REGAINING OF TRIBOLOGICAL BEHAVIOR OF USED LUBRICANT

MASTERS OF ENGINEERING IN MECHANICAL ENGINEERING

Submitted By

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REGAINING OF TRIBOLOGICAL BEHAVIOR OF USED LUBRICANT

The Project Report submitted in partial fulfilment

of the requirements for award the degree of

Masters of Engineering in Mechanical Engineering

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APPROVAL

The Project Report titled "**Regaining of Tribological Behavior of Used Lubricant**" submitted by Biswajit Das, Student ID: 11MME010P, Session: 2011-2012, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Engineering on June 2023.

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DEDICATION

Dedicated to

My Father & Mother

And all beloved whose continuous encourage

& help me to complete this Project successfully.

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ABSTRACT

This research Project deals with the experimental analysis of regaining of tribological behavior of used Lubricant, for proper use of lubricants is very important. It has impact to the lifetime of machineries & friction of moving parts. And also improve of machine performance and increase smooth rotation of moving parts.

In Bangladesh up to now there has not been proper management of used lubricating oil. Refining used lubricating oil would reduce the dependency on lubricating oil import as well as safeguards the environment. The aim of this project was to study the possibility of refining used lubricating oil generated in Bangladesh. The used lubricating oil Samples that have collected to find out data collection and its analysis.

In our Study, we collected used lubricants from Fuchs Bangladesh Limited, Chattogram and BNO, Chattogram and a renowned workshop, Chattogram and also testing from a Standard Laboratory, Chattogram which provide available data for various Lubricants.

This research effort focuses on comparative study experimentally of refined engine oils SAE 40, refined hydraulic oil ISO VG 46 & also refined gear oil ISO VG 150 by extraction of composite solvent, single solvent, and distillation methods. Composite solvent was made up of Methyl Ethyl Ketone (MEK) which is soluble in water and also commonly used as an industrial solvent. Different properties of refined oil and waste oil were analyzed, such as appearance, color, pour point, flash point, density, Kinematic viscosity, viscosity index, etc. Results found that the above properties were improved at different degrees. From analysis, viscosity was found nearly same at difference temperature for three Samples of Refined & Fresh engine oil, hydraulic oil and gear oil. Also further analysis the others properties such as Appearance, Color, Density, Kinematic viscosity, Viscosity index, Flash point & Pour point are near about same as fresh oil.

The financial analysis of the selected process was done using different techniques. From the calculation we get payback period = 5.448 year, discounted payback period = 6.56 year, Net present worth = NBDT 3425.05 lakh, IRR = 26%. From the above values it was clear that the project is financially feasible.

সারসংক্ষেপ

এই গবেষণা প্রকল্পটি ব্যবহৃত লুব্রিকেন্টের ট্রাইবোলজিক্যাল আচরণ পুররুদ্ধারের পরীক্ষামূলক বিশ্লেষণ নিয়ে কাজ করে, লুব্রিকেন্টের সঠিক ব্যবহারের জন্য এটি খুবই গুরুত্বপূর্ণ। এটি মেশিনারির জীবনকাল এবং চলমান অংশগুলির ঘর্ষণকে প্রভাবিত করে। এছাড়াও মেশিনের কর্মক্ষমতা উন্নত করে এবং চলমান অংশগুলির মসৃণ ঘূর্ণন বৃদ্ধি করে।

বাংলাদেশে এখন পর্যন্ত ব্যবহৃত লুব্রিকেটিং তেলের সঠিক ব্যবস্থাপনা হয়নি। ব্যবহৃত লুব্রিকেটিং তেল পরিশোধন করলে তা লুব্রিকেটিং তেল আমদানির ওপর নির্ভরলীলতা কমবে এবং সেই সঙ্গে পরিবেশ রক্ষা করবে। এই প্রকল্পের উদ্দেশ্য ছিল- বাংলাদেশে ব্যবহৃত লুব্রিকেটিং তেল পরিশোধন করার সম্ভাবনা অধ্যয়ন করা। ব্যবহৃত লুব্রিকেটিং তেলের নমুনা যা তথ্য সংগ্রহ এবং তার বিশ্লেষণ খুঁজে বের করার জন্য সংগ্রহ করা হয়েছে।

