4]. Mineral oil is the most inexpensive and commonly used lubrication oil compared to the other available types of lubrication oil. Further, there are a number of mineral oils in use and already exists. In addition, mineral oils can be used to produce a range of viscosities which gives an additional advantage during the usage stage (Viscosity refers to the substance's resistance to flow for diverse applications).

Crude oil is undergone the sedimentation (purifying process) and after that the fractionating towers are used to heat up the crude oil. Various vapors can be used to make fuel, waxes, or propane, among other substances which are boil off in different points of these towers. Lubrication oil properties can be improved after mixing required amounts of additives with the completion of filtering process. Fig 2.2 shows the production process of lubricants [5].

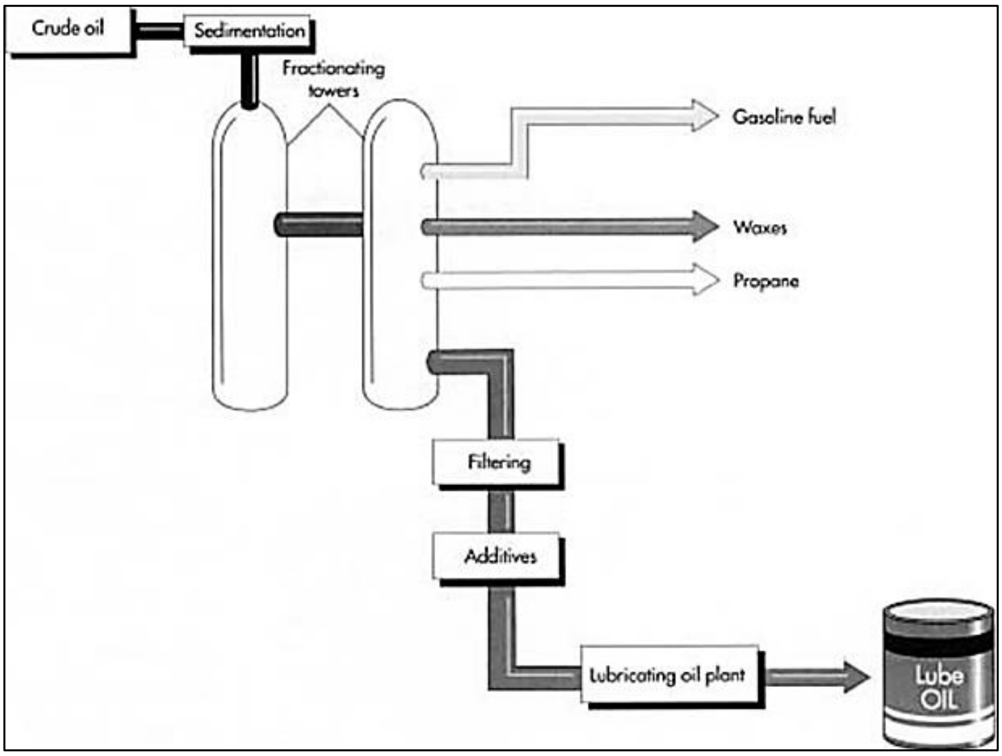

Fig 2.2: Lubricant production process

2.2 Functions of Lubricants

The main functions of lubricants are as follows [6];

a. It avoids direct metal to metal contact between the rubbing surfaces and reduces wear and tear (Lubricants will create an oil film within the rubbing surfaces).
b. When the surfaces are rubbed together, heat is generated due to friction and it destructs the material. Lubrication oil reduces the expansion of metal due to generated heat.
c. It acts as a coolant of metal since it is a media to heat transfer.
d. It avoids rough conditions of the relative movement of the rubbing surfaces (due to unevenness of the surfaces).
e. It minimizes the cost of maintenance since the associated components expand the life expectation of the equipment by using a proper lubricant.

2.3 Theories of Friction

The theories of friction can be discussed as follows;

2.3.1 **Welding theory** - The metal surfaces are appeared to be mirror polished to the naked eye. However, there are series of aspirates (peaks) and valleys in each surface. During the process of rubbing of metal surfaces together, the peaks will touch each other. If these two surfaces are operated with a load, then the pressure on top of the peak will increase and deformation of the peaks may lead to create weld junction between them.

2.3.2 **Mechanical Interlocking** - As mentioned in welding theory, metal surfaces are having series of aspirates and valleys. Interlocking means the movement of two rubbing surfaces which can be restricted due to overlapping of peaks of one surface to valley of other surface. This will create static friction. A simple schematic diagram of the phenomenon is shown in Fig 2.3 [7].

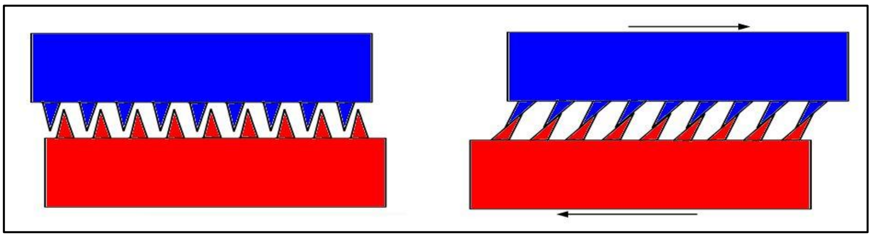

Fig 2.3: Schematic diagram of mechanical interlocking

2.3.3 **Molecular Attraction** - When two rubbing surfaces in operation, atoms of one surface may be in attracting range of the atoms of other surface. This leads to create a friction between the surfaces. A schematic diagram of the molecular attraction is shown in Fig 2.4 [4].

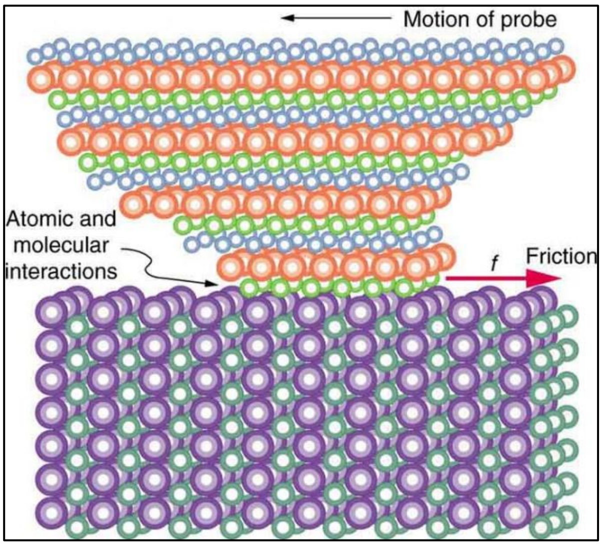

Fig 2.4: Schematic diagram of a molecular attraction

2.3.4 **Electrostatic Attraction** - When two rubbing metal surfaces are in operation there could be a flow of electrons producing a cluster of charges of opposite polarity at the interface. These charges are responsible for holding the surfaces together by electrostatic attraction.

2.4 Methods of Lubrication

There are three methods of lubrication as describes below;

2.4.1 **Thick-Film lubrication** - The phenomenon of thick-film lubrication is the moving/ sliding surfaces which are separated by each other with the help of thick film of lubrication oil (at least 1000 A^0 thick). It will result in minimizing direct surface contact or welding of peaks (welding theory). The layer of lubrication oil covers the peaks and valleys of both metallic surfaces and the thick layer of oil will act as a barrier to avoid direct contact between metal surfaces which ultimately reduces the friction. Fig 2.5 illustrates the phenomenon of thick-film lubrication.

The minimum viscosity to be selected is depend upon the resistance creates each other by the internal particles of the lubricant with the environmental condition. The most suitable lubricants for thick-film lubrication is said to be the hydrocarbon oils which consists with 12 to 50 carbon atoms. However, the ordinary hydrocarbon lubricants should be blended with proper additives to maintain the viscosity of the oil during the different seasons of the year.

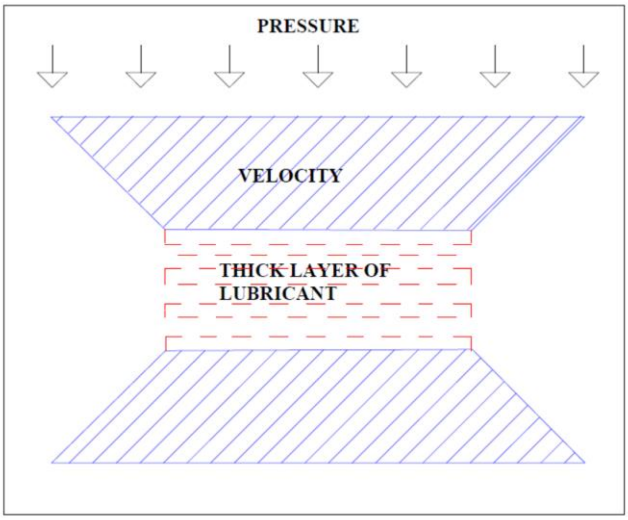

Fig 2.5: Thick-film lubrication

2.4.2 **Thin Film lubrication** -Thin film lubrication is applicable for the moving/ sliding surfaces which cannot be kept with a continuous film of lubricant in-between. In this situation, the system can be lubricated by using a lubricating oil which can get absorbed on both surfaces either physically or chemically. This absorbed lubricating oil will keep the surfaces without touching each other. Fig 2.6 illustrates the phenomenon of thin film lubrication.

The most common lubricating oils that can be used as thin film lubrication are vegetable, animal oils and their soaps. The reason behind that is the capability of those oils to chemically absorbed or physically react with the rubbing surfaces to initiate a thinner layer of lubricant which will enable the lubrication. Even though, vegetable and animal oils are possessed with the property of good oiliness, but other properties tend to break away at high temperatures as a disadvantage. Because of that, the more thermally stable mineral oils could be blended together with vegetable/ animal oils to improve the oiliness of mineral oils. Graphite and molybdenum disulphide are also suitable for thin-film lubrication.

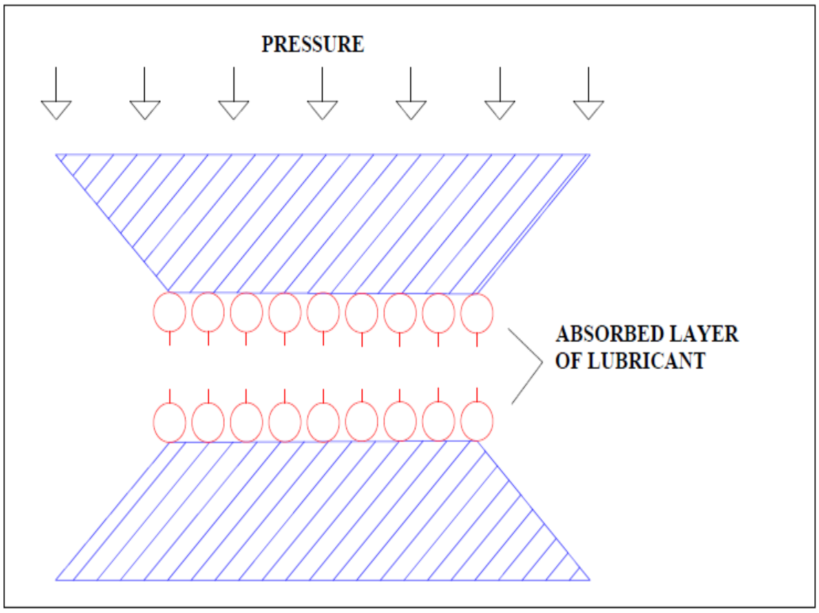

Fig 2.6: Thin film lubrication

2.4.3 **Extreme Pressure lubrication** - During the application of high pressure and high speed moving/ sliding surface operations, the generated temperature could be high and it may decompose the lubricating oil or even vaporize the oil. The mineral oils can be used for this extreme pressure and temperature conditions by adding special additives called extreme pressure additives. Adding of aforesaid additives will create more stable films within the system. Chlorine, Potassium-borate and Sulfur-phosphorus can be introduced as extreme pressure additives which are used for industrial gear lubrication purposes. Further, the above additives are temperature activated and can be react with metal aspirates which can form a sacrificial film.

2.5 Classification of Lubricants

The physical condition is the primary measurement of the classification of the lubricants [8];

2.5.1 **Lubricating oils** - Lubricating oils could be introduced under three categories.

(i) Vegetable and Animal oils.

Animal oils are extracted from crude fat. Cotton seed oil and caster oil can be introduced as examples for Vegetable oils. The effective capability of these oils is to wrap around the surfaces of the metal parts during high temperature operating conditions and loading conditions. These conditions can be obtained due to their inherent oiliness. However, these oils are costly and oxidize to sticky condition with the contact of water which could be identified as disadvantages of these oils. Because of that, these oils are used very rarely. Moreover, animal and vegetable oils are used as additives to improve the oiliness of petroleum-based lubricants.

(ii) Mineral or Petroleum oils.

Mineral oils are hydrocarbons having 12 to 50 carbon atoms (lower molecular weights) and they are produced through crude oil refining. Further, the cost of mineral oil is comparatively cheaper due to the availability in abundance and they are stable under many service conditions. Because of that, mineral oils are widely used as lubricants in various machinery. Higher molecular weight compounds are added to increase the oiliness of mineral oils.

(iii) Blended oils.

Addition of correct additives to the lubrication oil is essential to make that lubrication oil to perform satisfactorily since single oil does not possess all the required properties. The lubricating oils which have been improved the properties after adding additives are named as blended oils. As examples, oleic, stearic, palmetic acid (compounds with larger molecular weights) or coconut, castor oil (increase the oiliness) can be highlighted.

2.5.2 **Semi-solid Lubricants or Grease -** Grease or semi solid lubricants are produced with the help of lubricating oils by adding thickening agents. The main component of grease is lubricating oil and it may be mineral oils or synthetic oils. The thickeners can be categorized as special soaps and non-soap thickeners. The higher load applications with low speeds are more suitable for applying of grease, but comparatively internal resistance is much higher in grease than lubricating oil. Hence, it is better to use lubrication oil rather than grease. Further, effective dissipation of heat can be obtained with the lubrication oil and it is the best for relatively higher temperature operations. However, heat dissipation of grease is uneven when compared to lubrication oil and it is suitable for work at relatively lower temperature.

2.5.3 **Solid lubricants** - Solid lubricants are used in conditions where,

(i) The lubricating oils or grease could not be used since the impact of environmental conditions which will not allow to create a thin film of lubricant.

(ii) The locations that the lubricating oils or grease will contaminate easily by dust particles or any other elements.

(iii) During the circumstances of higher operating temperatures or load conditions.

Graphite, molybdenum disulphide, tungsten disulphide and zinc oxide are some of the most commonly used solid lubricants. Solid lubricants could be used for continuous operating environments where the operating temperature can be up to 650^0C. Further, solid lubricants are also used as additives to improve mineral oils and grease to enhance their load carrying capacity. Fig 2.7 illustrates the Molybdenum Disulphide which has a sandwich-like structure with a layer of molybdenum.

Graphite is the most widely used solid lubricant and its physical configuration is commonly in powder form. Further, it is stable up to a maximum temperature of 375^0C. The structure of graphite is consisted of flat plates which are arranged on top of each other. However, these plates are bonded each other with the help of weak van der waal’s forces. Graphite is an effective lubricant because the parallel flat layers could be moved easily relative to another.