এই গবেষণায়, ফুকস্ বাংলাদেশ লিমিটেড, চট্টগ্রাম এবং বিএনও, চট্টগ্রাম এবং একটি ইঞ্জিন ওয়ার্কশপ, চট্টগ্রাম থেকে ব্যবহৃত লব্রিকেন্ট সংগ্রহ করেছি এবং একটি স্ট্যান্ডার্ড ল্যাবরেটরি, চট্টগ্রাম থেকে পরীক্ষা করেছি যা বিভিন্ন লুব্রিকেন্টের জন্য উপলব্ধ ডেটা সরবরাহ করে।

এই গবেষণা প্রচেষ্টাটি কম্পোজিট দ্রাবক, একক দ্রাবক, এবং পাতন পদ্ধতির নিষ্কাশনের মাধ্যমে পরিশোধিত ইঞ্জিন তেল SAE 40, পরিশোধিত হাইড্রোলিক তেল ISO VG 46 এবং এছাড়াও পরিশোধিত গিয়ার তেল ISO VG 150 -পরীক্ষামূলকভাবে তুলনামূলক অধ্যয়নের উপর দৃষ্টি নিবদ্ধ করে। যৌগিক দ্রাবক মিথাইল ইথাইল কিটোন দ্বারা গঠিত যা জলে দ্রবনীয় এবং সাধারণত একটি শিল্প দ্রাবক হিসাবে ব্যবহৃত হয়। পরিশোধিত তেল এবং বর্জ্য তেলে বিভিন্ন বৈশিষ্ট্য বিশ্লেষণ করা হয়েছে, যেমন চেহারা, রঙ, ঢালা বিন্দু, ফ্ল্যাশ পয়েন্ট, ঘনত্ব, কাইনেম্যাটিক সান্দ্রতা, সান্দ্রতা সূচক, ইত্যাদি। এই ফলাফলে দেখা গেছে যে উপরের বৈশিষ্ট্যগুলি বিভিন্ন তাপমাত্রায় উন্নত হয়েছে। তবু বিশ্লেষণ থেকে, রিফাইন্ড এবং ফ্রেশ ইঞ্জিন তেল, হাইড্রোলিক তেল এবং গিয়ার তেলের তিনটি নমুনার পার্থক্য তাপমাত্রায় সান্দ্রতা প্রায় একই পাওয়া গেছে। এছাড়া আরও পরিক্ষামূলক বিশ্লেষণে দেখা গেছে যে, অন্যান্য বৈশিষ্ট্য যেমন - চেহারা, রঙ, কাইনেম্যাটিক সান্দ্রতা, সান্দ্রতা সূচক, ফ্ল্যাশ পয়েন্ট এবং ঢালা বিন্দু, যাহা তাজা তেলের কাছাকাছি।

অতএব, নির্বাচিত প্রক্রিয়ার আর্থিক বিশ্লেষণ বিভিন্ন কৌশল ব্যবহার করা হয়েছিল। এই হিসাব থেকে আমারা পেব্যাক পিরিয়ড = 5.448 বছর, ডিসকাউন্টেড পেব্যাক পিরিয়ড = 6.56 বছর, নেট বর্তমান মূল্য = 3425.05 লক্ষ টাকা, IRR = 26% । উপরের মানগুলি থেকে এটি স্পষ্ট ছিল যে প্রকল্পটি আর্থিকভাবে সংগতিপূর্ণ।

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LIST OF ABBREVIATIONS

API	American Petroleum Institute
AN	Acid Number
AW	Antiwear
AGMA	American Gear Manufactures Association
ASTM	American Society for Testing and Materials
BN	Base Number
BDT	Bangladeshi Taka
COC	Cleveland Open Cup
cSt	Centistokes
DIN	Deutsches Institut fur Normung
EP	Extreme Pressure
ISO	International Standard Organization
LOBS	lube oil base stock
SN	Solvent Neutral
SAE	Society of Automotive Engineers
SUS	Saybolt Universal Seconds
UN	United Nation
VI	viscosity index