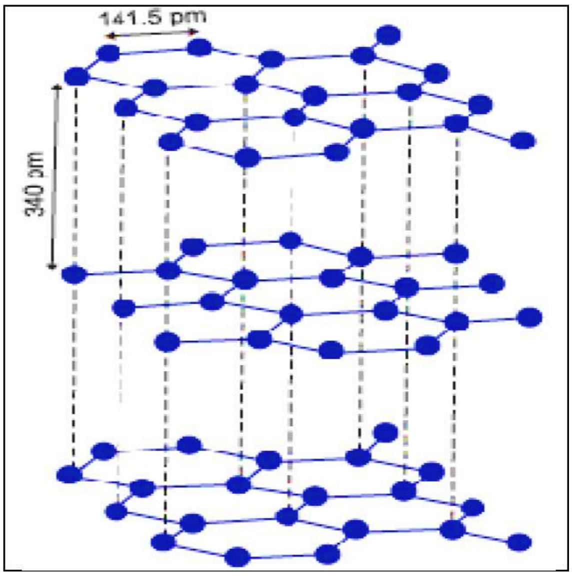

Fig 2.7: Molybdenum Disulphide structure

2.6 Properties of Lubricants

The most important properties of lubrication oil are as follows [9];

2.6.1 **Viscosity** - The resistance to the movement of a particular lubricant to its own flow is known as viscosity. It is the most important property for any lubricant. Viscosity is measured through the unit of poise. Further, for any lubricant, viscosity provides the operating characteristics and it is the important property to decide any lubricants application. If the viscosity of the oil is too low, a liquid oil film cannot be maintained between two moving/sliding surfaces. The high viscosity lubrication oils will increase the friction between the rubbing surfaces.

Further, with the increasing temperature, the viscosity of the lubrication oil will decrease and lubricating oil becomes thinner. Because of that, the changes in the temperature should not affect a good lubricating oil since it will enhance the operating capability during changing of temperatures.

Viscosity Index **-** The rate of change of viscosity of an oil in relation to change of temperature is indicated by its viscosity index (VI). An oil with a low viscosity index has a rapid change of viscosity with changing temperature than an oil with high viscosity index. Viscosity index is important especially when oils are subjected to large variations in temperature as in the case of engines being started from cold or in low temperature conditions.

2.6.2 **Flash point and Fire point -**

(i) Flash point can be defined as the minimum temperature where a lubricating oil produces required amount of vapors, which can ignite for a moment, when a small flame is near it.

(ii) Fire point is described as the minimum temperature where a lubricating oil produces vapors to keep a flame continuously for a minimum five seconds, when a small flame is near it.

However, it is observed that the temperature of fire point is always higher than the flash point. When we consider about the lubricating oil property, fire and flash points are not directly involved with it. However, they are important when lubricating oil is operating under high temperature. The flash point is very important for a good lubricant because it should be above the temperature where the lubricating oil is going to be used and this will reduce the fire risk during the usage.

2.6.3 **Cloud point and Pour point -** Cloud point is the temperature where the lubricant physical condition appears as cloudy when it cools gradually. Pour point can be identified as the temperature which the lubricant stops flowing or pouring when it cools slowly. These properties will indicate the ability of a particular lubricating oil to use in cold environmental conditions. Low pour point is required for a lubricant oil which is going to operate at low temperatures. If not, the lubrication oil will solidify and it disturbs the proper functioning of the system.

2.6.4 **Oxidation Stability** - When the lubrication oil is disturbed and heated with the presence of air and moisture, the oxidation of a lubricating oil will increase. Lubricating oils which are having poor oxidation stability will have a shorter useful life than which oxidize slowly. During the oxidation process, the viscosity and acidity will increase due to the soluble products which are created. Because of that, the lubrication oil condition will not be suitable for further use [10]. However, the oxidation stability of a lubricating oil can be increased with addition of chemical additives.

2.6.5 **Aniline Point** - The minimum equilibrium solution temperature where the same volume of aniline and lubricating oil samples produce is the aniline point. Aniline point will give an idea about the degradation of lubricating oil when it operates under the contact with packing, rubber products, etc. Rubber products (natural, some of the synthetic rubber) are having a possibility to dissolve in aromatic hydrocarbons. Because of that, the content of aromatics should be minimal in a lubricant. When a lubricant is having a larger paraffinic hydrocarbon percentage, which means a smaller number of aromatics, this lubricant is having a higher aniline point.

During the process of determining the aniline point same volume of lubricant oil will be mixed with aniline in a test tube mechanically. Then the mixture will be heated until the solution becomes homogenous and cooled at a controlled rate. Aniline point is the temperature where the lubricant oil and aniline phases separates out.

2.6.6 **Corrosion stability** - The corrosion test is used to identify the corrosion stability of a particular lubricant. During the corrosion test, the lubricating oil sample will be heated up to a particular temperature and a polished copper strip is placed for a specified time. At the end of the stipulated time period, the copper strip is inspected for any corrosion. If the copper strip has corroded, that means the lubricant is comprised of chemically unstable elements which corrode the copper strip. However, a quality lubricant should not possess these types of chemically active substances. The chemicals which active the corrosion effect can be minimized by adding certain inhibitors. The most frequently used inhibitors are P, As, Cr, Bi or Pb which contain organic compounds.

2.7 Methods used to analyze lubricating oils

There are several methods to analyze used lubrication oil and those methods can be categorized mainly into two parts. They are;

a. Mobile oil analysis tools
b. Off-site oil analysis (Labs which are operated commercially and industrially by the individual owners)

It is essential to replace the lubrication oil with an early notice during the industrial applications because an unexpected failure of any machinery will affect the process of the production directly and also the particular machine requires to be stopped to minimize further damages or wear. The performance parameters are under the variations of optical, electrical, chemical and physical properties which will effect on the characteristic changes of a particular lubrication oil towards its degradation. The performance parameters could be identified as viscosity, water content, Total Acid Number (TAN), Total Base Number (TBN), particle counting, flash point, spectrometric oil analysis, etc. The relationship between the degradation of lubricating oil, parameters of performance, and sensors available at present are shown in Fig 2.8.

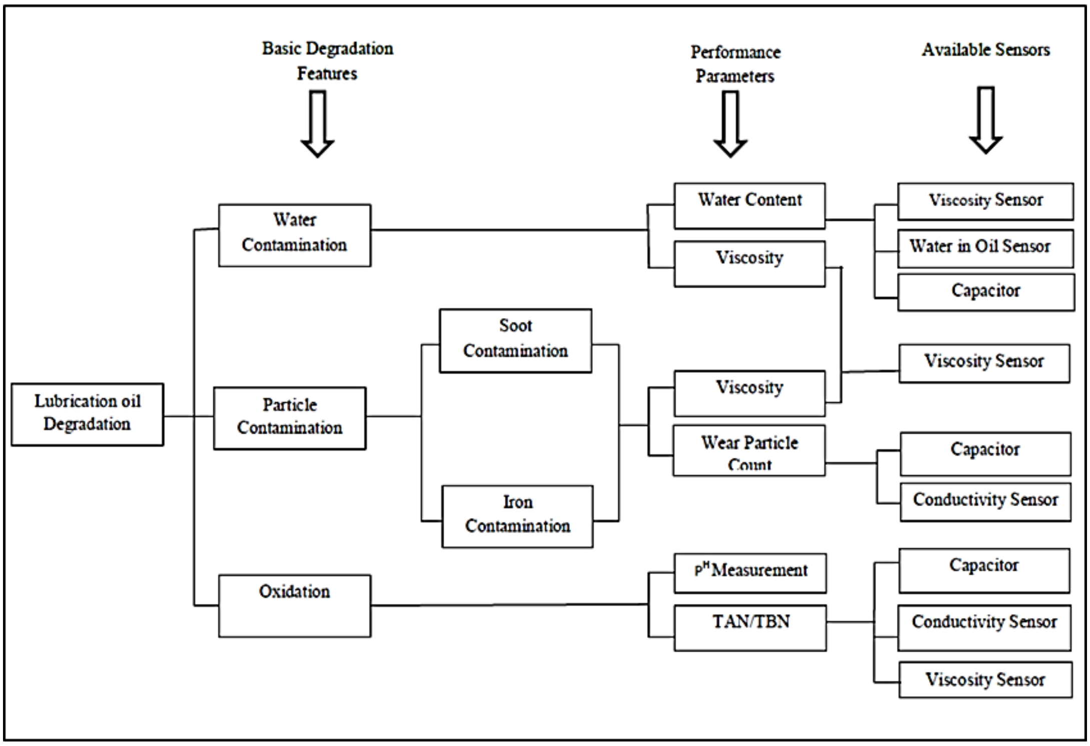

Fig 2.8: Relationship between degradation features and parameters

However, the methods that are commonly used to identify the quality of lubricating oil are as follows;

a. Atomic Emission Spectroscopy (AES)
   In a lubricating oil sample, the level of contaminants, wear metals, impurities and additives are measured in parts per million (ppm) with the help this method. The technique of spectroscopy is used to detect and measure the availability of elements in a sample and the unique atomic structure of each element is identified during the spectroscopy. Each element emits light of specific wave lengths or colours during the addition of energy and every element can be differentiated each other since they have different pattern of spectral lines [11]. Fig 2.9 is showing the schematic diagram of atomic emission spectroscopy.

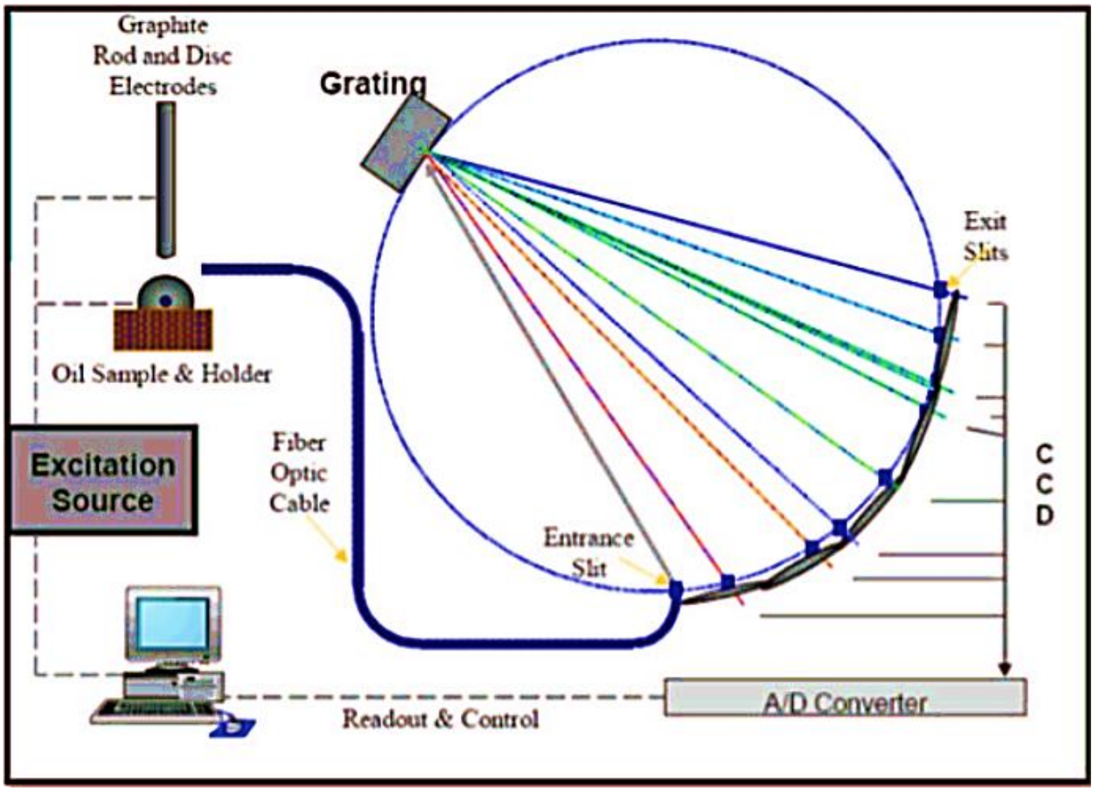

Fig 2.9: Schematic diagram of Atomic Emission Spectroscopy

b. Viscometer

The viscometer indicates the sample flow kinematics to understand the shear strain rate precisely, and it is independent to each fluid type (it is one dimensional, isometric flow). Then the shearing stress can be calculated through the measured value of resistance to the flow. The ratio between the shearing stress and the equivalent shear strain rate (it is not ideal since one dimensional flow is very difficult to obtain practically) will provide the shear viscosity [12]. A list of available viscometers is given below.

(1) Concentric cylinders (the viscometer geometry is shown in Fig 2.10)

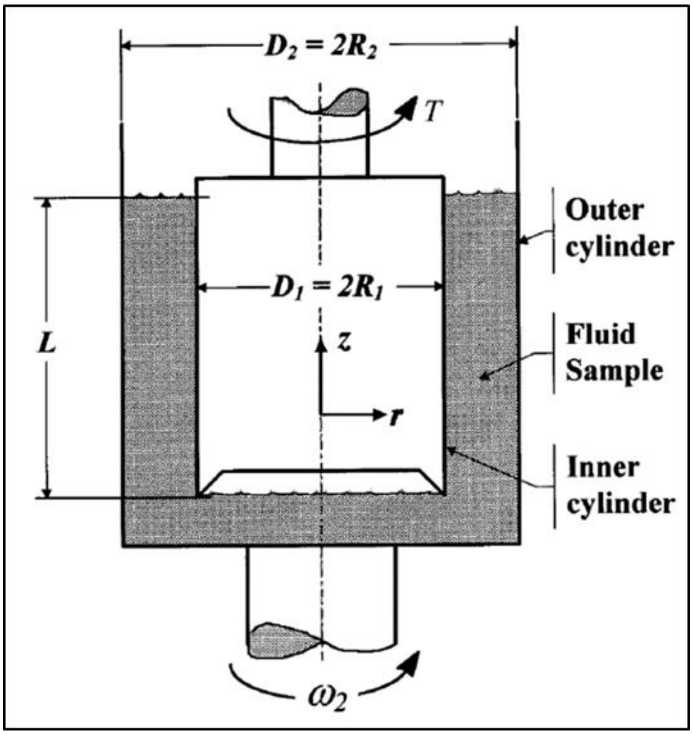

Fig 2.10: Concentric cylinder viscometer geometry

(2) Cone-and-plate Viscometer (the viscometer geometry is shown in Fig 2.11)

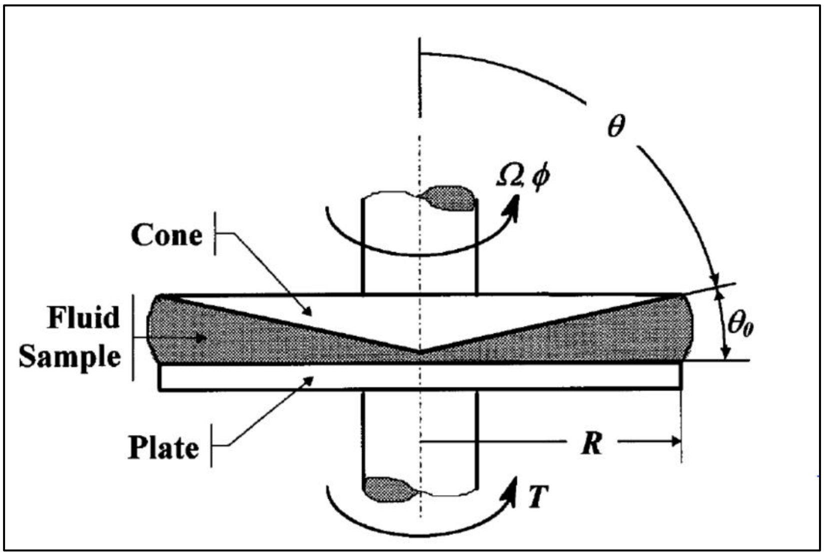

Fig 2.11: Cone-and-plate viscometer geometry

(3) Capillary viscometer

(4) Falling body method

c. Infrared Spectroscopy

In infrared spectroscopy, the absorption of infrared radiation by the lubricant is calculated as frequency function of that radiation. Because of that, a precise spectrum of infrared need to be obtained. Hence, as captured in Fig 2.12, dissimilar spectrum for each lubricant can be obtained for different types of application [11].

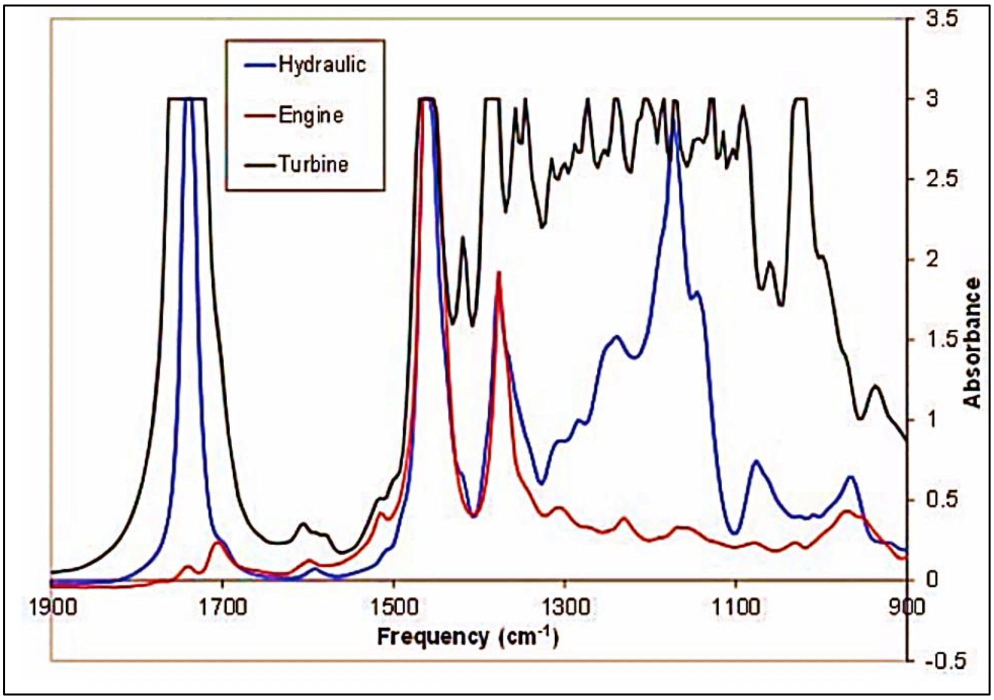

Fig 2.12: Infrared Spectra for typical lubricants

d. Water measurement using Infrared (IR) technique

The chemical bonds that are formed with the water particles and the lubricant molecules are having solid mid-infrared resonances. With that reason, during certain vibrational frequencies the bonded oil-water molecules absorb different mid-infrared energy [11]. This absorption is due to the vibrations of the bonded molecules at natural frequencies. Fig 2.13 shows the variations in a multi-weight motor oil. The absorption resonance will increase continuously when the water content is high. The correlation between the water content in a lubricant and absorption resonance could be obtained because the process is repeatable and it is a fundamental chemistry of molecules.

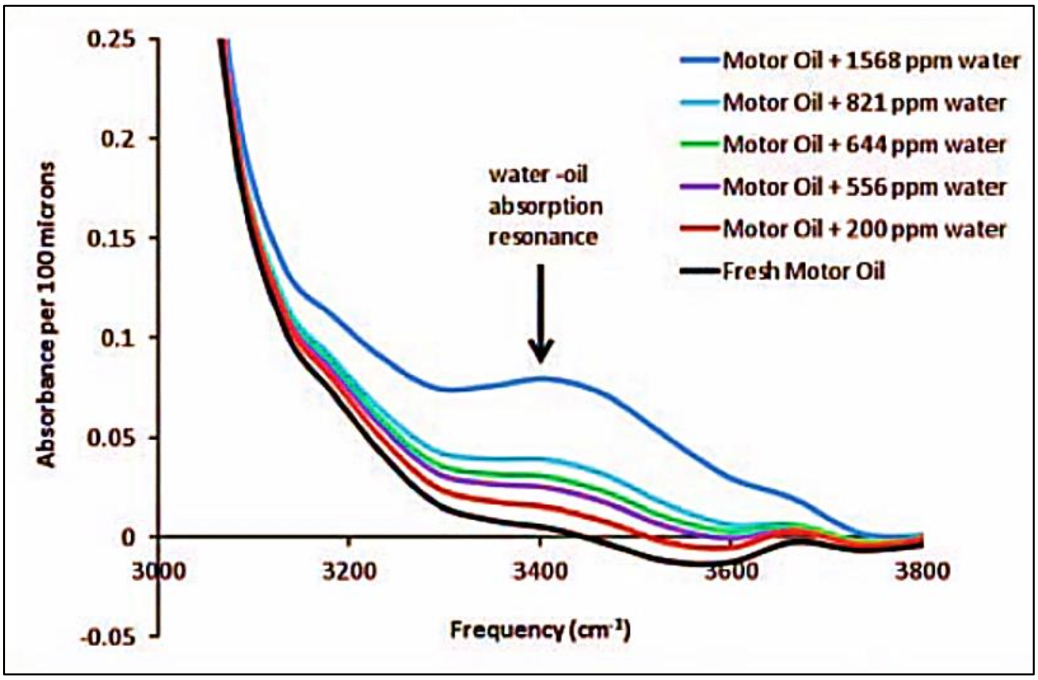

Fig 2.13: Mid-infrared energy at specific vibrational frequencies

e. TAN – TBN measurements using IR technique

The measured values for Total Base Number (TBN) and Total Acid Number (TAN) are important to identify the lubricant degradation of a machinery and to minimize the possibility of failure of a machine due to wear and other related problems. The commonly used method for calculating TAN and TBN is through Electrochemical titration [11]. The acid in the oil (TAN) or reverse alkalinity (TBN) is calculated using IR techniques.

f. Fuel Dilution Meter

All engineers highly concern about the possibility of fuel mixing with the lubricating oil since it will totally hamper the properties of lubricating oil. Fuel dilution levels are being checked frequently in lubricating oil samples of machinery with the help of laboratory assistance. The basic methods to identify the fuel dilution is to check the viscosity or flash point. However, the available methods are required sophisticated and expensive equipment like complex data analysis algorithms to measure the dilution [11].

The performance parameters and available measurement approaches to analyze lubrication oil are indicated in table 2.1.

Table 2.1: Performance parameters and available measurement approaches

Performance Parameters	Measurement Function	Unit	Benchmark of Degradation	Available Measurement Approach
Viscosity (40 ^{0}C)	Contamination of lubricant by some other oil, oxidation	Cst (mm^2/s)	≥ 55 ≤ 50	Kinematic Viscometer
Viscosity (100 ^{0}C)			≥ 10 ≤ 8	Micro-acoustic Viscometer
Water content	Presence of Water	%	≤ 2	Capacitance sensor (Dielectric constant)
				Kinetic Viscometer
				Water in oil sensor
TAN/TBN	Acidity/ alkalinity of lubricant (oxidation level)	mgKOH/ gm	≥ 0.6 ≤ 0.05	Capacitance sensor (Dielectric constant)
				Kinetic Viscometer
				Conductivity sensor
Flash point	Presence of dissolved solvents or gases in the lubricant	^{0}C	≥ 220 ≤ 140	Thermometer
Wear Particle Count	Wear particles in parts per million	ppm	≤ 40	Capacitance sensor (Dielectric constant), Kinetic Viscometer, Conductivity Sensor, Inductive Sensor
Particle Counting	Detect number of particles for sample size of 100cc	mg/L	≤ 200	

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter presents the design and the working principle of a proposed lubrication oil analyzing equipment. Further, the theories which are going to be used during the design of the equipment are discussed through this chapter.

3.2 The constraints of available lubrication oil analysis methods

The available lubrication oil analyzing methods are based on the degradation on lubrication oil, which can be categorized into two parts. They are namely oil degradation due to lubrication oil by itself (Polymerization, partial burning, Oxidation etc.) and adding of impurities to the lubrication oil (water, carbon, fuel, metal particles etc.).

However, the available lubrication oil analysis methods are based on the identifying the changes in a single property of a lubricating oil or calculating the amount of impurities added to lubrication oil. Hence, the lubricating oil analysis reports are providing only the quantitative valves of changes related to the aforesaid lubricating oil properties or added impurities. The lubricating oil analyzing authorities are providing those details to the owners of relevant machinery to decide whether to change the oil or to analyze the condition of the machine.

The main disadvantage of this analyzing system is the cost to analyze a single method of lubrication oil and also the time duration to obtain the reports. Further, the oil samples are to be taken very carefully and the same to transfer to relevant laboratory (where the lubricating oil analysis equipment are available) for analysis. Furthermore, after sending the sample, the process of analyzing the lubrication oil will be carried out by the service provider where they will be handling lots of oil samples which are obtained by different organizations. Hence, the guarantee of the accuracy of the provided sample is having a probability that it may not be the correct report.

Mishandling of provided sample, adding impurities to the sample and misplacing of provided sample may be the reasons for inaccuracy of the reports.

The lubricating oil analyzation is expensive due to the following reasons;

a. The initial cost in manufacturing the lubrication oil analyzing equipment.

b. Maintaining the required environmental conditions for the analyzation.

c. Labor charges to the operating of equipment and to obtain consultancy for expert opinion.

d. The lubricating oil analyzing laboratories / authorities are maintaining their standards through classification societies.

The available lubricating oil analyzing methods which are discussed previously could be summarized into four categories namely physical, electrical (magnetic), chemical, and optical techniques. However, these techniques can be elaborated as follows;

Electric (magnetic) techniques

a. Dielectric constant
b. Conductivity
c. Micro acoustic viscosity
d. Magnetic Susceptibility

Physical techniques

a. Kinematic viscosity
b. Ultrasound
c. Thermal conductivity
d. Ferrography

Chemical techniques

a. pH measurements
b. Thin film contaminant monitor

Optical techniques

a. Optical transparency
b. IR absorption

Hence, it is clearly understood that the available lubricating oil analysis methods are lab-based. The lubricating oil samples are collected from the machinery and send them to laboratories for oil condition analysis. However, this process may take a considerable time hence the actual condition of the oil cannot be determined due to the delay of sampling and analyzation process.

Introducing a cost-effective lubrication oil analyzing method will be beneficial for the organizations which are having number of machinery to minimize the defects.

a. Could be operated and understood by the machine operator where the machine is installed.
b. Testing method does not require special environmental conditions.

Therefore, it is essential to design a cost-effective lubricating oil analyzing method considering the common property to overwhelm most of the degradation methods of lubricating oil.

With a keen scrutinizing of the available lubricating oil analysis methods and the knowledge obtain by the literature review it is effective to use an optical method to design a cost-effective lubrication oil analyzing device. Hence, this device is to be designed based on the Refractive Index (RI) which is a physical property with the characteristic of a pure compound. Further, refractive index depends on the following lubrication oil properties;

a. Viscosity
b. Availability of particles
c. Dilution

d. Water content

3.3 Materials requirement

The proposed cost-effective lubrication oil analyzing equipment requires the following materials.

a. A prism
b. Light source with an electrical circuit
c. Camera to capture the refracted image
d. Computer with accessories

3.4 The working principle of the designed lubricating oil analyzer

Any visible light changes its direction when it passes through a material with a higher refractive index (RI) to that with a lower refractive index. As the incident ray angle ‘α’increases, the refractive angle ‘β’ will increase in accordance with Snell’s Law, and when the refractive angle ‘β’ (where the incident ray angle ‘α_c’) reaches the critical angle (=90°), the total refraction will occur at the boundary between the prism and the lubricating oil sample (as shown in Fig 3.1). However, when the incident ray angle increased beyond ‘α_c’ (when refraction passes the critical angle), the light cannot enter to the medium (which is the oil sample) and reflects back to the prism. This phenomenon is called the internal reflection. The special feature of this action is the critical angle of lubrication oil sample will vary with the Refractive Index (RI) of the particular sample. The RI of a lubrication oil sample will based on the properties of it such as viscosity, suspended particle density, dilutions (liquid impurities), water content and chemical properties.

When we use a divergence beam of light towards the lubrication oil sample through the prism, a fraction of light rays will have an incident angle higher than the critical angle. A schematic diagram of working principle of the designed lubrication oil analyzer is shown as Fig 3.2. Because of that, the internally reflected light could be obtained as an image to a separate plane. This image will have a brighter and darker region due to the partial internal reflection of light. When the critical angle changes with refractive index of the lubrication oil sample, the brighter and darker region of internally reflected image will change. Further, the appearance of the internally reflected image will vary as per the quality of the lubrication oil sample and also the image may be more or less the same for similar kind of liquids which is having same qualities.

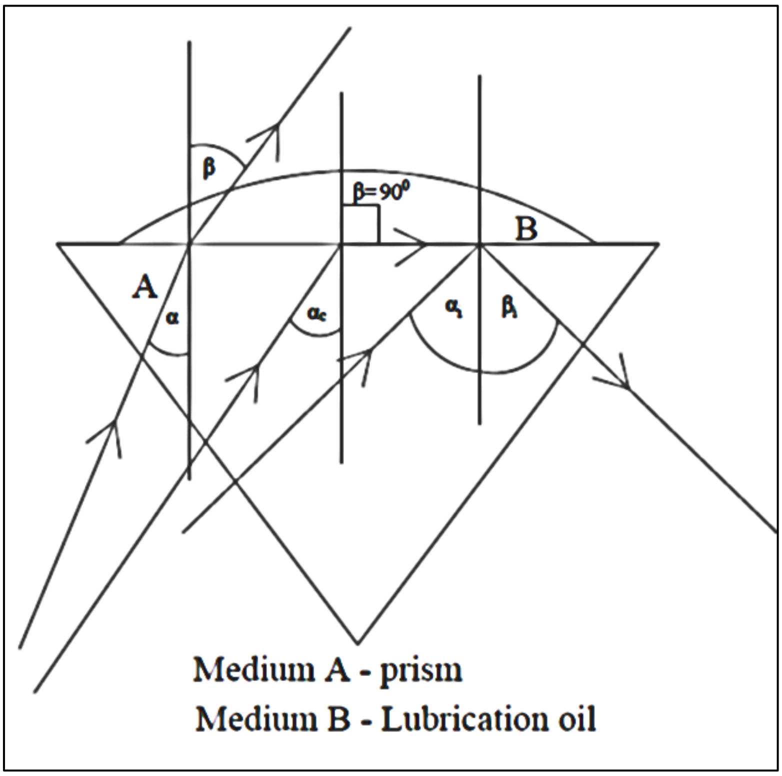

Fig 3.1: Refraction and reflection between the prism and lubrication oil sample

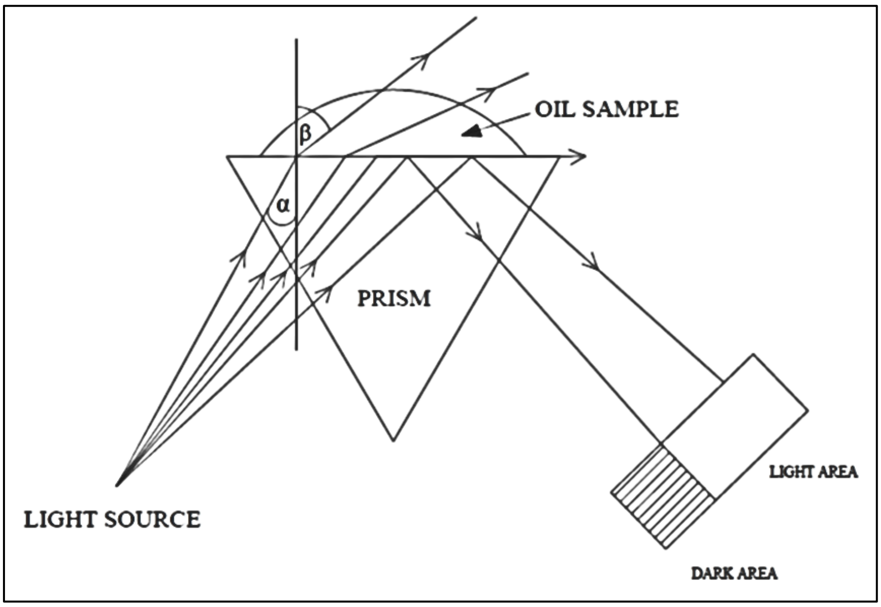

Fig 3.2: Working principle of the designed lubrication oil analyzer

The proposed design of lubrication oil analyzing equipment is based on the reflection theory. It has the capability of comparing the internally reflected image of the original lubrication oil (brand new oil or unused oil) and used lubrication oil.

The internally reflected image that is going to be obtained by analyzing unused oil will be examined to understand the main features of the image. Basically, the image will be identified as shown in Fig 3.3 and it can be categorized as darken area and brighter area.

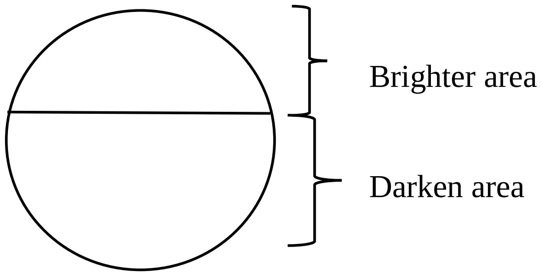

Fig 3.3: Internally reflected image of unused oil

The internally reflected image of the unused oil sample, the area of brighter region will indicate the quality of the lubrication oil sample where it will depend upon the refractive index. It can be taken as a reference to check the used oil samples which have been taken from the engines. However, the used oil samples are going to be obtained as per pre-defined time frames to identify the variation in internally reflected image until the OEM given lubrication oil changing interval. Schematic diagram of the working principle of the designed lubrication oil analyzer is shown in Fig 3.4.

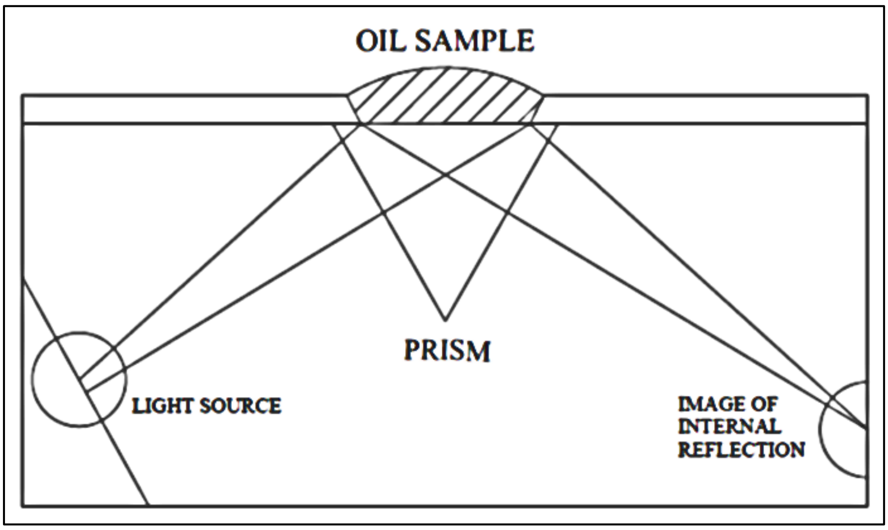

Fig 3.4: Schematic diagram of the designed oil analyzer

A separate comprehensive computer programme is to be written to identify and calculate the variations of the brighter area of the image which is taken through the designed equipment to analyze original oil and the used oil. This programme could be used to analyze the condition of any given lubrication oil sample by understanding the internally reflected image comparing with the image of original oil. However, the reference image is to be obtained by using fresh oil/ new oil samples of any kind of lubrication oil before starting the checking of the used oil samples through the designed lubrication oil analyzer. It can be highlighted as an essential requirement.

3.5 Proposed design of lubrication oil analyzer

As discussed in the theory, the proposed equipment is going to use which is based on the refractive index to identify the condition of lubrication oil. A prism is used because it has a higher reflective index (RI) than the lubrication oil samples that we are going to analyze. Because of that any visible light passes through it will change the direction of the light drastically and some of the incident rays will internally reflect.

The prism is fitted to the upper cover of the equipment with a circular groove to pour the lubrication oil that we are going to analyze. A light source is directed towards a plane of the prism and it will pass through the prism to the poured lubrication oil sample. As per the refractive index of the sample, a part of the light will reflect and part will pass through it. When the incident rays angle increases beyond the critical angle, the internally reflected light could be obtained as an image to a plane. This image will be captured by a camera which is fixed to the system and it is an input to a computer.

The image analysis will be carried out after obtaining several readings of used oil samples as shown in table 3.1.

Table 3.1: Lubrication oil sampling method

Sr No	**Description**	**Image**		
		Sample 1	Sample 2	Sample 3
01	Fresh oil	New 1	New 2	New 3
02	After 100 operating hrs	100 – 1	100 – 2	100 – 3
03	After 200 operating hrs	200 – 1	200 – 2	200 – 3
04	After 300 operating hrs	300 – 1	300 – 2	300 – 3
05	After 400 operating hrs	400 – 1	400 – 2	400 – 3
06	After 500 operating hrs	500 – 1	500 – 2	500 – 3

Since this oil analysis is going to be carried out in MTU 12V 396 TE 94 engines, the oil changing interval is 500 operating hours (where centrifugal filters are fitted) and 250 operating hours (without centrifugal filters) as indicated by the OEM.

After obtaining the indicated readings as shown in table 3.1 for several numbers of engines, the readings can be summarized to understand the variation of the internally reflected image that is visualized during the testing of fresh and used lubrication oil. Then that will be a reference to understand the condition of the used oil.

3.6 Practical application of the equipment

During the testing of the designed cost-effective lubrication oil analyzer, the lubrication oil (Shell Gardenia 40) is used in MTU 12 V 396 TE 94 engines {fitted in Fast Attack Craft (FAC) which are used in Sri Lanka Navy} because these engines are high speed marine engines. A real picture of a MTU 12V 396 TE 94 engine is shown in Fig 3.5 and the specifications of the same engine is shown in table 3.2.

Fig 3.5: Real picture of a MTU 12V 396 TE 94 engine

Table 3.2: Specifications of a MTU 12V 396 TE 94 engine

Sr. No.	Model specification	Description
01.	12	Number of cylinders
02.	V	Vee configuration
03.	396	Engine series displacement of one cylinder
04.	T	Exhaust turbocharging
05.	E	Change air cooling in split coolant system
06.	9	Marine engine
07.	4	Design digit

The MTU 12 V 396 TE 94 engines which are fitted with centrifugal filters can operate up to 500 hours before changing the lubrication oil (these values are given by the OEM). Further, the engines which are not fitted with centrifugal filters require to change the lubrication oil within 250 operating hours. However, during the lubrication oil analyzing process, engines which are fitted with centrifugal filters are considered for better understanding.

3.6.1 Engine Oil Requirements (MTU 12 V 396 TE 94) as per the Original Equipment Manufacturer (OEM)

(The MTU engine oil is specified in the MTU factory standard No. MTL 5044)

Following categories are the approved engine oils;

a. Oil type 1 : Normal quality oils

Correspond in general API - CD 02

Mercedes - Benz fluids and lubricants specification

b. Oil type 2 : Higher quality oils

Quality rating to SHPP - Super high

Performance diesel oil standard or Mercedes - Benz fluids and lubricants specification

3.6.2 Viscosity Class Selection

Viscosity class selection is determined in accordance with the engine oil temperature at the time of starting. The engine lubrication oil needs to be preheated, if the environment temperature is low. The temperature ranges to operate for different lubrication oils are indicated in Fig 3.6.

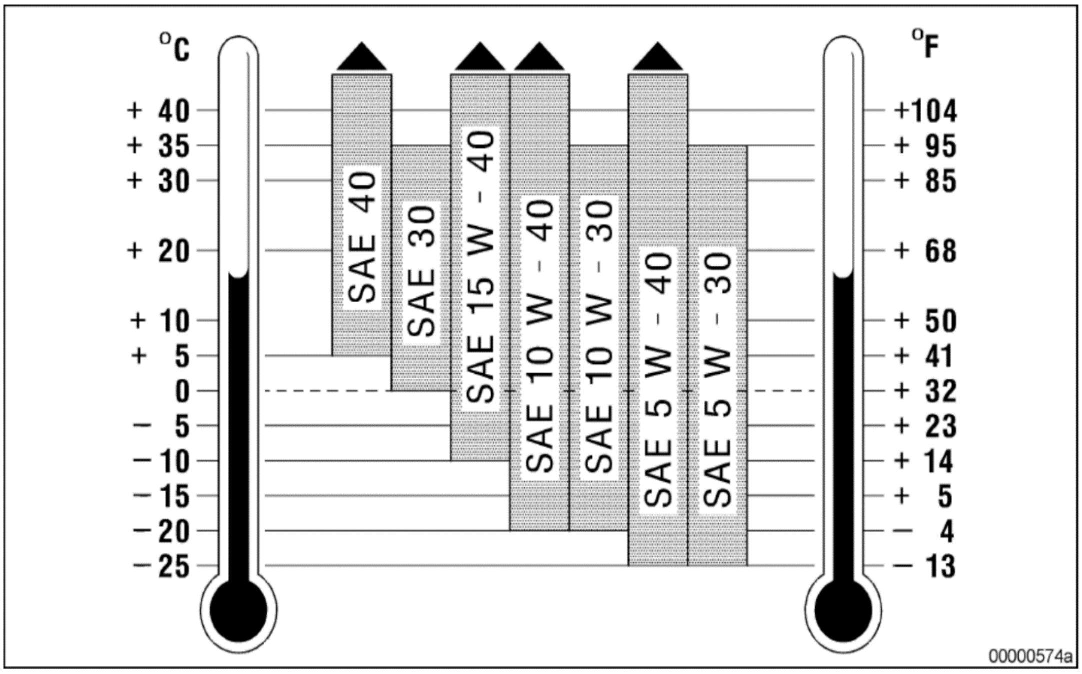

Fig 3.6: Temperature ranges to operate different lubrication oils

3.6.3 Service Life

Engine oil service life is influenced by its quality and treatment, engine operating conditions and the fuel used. The oil service life can be doubled with the use of oil type 2, or use of either and additional filter or centrifuge to improve the bypass flow.

The oil service life is to be halved if the following operating conditions are encountered during the operation.

a. Extreme climatic conditions.
b. If the frequency of engine start-up is high.
c. Prolong low load operation.
d. Use of fuels with a sulfur content of 0.5 to 1.0 % by weight.

The engine oils are always to be changed after one year in applications with short operation periods. Engine oils with higher corrosion-inhibiting properties have to be changed every 02 years. In the individual usage, the engine oil service life can be more precisely determined by regular laboratory analysis and engine inspections.

a. The first or “Reference” sample of the new oil is be taken after 15 to 30 minutes operation.

b. The appropriate engine inspections are to be carried-out before and after the oil analysis.

3.6.4 Analytical Limit Values

The Original Equipment Manufacturer (OEM) has given limiting values for specific properties of the lubrication oil which is recommended to use and the same details are shown in the table 3.3.

Table 3.3: Limiting values for the recommended lubrication oils by the OEM

Sr. No.	Description	Test Method	Limit Value
01.	Total contamination	DIN 51365 ASTM D893	Max. 2.5g/100g
02.	Viscosity loss due to fuel dilution and shearing with multi grade oils	DIN 51562 ASTM D445	Min. 9.0 mm^2/S at 100 ^oC
03.	Viscosity increase due to ageing or contamination	DIN 51562 ASTM D445	Max. 25% of fresh oil value
04.	Flash point	DIN 180 2592 ASTM D92	Min. 190 ^oC
05.	Water Content	DIN 180 3733 ASTM D95	Max. 0.2%
06.	Total Base Number (TBN)	DIN 180 3771 ASTM D2896	Min. 50% of fresh oil value depending on sulfur content of fuel used

However, other than the analytical limit values, engine condition, operational requirements and possible malfunctions are also divisive factors for a genuine oil service life.

Further, indications of oil fatigue are;

a. Abnormally heavy deposit or precipitates in the engine oil filters, centrifugal oil filters, separators etc. especially in comparison with previous analysis.

b. Abnormal dis-colouration of subassemblies

3.7 Collecting of samples

Initially, the samples of used lubrication oil are obtained through the MTU 12 V 396 TE 94 engines which are fitted with centrifugal filters and a list of craft with MTU 12V 396 TE 94 engines are indicated in table 3.4. Further, the lubrication oil samples are taken to cover all the ranges of operating hours as tabulated in table 3.1. The collected oil samples are kept in a separate location and analyzing of these samples will be carried out as discussed earlier.

Table 3.4: MTU 12V 396 TE 94 engines fitted FACs

Sr No	Craft	Engine Sr No	Availability of Centrifugal Filter
1	X 1 (P)	5582959	Available
2	X 1 (S)	5582960	Available
3	X 2 (P)	5582945	Available
4	X 2 (S)	5583193	Available
5	X 3 (P)	5582997	Not available
6	X 3 (S)	5582998	Not available
7	X 4 (P)	5583113	Not available
8	X 4 (S)	5583284	Not available
9	X 5 (P)	5583124	Not available
10	X 5 (S)	5583123	Not available
11	X 6 (P)	5583535	Not available
12	X 6 (S)	5583536	Not available
13	X 7 (P)	5583483	Not available
14	X 7 (S)	5583484	Not available
15	X 8 (P)	5583194	Not available
16	X 8 (S)	5583302	Not available
17	X 9 (P)	5583057	Not available
18	X 9 (S)	5583058	Not available
19	X 10 (P)	5583111	Not available
20	X 10 (S)	5583283	Not available
21	X 11 (P)	5583022	Available
22	X 11 (S)	5583023	Available
23	X 12 (P)	5583528	Available
24	X 12 (S)	5583529	Available
25	X 13 (P)	5582944	Available
26	X 13 (S)	5583114	Available
27	X 14 (P)	5583344	Available
28	X 14 (S)	5583303	Available
29	X 15 (P)	5583059	Available
30	X 15 (S)	5583060	Available

Further, the samples of lubrication oil are to be obtained from the engine itself when the engine is in running condition or immediately after stopping. There are several ways to obtain lubrication oil samples as follows.

a. Directly from the lubrication oil system.
b. From oil sump through inspection doors.
c. From oil draining plug.

CHAPTER FOUR

FABRICATION OF LUBRICATION OIL ANALYZER

4.1 Components used to design the oil analyzer

Following components are used during the fabrication of the designed lubricating oil analyzer and the accuracy of the output is highly dependent on these components. Even though, the fabricating materials of this oil analyzer are simple, it has the ability of providing a highly accurate result for the used lubrication oil in any kind of engine.

4.1.1 Prism

A prism is a transparent optical element with flat, polished surfaces that reflect light. The traditional geometrical shape is that of a triangular prism with rectangular base and rectangular sides [18]. During the design of the lubrication oil analyzer a traditional geometric shape prism is used to obtain the internally reflected image of the new/ used lubrication oil. Fig 4.1 Shows the prism used to design the equipment.

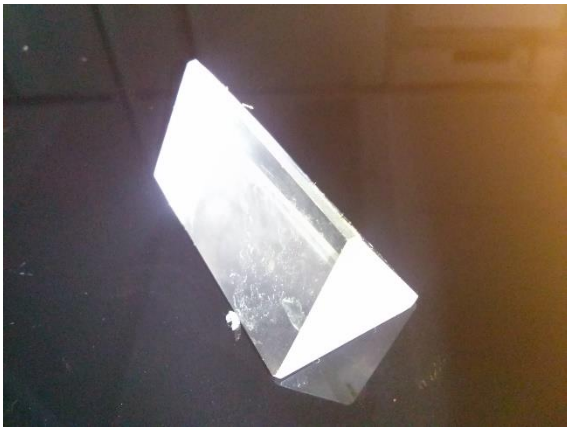

Fig 4.1: Prism used to design the lubrication oil analyzer

The principle of prism is that the light changes speed as it moves from one medium to another. This speed changes cause the light to be refracted and to enter the new medium at a different angle [20]. The degree of bending of the light path depends on the angle that the incident beam of light makes with the surface, and on the ratio between the refractive indices of the two media. This phenomenon fulfills the Snell's law.

Snell's law is a formula used to describe the relationship between the angles of incidence and refraction, when referring to light or other waves passing through a boundary between two different isotropic media and the same phenomenon is shown in Fig 4.2 [19]. In experimental optics, the Snell's law is used to find the refractive index of a material. The law is also satisfied in metamaterials which allow light to be bent 'backward' at a negative refraction index.

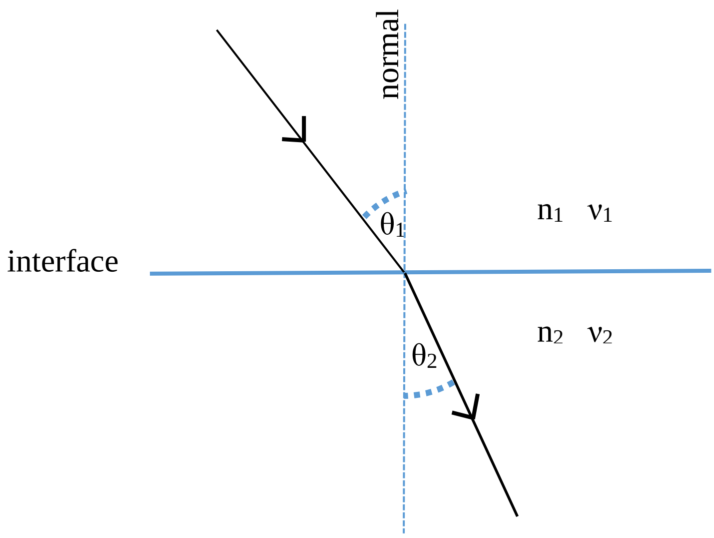

Fig 4.2: Phenomenon of Snell's law

Where;

$$\frac{\text{Sin } \theta_1}{\text{Sin } \theta_2} = \frac{\nu_2}{\nu_2} = \frac{n_1}{n_1}$$

ν - Velocity of light in the respective medium

n - Refractive index of the respective medium

The next phase is to select the required size of the prism to get the correct observations with clear images of the internally reflected light rays. Further, the effective and low-cost lubrication oil analyzer should use a small amount of used lubrication oil to analyze because the size of the sample may affect on the operation of the equipment/ machinery. The intensity of the light beam will also effect on selecting the size of the prism hence the selected dimensions of the prism is 1”x 1”x 2”.

4.1.2 Wiring system

The design of lubrication oil analyzer has a light emitting source which will require to obtain the image of internal reflection and it needs a small electrical circuit to power the light source. Even though, the power requirement could be fulfilled with the help of 9 volts battery, 230 V electric power supply has been utilized with a power pack. Further, the intensity of the light source could be varied with the support of a variable resister. A simple circuit has been introduced to fulfill the requirement and the circuit is shown in Fig 4.3.

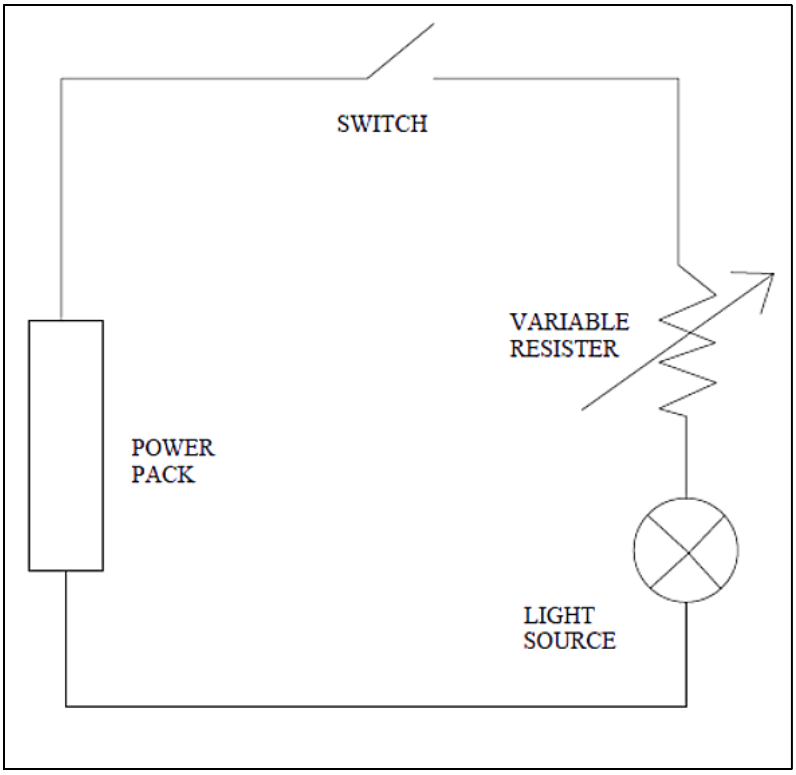

Fig 4.3: Schematic diagram of the electrical circuit

4.1.3 Converging lens

A converging lens (converging meniscus) is used to focus the light beam towards the prism to improve the intensity of the light beam and also to direct the light beam towards the prism. Fig 4.4 shows the converging lens used to design the equipment.

Fig 4.4: Converging lens

4.1.4 Camera

The requirement of a web camera is to capture the image of the internal reflection from the light beam after hitting the interface of the lubrication oil sample and the prism. This image is vital to analyze the condition of the lubrication oil samples since the features of the image (the area of the brighter region) will be analyzed to identify the suitability of the sample. Fig 4.5 shows the web camera used to design the equipment.

Fig 4.5: Web-camera used to design the lubrication oil analyzer

The basic function of the web-based camera is that the light is reflected off of an object and passes through a lens, which focus the light rays, onto the film or an image sensor. However, by connecting the camera and a personal computer (PC) with a commercially available USB cable, the camera can be used as a ‘web camera’. Making use of a communication software which confirms to USB video class enables the PC to receive the image from the camera.

4.1.5 Computer

A computer is required to feed the image that is going to be obtained through the web-based camera and a separate computer programme is written to analyze the internally reflected image according to the features of the image. The same computer programme could be used to analyze any kind of lubrication oil since the brighter region of the internally reflected image is calculated as per the input data of the decided threshold value of the image.

4.1.6 Computer programme

A computer programme has been written to calculate the brighter area of the internally reflected image with the help of ‘Mathlab’ software. The limit for the brightness of the image is pre-defined in the programme by selecting a constant threshold value and number of pixels in the brighter region is identified as the area of the region. The web-camera output image (internally reflected image) can be uploaded to the programme and obtain the area of brighter region.

4.2 Construction process

The requirement of a cost-effective lubrication oil analyzer is originated to overcome the costly lubrication oil analyzing techniques available. Further, the analysis of lubrication oil could carry out where the machine is fitted to minimize the delay of checking the condition of the used oil. Hence, the sample of the used lubrication oil should have the capability to remain within the position even in rough environmental conditions. Therefore, to cater the above requirement, the prism is positioned on the top most part of the equipment (horizontally). Further, there is a circular groove on the upper most plate to pour the lubrication oil samples and the prism is fixed to the cover with a rubber packing to stop leaking of lubrication oil towards the wiring/ components within the equipment. The arrangement of the prism is shown in the Fig 4.6.

Fig 4.6: Arrangement of the prism

A light beam is produced with the help of a LED bulb and the direction of the light beam can be adjusted with the help of the arrangement as shown in the Fig 4.7 and the position of the light could be regulated through the screw. In addition, a converging lens is fixed to the end of the screw to focus the light beam towards the prism and it will enhance the intensity of the light beam by improving the quality of the internally reflected image.

Fig 4.7: Arrangement of the light beam adjusting mechanism

The electrical circuit is powered by 230 V electric power supply through a power pack and it consists with a variable resister and a switch. When the circuit is completed (switch on) it will power the bulb and the light beam is emitted towards the prism through the converging lens. Further, the camera is fixed in a side wall of the lubrication oil analyzer, where it can be adjusted to get a clearer image to the computer. The arrangement of the camera is shown in Fig 4.8.

Fig 4.8: Arrangement of the web-camera

The design of the cost-effective lubrication oil analyzer is functioned with an optical method and it is mandatory to remove the effect of natural light and other light sources to get an effective outcome of the results. Hence, the equipment is fabricated in a box-shaped arrangement by covering all sides as shown in Fig 4.9.

Fig 4.9: Box-shaped arrangement of the designed lubrication oil analyzer

CHAPTER FIVE

DATA PRESENTATION AND ANALYSIS

5.1 Sample characteristics

The fabricated lubrication oil analyzer is tested using the lubrication oil samples obtained through the MTU 12V 396 TE 94 marine engines (fitted in FACs in Sri Lanka Navy). Shell Gardenia 40 mono grade lubrication oil is used for these engines and the samples are taken from the engines which are fitted with the centrifugal filters since the ODI (Oil Draining Interval) of these engines are 500 operating hours. The samples are collected from the relevant engines as per the indicated time frames tabulated in table 5.1.

Table 5.1: Actual sample data

Sr No	**Description** (Shell gardenia 40)	**Image will be taken from**		
		Sample 1	Sample 2	Sample 3
01	Fresh oil	New 1	New 2	New 3
02	After 100 operating hrs	100 – 1	100 – 2	100 – 3
03	After 200 operating hrs	200 – 1	200 – 2	200 – 3
04	After 300 operating hrs	300 – 1	300 – 2	300 – 3
05	After 400 operating hrs	400 – 1	400 – 2	400 – 3
06	After 500 operating hrs	500 – 1	500 – 2	500 – 3

After analyzing the obtained lubrication oil samples through the designed analyzer, the variations of internally reflected images (the area of the brighter region) are carefully analyzed to identify the condition of lubrication oil samples. Further, to calculate the variations in area of brighter region of the internally reflected image, a separate computer programme is written.

5.2 Constraints in designed lubrication oil analyzer

The actual configuration of the designed lubrication oil analyzer has a restriction to capturing the image right angle to the camera. Hence, it has to be captured with an angle which produces an elliptic image. The available space is very limited and also it is essential to capture the image closer to the prism since the quality of the image is important to analyze the oil samples. The actual positioning of the web camera with the angle is shown in Fig 5.1.

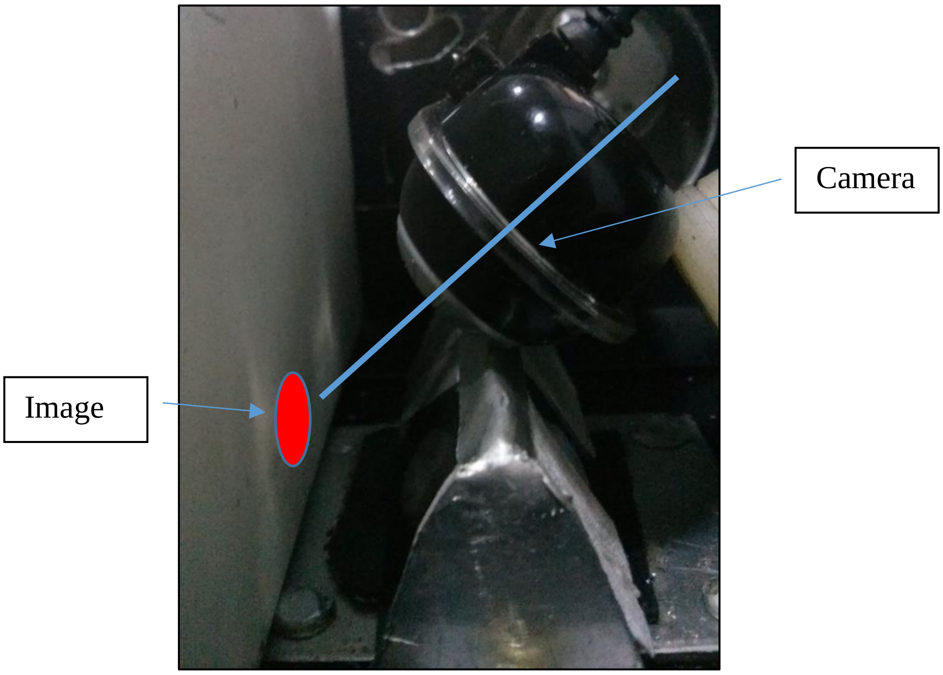

Fig 5.1: Actual positioning of the web-camera

Further, the position of the light source and the intensity of the light beam are also to be constant to check the lubrication oil samples since by varying these two components will produce inaccurate conclusions during the analysis.

5.3 Data presentation

The internally reflected image obtained without pouring the test samples through the designed lubrication oil analyzer is a single elliptic shaped image since the camera is not in-line with the image. The obtained image of the internally reflected light beam without pouring the lubrication oil is shown in the Fig 5.2.

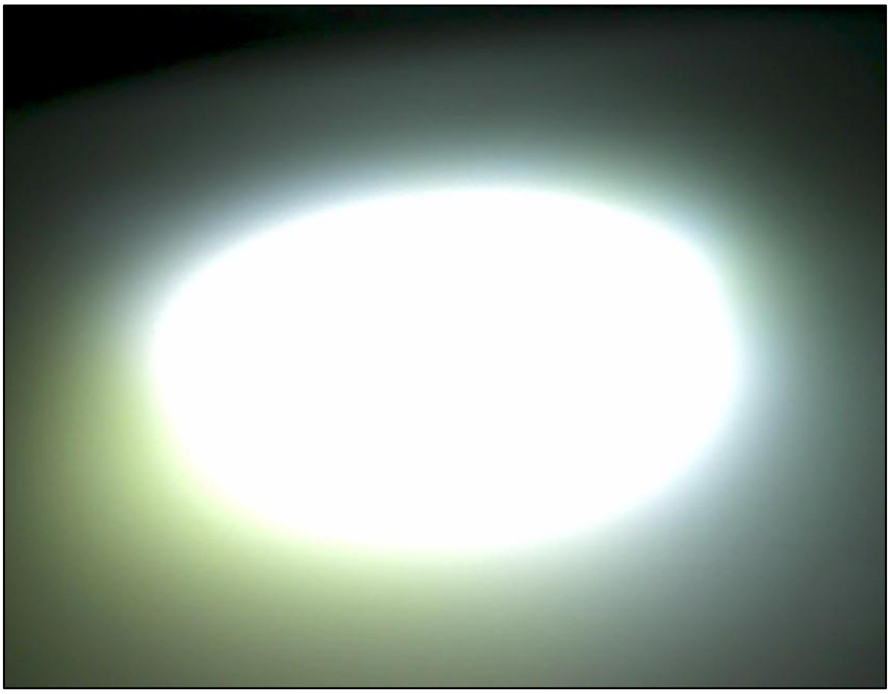

Fig 5.2: Internally reflected image without pouring oil samples to the designed analyzer

The design lubrication oil analyzer is highly depending upon the original oil condition (fresh oil sample of the particular lubrication oil) because of that the initial sample checking is carried out with a new lubrication oil sample. Hence, the new lubrication oil sample of Shell Gardenia 40 is analyzed through the designed analyzer and capture the image. The same process has been carried out for three new lubrication oil samples to check the uniformity of the test results. The images of original lubrication oil samples (03 Nos samples) are shown in Fig 5.3. Through visual inspection, we can identify the changes of the image with the original image before pouring the oil sample. Further, the images of the new lubrication oil samples are to be saved in a computer to compare it with the image that is going to obtain through the analysis of used oil.

Fig 5.3: The captured images of the new lubrication oil samples (Shell Gardenia 40)

The comparison of images which is obtained through the designed lubrication oil analyzer for the new Shell Gardenia 40 oil sample and the image without pouring any oil sample will give a comprehensive idea about the variations in the images. The undermentioned observations can be extracted from the two images. Fig 5.4 shows the comparison of the images of new oil and without any oil sample.

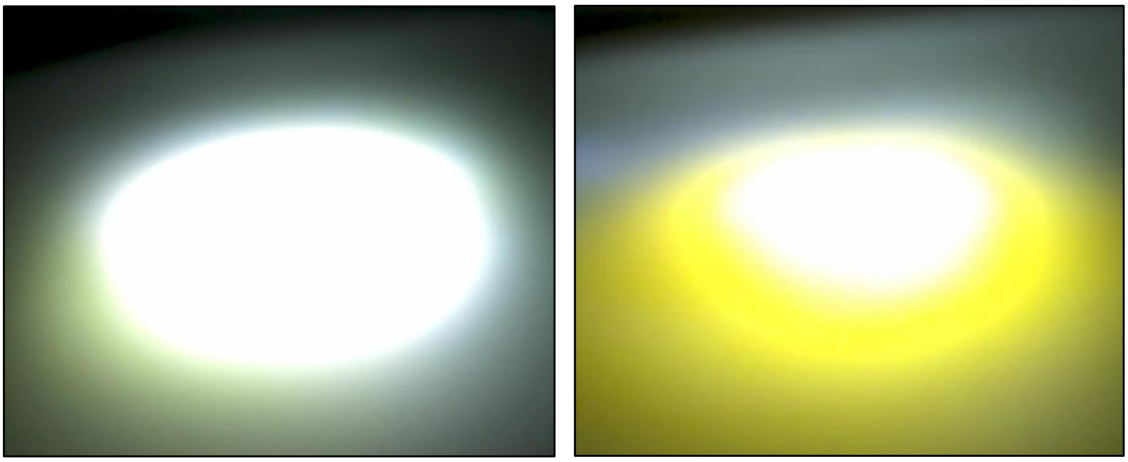

Fig 5.4: Comparison of the received images of new oil and without pouring the oil sample to the designed analyzer

a. Changes in the shape of the internally reflected image
b. Changes in the area of brighter region of the image

The second stage is to be obtain the internally reflected image for the first used oil sample, after 100 operating hours. A significant difference can be observed between the images for new lubrication oil sample and the 100 hours operated lubrication oil sample. The images of the three samples (100 operating hours) are shown in Fig 5.5.

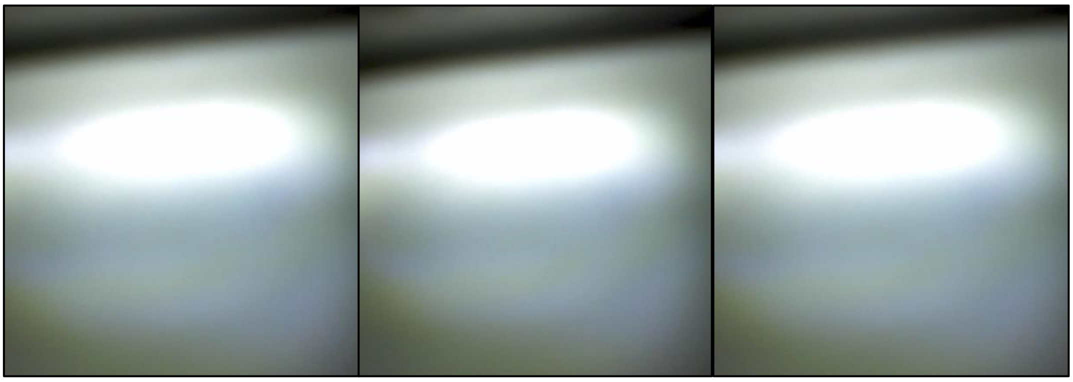

Fig 5.5: The captured images for the 100 hours operated used lubrication oil samples (Shell Gardenia 40)

The comparison of the images obtained through the designed lubrication oil analyzer for the new Shell Gardenia 40 oil sample and 100 operating hours used oil is shown in Fig 5.6. A considerable deviation in the area of bright region between the two images can be identified. The differences of the images are due to the different refractive index of used oil and the fresh lubrication oil (Shell Gardenia 40). However, the reason could be the adding of impurities to used oil during the operation of 100 hours.

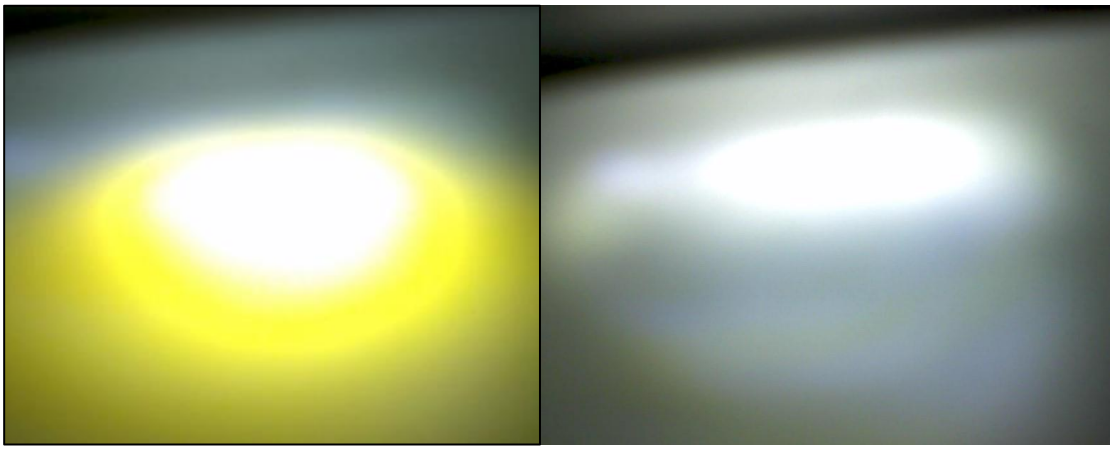

Fig 5.6: Comparison of the received images of new oil and 100 hours operated used oil sample

The third stage is to check the used oil after 200 operating hours. However, a vast difference between the images of 100 hours operated used oil and the 200 hours operated used oil may not be observed during the comparison. The images of the three samples (200 operating hours) are shown in Fig 5.7.

Fig 5.7: The captured images for the 200 hours operated used lubrication oil samples (Shell Gardenia 40)

The next step is to check the condition of the third used oil samples after 300 operating hours. In this stage also there may be no any significant difference between the images of the 200 hours operated used oil and the 300 hours operated used oil. The images of three samples (300 operating hours) are shown in Fig 5.8.

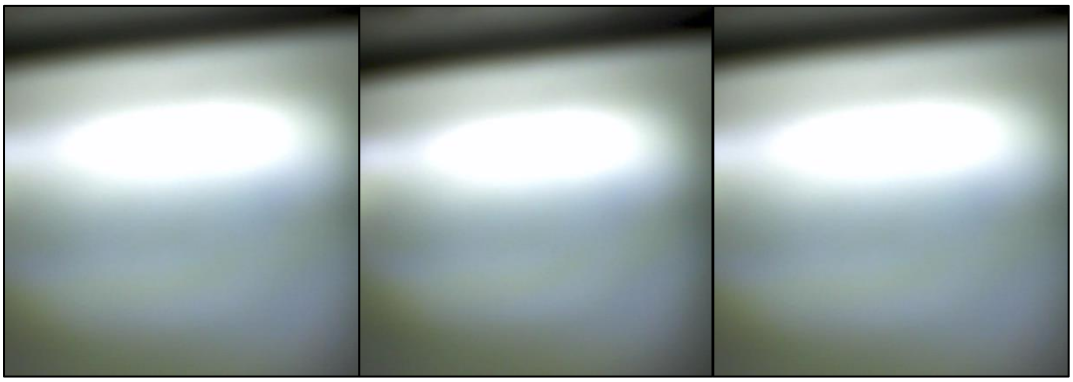

Fig 5.8: The captured images for the 300 hours operated used lubrication oil samples (Shell Gardenia 40)

The fourth stage is to check the used oil samples after 400 operating hours through the designed lubrication oil analyzer. The images which are obtained for 400 hours operated used oil and 300 hours operated used oil have been compared and observed slight differences between the images. The images of three samples (400 operating hours) are shown in Fig 5.9.

Fig 5.9: The captured images for the 400 hours operated used lubrication oil samples (Shell Gardenia 40)

The fifth used oil samples which are taken after 500 operating hours are checked through the designed lubrication oil analyzer. However, a significant difference between the images is not observed for the 400 hours operated used oil and the 500 hours operated used oil. The images of three samples (500 operating hours) are shown in Fig 5.10.

Fig 5.10: The captured images for the 500 hours operated used lubrication oil samples (Shell gardenia 40)

5.4 Comparison of the results

As per the results obtained through the designed lubrication oil analyzer for the samples after completion of the checking of 100 hrs, 200 hrs, 300 hrs, 400 hrs, and 500 hrs operating hours, the brighter area of internally reflected images does not deviate considerably. The results obtained for the 100 hrs used oil to 500 hrs used oil are similar to each other. It indicates the condition of used oil up to 500 hrs operating hours is suitable to operate for a longer period. Even though, OEM recommended Oil Draining Interval (ODI) is after 500 operating hours (for centrifugal filters fitted engines), the condition of the lubrication oil after 500 operating hours is also can be extended another time period beyond 500 operating hours.

However, to cross examine whether the obtained readings through the designed lubrication oil analyzer is accurate, the same lubrication oil samples are analyzed with the help of under mentioned lubrication oil analyzing methods.

a. Viscosities of the samples through Viscosity Comparator (detail description of the equipment is attached as Appendix – A).

b. ASTM Standards
   (1) ASTM D 5185 – 05 (Standard test method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating oil and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Automatic Emission Spectrometry (ICP-AES)) {Attached as Appendix – B}.
   (2) ASTM D 445 – 06 (Standards test method for Kinematic Viscosity of Transparent and Opaque Liquids (abd Calculation of Dynamic Viscosity) {Attached as Appendix – C}.
   (3) ASTM D 4739 – 06a (Standard test method for Base Number Determination by Potentiometric Titration) {Attached as Appendix – D}.
   (4) ASTM D 7899 – 13 (Standard test method for Measuring the Merit of Dispersancy of In-Service Engine Oils with Blotter Spot Method) {Attached as Appendix – E}.
   (5) ASTM D 893 – 05a (Standard test method for Insolubles in Used Lubricating Oils) {Attached as Appendix – F}.
   (6) ASTM D 92 – 05a (Standard test method for Flash and Fire Points by Cleveland Open Cup Tester) {Attached as Appendix – G}.
   (7) ASTM D 95 – 05 (Standard test method for Water in Petroleum Products and Bituminous Materials by Distillation) {Attached as Appendix – H}.

5.4.1 Viscosity test of the samples through Viscosity Comparator.

Viscosity Comparator is an equipment that the OEM of MTU engines has recommend to check the viscosity of lubrication oils. The configuration of the equipment is shown in the Fig 5.11. The lubrication oil samples which are obtained to analyze through the designed lubrication oil analyzer should be re-analyzed to test the viscosity with the help of a Viscosity Comparator. The requirement for the comparison of the results through the designed lubrication oil analyzer and the viscosity comparator is to verify the accuracy.

Fig 5.11: Viscosity Comparator

All the used lubrication oil samples are tested with the help of viscosity comparator and the results of 100 hrs, 200 hrs, 300 hrs, 400 hrs, and 500 hrs are shown in Fig 5.12, Fig 5.13, Fig 5.14, Fig 5.15 and Fig 5.16 respectively.

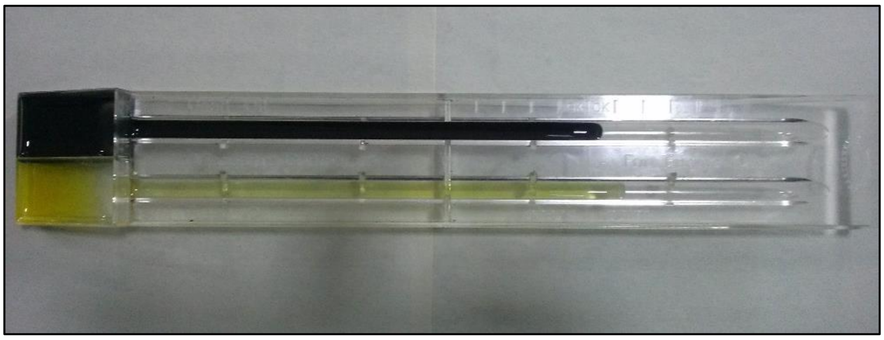

Fig 5.12: Viscosity reading for 100 hrs used lubrication oil

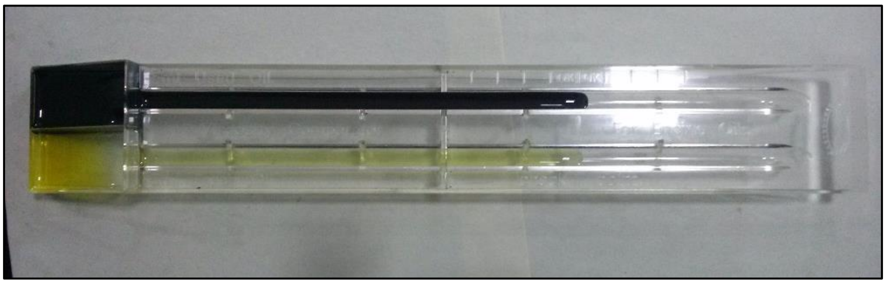

Fig 5.13: Viscosity reading for 200 hrs used lubrication oil

Fig 5.14: Viscosity reading for 300 hrs used lubrication oil

Fig 5.15: Viscosity reading for 400 hrs used lubrication oil

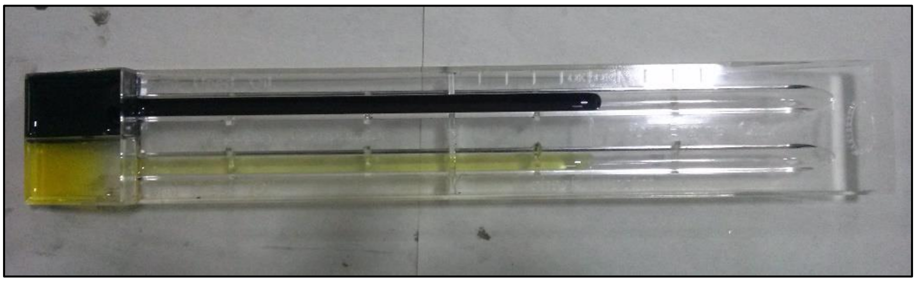

Fig 5.16: Viscosity reading for 500 hrs used lubrication oil

As per the viscosity readings of each used lubrication oil sample, the viscosity is within acceptable limit. It indicates that the property of viscosity is within the acceptable limit for the used lubrication oil samples up to 500 operating hours.

5.4.2 ASTM standards check for the lubrication oil samples

Even though the lubrication oil samples are taken within the intervals of 100 operating hours for the designed lubrication oil analyzer, for the ASTM standards checking used oil samples are obtained considering the intervals of 50, 250, and 500 operating hours since the results of these intervals will predict the other ranges covering the operating hours from 100 hrs to 500 hrs.

5.4.2.1 After 50 operating hours

On completion of the first 50 operating hours, the sample is sent to the Machinery Testing and Trial Unit (MTTU) at Welisara (Sri Lanka Navy establishment) and the comprehensive report is attached as appendix – I. The basic details are indicated in table 5.2 for the element concentration and the graphical presentation is shown in Fig 5.17. Further, the analysis report for other ASTM standards requirements is indicated in table 5.3.

Table 5.2: Element Concentration after 50 operating hours

Element	Maximum Permissible Limit	Fresh Oil Sample	Port Main Engine (S/I-M000514)	Stbd Main Engine (S/I-M000515)
Fe	80	< 1.000	10.848	11.705
Cr	10	< 1.000	2.868	1.336
Si	15	< 1.000	1.739	1.947
Al	20	< 1.000	< 1.000	< 1.000
Pb	20	< 1.000	< 1.000	< 1.000
Cu	25	< 1.000	2.589	3.488
Sn	10	< 1.000	< 1.000	< 1.000
Ni	10	< 1.000	< 1.000	< 1.000

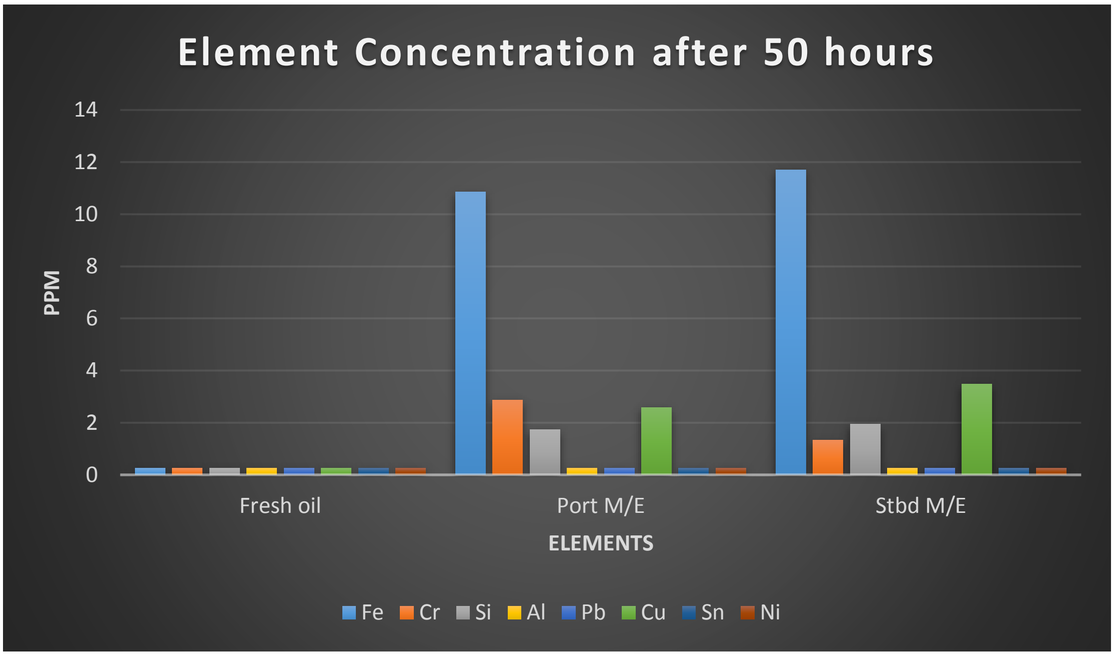

Fig 5.17: Graphical presentation of Element Concentration after 50 operating hours

Table 5.3: Analysis for other ASTM Standards

Description	Method	Fresh Oil	Port M/E	Stbd M/E
Viscosity @ 40^0 (cSt)	ASTM D 445	139.00	133.25	132.73
Viscosity @ 100^0 (cSt)		14.40	14.00	14.14
Viscosity Index	ASTM D 2270	103	101.94	103.68
Total Base No. mg KOH/g	ASTM D 4739	10.48*	6.78	6.43
Water Content	ASTM D 95	<0.2	<0.1	<0.1

*The results are taken from a fresh oil sample which is tested at MTTU laboratory as per ASTM D 4739 method.

5.4.2.2 After 250 operating hours

On completion of 250 operating hours, the basic details are indicated in table 5.4 for the element concentration and the graphical presentation is shown in Fig 5.18. Further, the analysis report for other ASTM standards requirements is indicated in table 5.5.

Table 5.4: Element Concentration after 250 operating hours

Element	Maximum Permissible Limit	Fresh Oil Sample	Port Main Engine (S/I-M000432)	Stbd Main Engine (S/I-M000433)
Fe	80	< 1.000	10.422	9.776
Cr	10	< 1.000	< 1.000	< 1.000
Si	15	< 1.000	1.738	1.532
Al	20	< 1.000	< 1.000	< 1.000
Pb	20	< 1.000	< 1.000	< 1.000
Cu	25	< 1.000	5.482	5.083
Sn	10	< 1.000	< 1.000	< 1.000
Ni	10	< 1.000	< 1.000	< 1.000

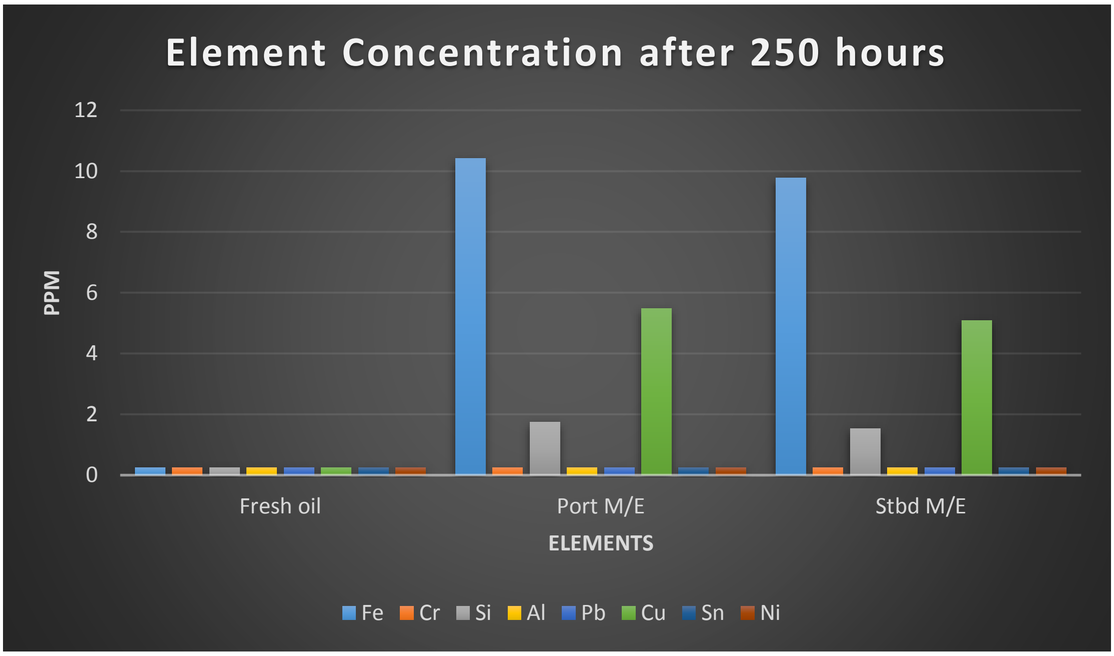

Fig 5.18: Graphical presentation of Element Concentration after 250 operating hours

Table 5.5: Analysis for other ASTM Standards after 250 operating hours

Description	Method	Fresh Oil	Port M/E	Stbd M/E
Viscosity @ 40^0 (cSt)	ASTM D 445	139.00	133.25	132.73
Viscosity @ 100^0 (cSt)		14.40	14.00	14.14
Viscosity Index	ASTM D 2270	103	101.94	103.68
Total Base No. mg KOH/g	ASTM D 4739	10.48*	6.78	6.43
Water Content	ASTM D 95	<0.2	<0.1	<0.1

*The results are taken from a fresh oil sample which is tested at MTTU laboratory as per ASTM D 4739 method.

5.4.2.3 After 500 operating hours

On completion of 500 operating hours, the basic details are indicated in table 5.6 for the element concentration and the graphical presentation is shown in Fig 5.19. Further, the analysis report for other ASTM standards requirements is indicated in table 5.7.

Table 5.6: Element Concentration after 500 operating hours

Element	Method	Maximum Permissible Limit	Fresh Oil Sample	Port Main Engine (S/I-M000268)	Stbd Main Engine (S/I-M000269)
Fe	ASTM D 5185	80	< 1.000	19.344	30.921
Cr	ASTM D 5185	10	< 1.000	< 1.000	1.107
Si	ASTM D 5185	15	< 1.000	1.498	2.955
Al	ASTM D 5185	20	< 1.000	< 1.000	< 1.000
Pb	ASTM D 5185	20	< 1.000	3.320	4.026
Cu	ASTM D 5185	25	< 1.000	**13.690**	**17.313**
Sn	ASTM D 5185	10	< 1.000	< 1.000	1.196
Ni	ASTM D 5185	10	< 1.000	< 1.000	< 1.000

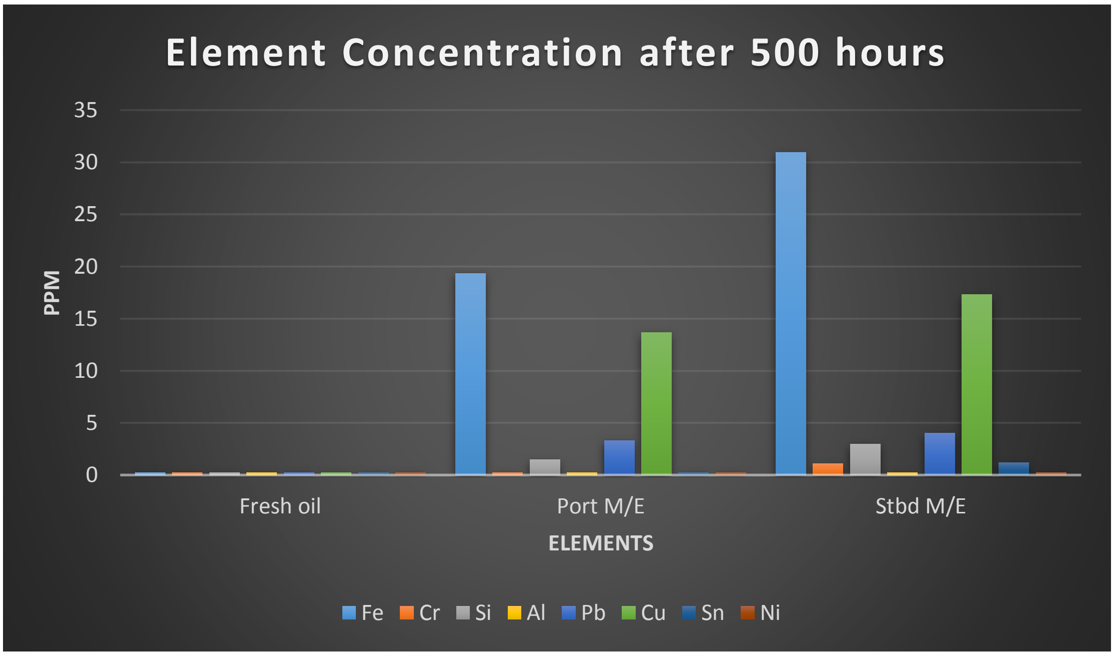

Fig 5.19: Graphical representation of Element Concentration after 500 operating hours

Table 5.7: Analysis for other ASTM Standards after 500 operating hours

Description	Method	Fresh Oil	Port M/E	Stbd M/E
Viscosity @ 40^0 (cSt)	ASTM D 445	139.00	126.96	120.96
Viscosity @ 100^0 (cSt)		14.40	13.36	13.24
Viscosity Index	ASTM D 2270	103	101.94	103.68
Total Base No. mg KOH/g	ASTM D 4739	10.48*	6.78	6.43
Water Content	ASTM D 95	<0.2	<0.1	<0.1

After the comparison of the results obtained through the viscosity comparator and the ASTM standards, it is observed that the condition of lubrication oil samples is good. Even though we change the lubrication oil after 500 operating hours as per the OEM recommended ODI it can further used beyond 500 operating hours. Moreover, it is observed that the results obtained through the lubrication oil analyzer is also accurate since it shows that the lubrication oil samples are in usable condition.

The results through the designed lubrication oil analyzer could be finalized with a help of a computer programme by considering the features of the obtained internally reflected images for a particular lubrication oil. The basic requirements are indicated below;

a. Fresh oil sample of the particular oil
b. As per the ODI of the equipment, decide the sample extracting intervals and keep the records.

A computer programme is written to identify the area of brighter region of the internally reflected image of each lubrication oil sample which is going to analyze through the designed lubrication oil analyzer. The computer program will identify the number of pixels within the area of brighter region. However, the user of the equipment could select the required threshold value of brighter region of the obtained image during the calculation of the area. As an example, the interface of the computer program for fresh oil sample of Shell Gardenia 40 is shown in the fig 5.20.

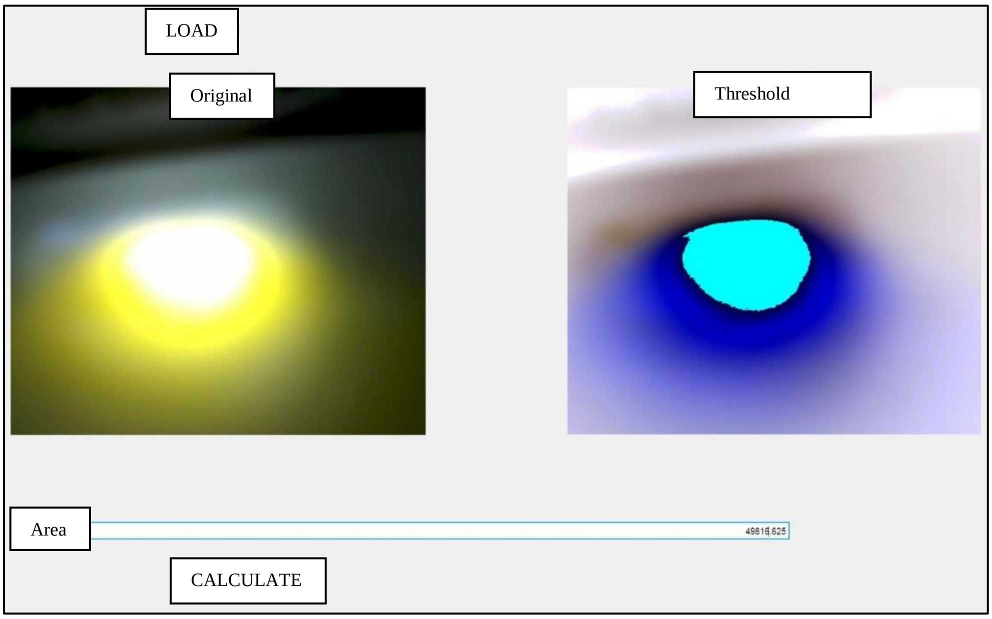

Fig 5.20: Computer program interface to calculate the area of brighter region for fresh oil sample of Shell Gardenia 40 oil

Further, the variation of the area (brighter area) can be identified for the fresh oil sample and all other used oil samples to visualize the changes of the image area. As per the images obtained for the Shell gardenia 40 lubrication oil samples, the calculated details of areas are indicated in table 5.8. Further, Fig 5.21 shows the graphical presentation of the obtained area variation.

Table 5.8: Area of the brighter part of the images obtained for Shell gardenia 40 oil samples

Operated hours	New oil (0 hrs)	100 hrs	200 hrs	300 hrs	400 hrs	500 hrs
Area of brighter region (No of pixel) of the image	116337	73369	71310	72258	71062	75374

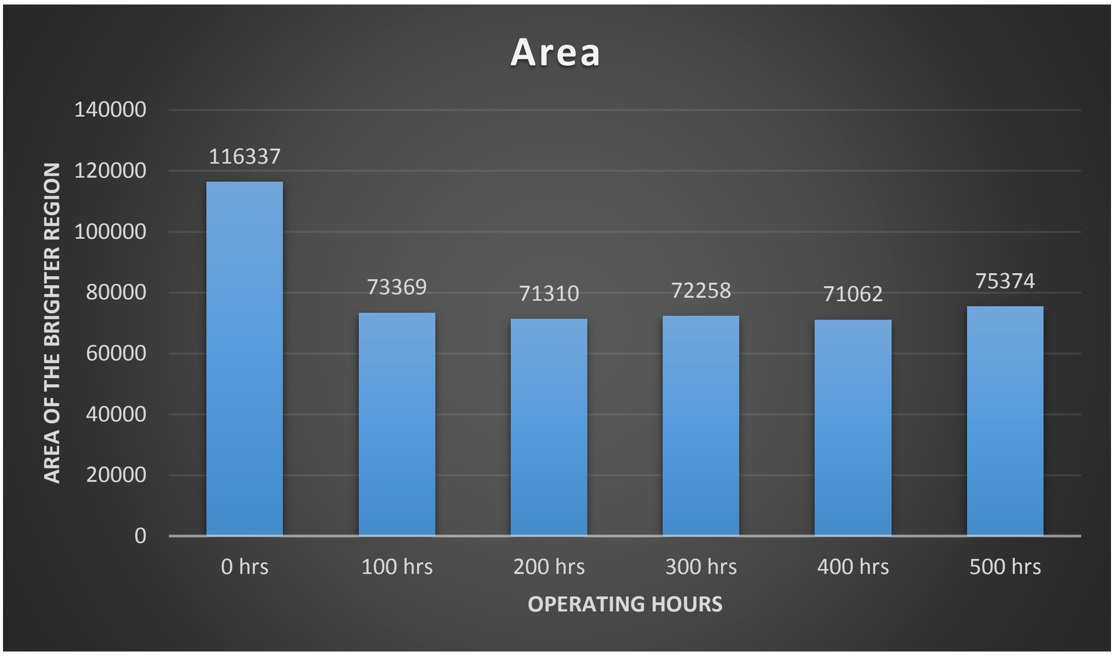

Fig 5.21: Graphical presentation of the variation of area

The used lubrication oil samples which are obtained from the MTU 12V 396 TE 94 marine engines are within the acceptable limits even after 500 operating hours in accordance with the visualized processes mentioned below. The results of the designed lubrication oil analyzer also could be justified with the following reports.

a. Viscosity reading of the viscosity comparator (for all sample intervals of 100, 200, 300, 400, and 500 operating hours).
b. ASTM standards checking for lubrication oil samples (for sample intervals of 50, 250, and 500 operating hours).

However, the readings obtained through the designed lubrication oil analyzer could be further justified by understanding the correlation between the usable lubrication oil and the diluted oil (mixed with diesel). The lubrication oil could be diluted with diesel due to malfunctioning of injectors of the combustion system of an engine.

This test is carried out with the help of usable lubrication oil sample which has been obtained from MTU 12V 396 TE 94 engine. Practically, diesel should not be mixed with lubrication oil since it will reduce the viscosity of the lubrication oil.

A usable lubrication oil sample of Shell Gardenia 40 is diluted forcibly with 25%, 50%, and 100% diesel quantities separately. After these lubrication oil samples are analyzed through the designed lubrication oil analyzer. As per the obtained internally reflected images for the oil samples, the areas of the brighter regions are calculated. The final details of areas are indicated in table 5.9. Further, Fig 5.22 shows the graphical presentation of correlation between usable and diluted lubrication oil with the area of brighter region.

Table 5.9: Areas of the brighter part of the images obtained for Shell gardenia 40 diluted lubrication oil samples

Dilution of lubrication oil (%) [Diesel mixed]	Used oil (>1)	25	50	100
Area of brighter region (No of pixels) of the image	23778	28525	34170	39686

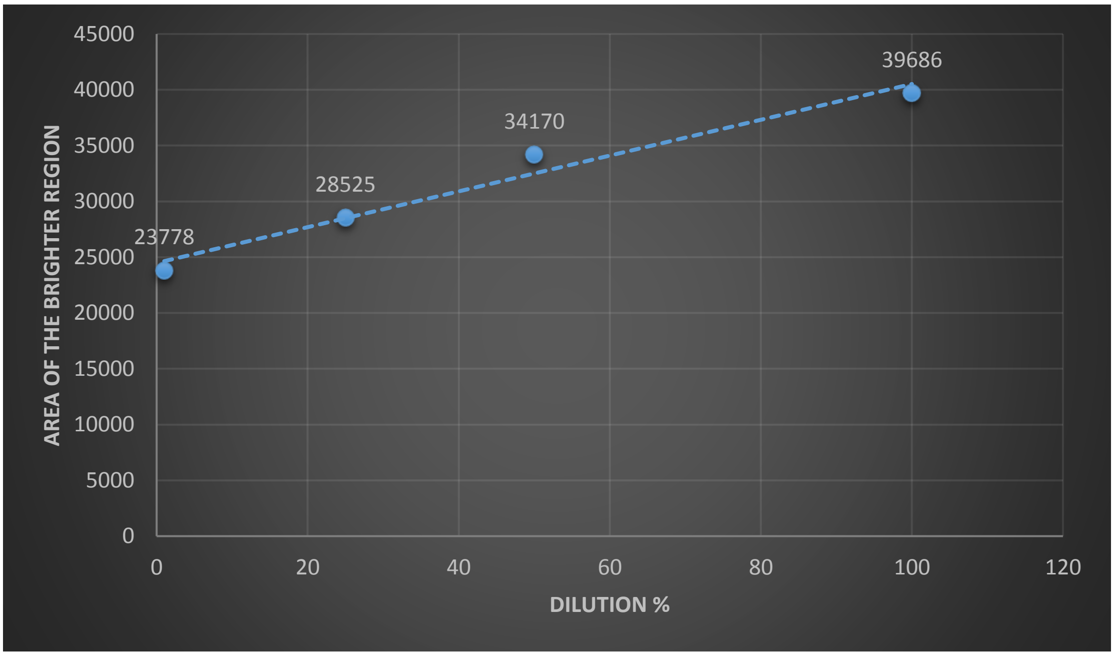

Fig 5.22: Graphical presentation of correlation between usable and diluted lubrication oil from the area of brighter region

During the analysis stage, the results have been obtained from the diluted lubrication oil samples. It is obvious that the brighter area of the internally reflected image is increasing (compared to good quality used lubrication oil) with the percentage increment of mixed diesel.

In accordance with the obtained results for diluted oil, it is obvious that there is a significant change in the area of brighter region where the designed lubrication oil analyzer could identify precisely. It means that the designed lubrication oil analyzer readings are accurate and justifiable.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

4.1 Introduction

This chapter presents the conclusion and the recommendations that can be highlighted with the knowledge obtained through the literature review, the design and the fabrication stage of the cost-effective lubrication oil analyzer.

CONCLUSION

During the literature review, it is understood that a proper lubrication system is highly essential to any machinery where two surfaces are going to be mutually rubbed each other to reduce the friction between the surfaces. Further, in addition to the reduction of friction between the rubbing surfaces, lubrication oil performs as a cooling medium, giving the sealing effect, cleaning the system, and lubricating the system. Hence, introducing a lubricating oil which is compatible to the operating environment of the machine is important. The analyzing of used oil in-between time periods will provide a precise idea about the condition of the machinery.

The properties of lubrication oil are vital to understand since it will be a reference point to decide the quality of any used lubrication oil when comparing with new lubricant. Even though, the OEM of the engine has indicated the changing intervals according to their principles based on considering the warranty/ guaranty that they provide for a particular engine. Further, the lubrication oil changing interval is decided after carrying out the lubrication oil analysis which are totally depend on the checking of properties of respective lubricating oil.

Understanding of the mechanism of lubrication is essential when it comes to select any kind of lubrication oil to a machine because it is the basis to identify the required properties of that selected oil. If the selected lubrication oil properties are correct, then the required functions of the lubricating oil could be attained to maximize the effectiveness or the efficiency of the machine. Further, the classification of lubrication oils could also be a factor to select the most suitable lubrication method to a specific machine. It will depend upon the operating condition, operating temperature (high or low), and the environmental condition where the machine is installed.

Basically, there are several methods to analyze the lubrication oil samples and mainly these techniques are based on the principles of identifying the properties of a lubricating oil. However, the available lubricating oil analysis methods are off line. The samples of lubricating oils need to be transferred to the laboratories and check them separately. Further, the cost involvement for this analysis methods are expensive and also it will take a considerable time duration to obtain the laboratory reports. Because of that, it will penalize the production process or the industrial requirements that the defective machine is performing.

The theoretical knowledge is essential to identify and understand the requirements to fulfil the analyzing techniques of lubrication oil. However, most of the techniques are required specific environmental conditions, special sampling methods, and sophisticated laboratory equipment to analyze lubricating oil samples. Further, it requires special skills to understand the results.

The requirement of a cost-effective lubrication oil analyzer is to understand the condition of the lubrication oil, at the location where the operator of the machinery. It is an integral requirement to fulfil since it will help the owner of the machine to come to a conclusion whether the machine is operating in a satisfactory condition. The available lubrication oil analyzing methods are carefully studied and observed to select the most cost-effective method of analyzing lubrication oil which is based on optical method. Hence, the Refractive Index of a lubrication oil (new or used) could be used to check the condition of a particular lubrication oil as an optical method.

A prototype equipment is designed to analyze the used lubrication oil by understanding the theoretical aspects of the optical devices (Snell’s law, Refractive Index, etc) and the same is tested by using used lubrication oil (Shell Gardenia 40) of MTU 12V 396 TE 94 marine diesel engines fitted onboard FACs in Sri Lanka Navy.

The results have been obtained through the designed lubrication oil analyzer are cross examined with the results obtained by using viscosity comparator and also with the ASTM standards lubrication oil analyzing methods. During the comparison, it is understood that the readings which are obtained through the designed cost-effective lubrication oil analyzer is accurate.

Further, the correlation between the dilution in a particular lubrication oil (mixing with diesel) samples and usable used oil samples are obtained through the designed lubrication oil analyzer. As per the results obtained through the analyzer it is understood that the output of the designed lubrication oil analyzer is justifiable.

A separate computer programme is written to calculate the brighter area of the internally reflected image (obtain as the output of the designed analyzer) and to understand the condition of a particular lubrication oil directly.

RECOMMENDATIONS

The requirement of a cost effective lubrication oil analyzing technique is to identify the condition of lubrication oil which will not require any special considerations on the environmental conditions (temperature and other atmospheric conditions) and also to fulfil the feasibility to conduct the lubrication oil analysis at the location where the machinery is installed will enhance the effectiveness and the efficiency of the production process which is the particular machinery is required. The fabricated equipment could be used to fulfil the above requirement since the output results are accurate when compared to prevailing lubrication oil testing methods.

Further, the ODI of a particular machine can be extended beyond the OEM provided oil changing interval after analyzing the results obtained through the designed cost-effective lubrication oil analyzer.

However, it is recommended to further improve the system by automating the analysis entirely to assess the condition of lubrication oil where it will not require human involvement and monitor the degradation trend of lubrication oil cost-effectively.

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