LIST OF SYMBOLS

% : Percentage
^{O}C : Degree Centigrade
°F : Degree Fahrenheit
bar : Unit of Pressure
L : litre, unit of volume
g : Gram
hrs : Hours
Kg : Kilogram
Km : Kilometer
m : Meter
m^{3} : Cubic Meter
Mpa : Mega Pascal
mg : MilliGram: Unit of Mass
ml : MilliLitre: Unit of Volume
N : Newton
P : Pressure
PB : Pay Back Period
s : Second
V : Volume

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Lubricants usually consist of fewer than 10% additives and 90% base oil, which are traditionally mineral oils made from petroleum fractions. Numerous additives are added to the lubricants to give them their performance attributes. The primary additive groups include anti-oxidants, metal deactivators, friction modifiers, anti-wear, corrosion inhibitors, anti-foaming agents, rust inhibitors, viscosity index enhancers, stickiness enhancers, demulsifying/emulsifying agent, adhesive properties towards tool surfaces and complexity agents (greases). The main purposes of lubricant oils have been to decrease friction between moving parts of various pieces of machinery or equipment, stop material deterioration, boost equipment and machinery efficiency, and save fuel and energy. Lubricants dissipate heat, maintain equipment clean, and stop corrosion by forming a thin liquid coating between moving surfaces to reduce friction and wear on the parts. Lubricants are necessary for moving parts in modern societies for several reasons [1].

The purpose of lubricating oil is to lessen wear, friction, and heat between mechanical parts that come into touch with one another, as shown in reference Figure 1.1. It is also known as lubrication or lube at times. Lubricating oil, sometimes referred to as motor oil or gearbox oil, is used in motorized vehicles. There are two main types of lubricating lubricants: synthetic and mineral oils. Mineral oils are lubricants made from crude oil that occurs naturally. These lubricating lubricants are industrially produced synthetic oils. When two surfaces come into touch with one another, lubricant, a fluid substance that is typically organic, is utilized to considerably minimize friction. As surfaces move, it helps to reduce the heat and keeps it under control. When it comes to enhancing the general performance of machines, equipment, vehicles, and other machineries, lubrication is a technique that is highly necessary. Numerous industries, including the automotive, manufacturing, and maritime sectors use it because of its broad range of applications. It extends the life of engines used in automotive products and significantly improves performance in the automobile sector [2].

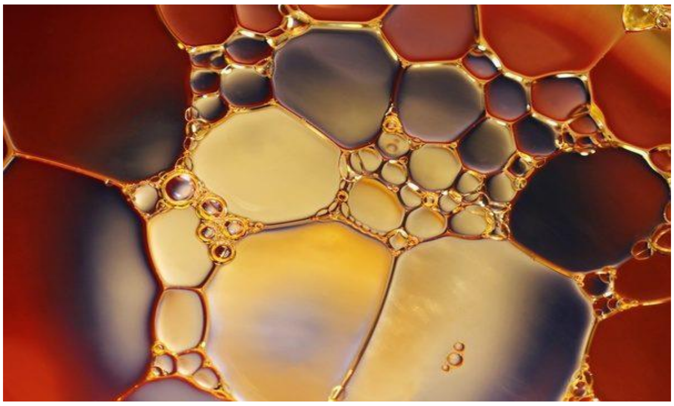


Figure 1.1 Lubricant a Fluid Substance [2]

Lubricant is essential to all machinery, tools, and equipment. It may also be utilized for surface heating or cooling, force transfer, or the transit of alien items. The characteristic that reduces friction is lubricity. Lubricating oils are necessary for vehicles to operate. The smooth sliding of well-oiled pistons minimizes the effort required to move the engine. When lubricating oil is applied properly, it increases vehicle efficiency and lessens wear and tear on moving engine components. Moving parts in machines and engines are lubricated using lubricating oil, which is a viscous liquid. For instance, grease, hydraulic oil, turbine oil, gear oil, and so forth. Lubricating oils from cars, engines, and gearboxes are by far the main source of spent oil in developing nations. In addition, small amounts are produced by hydraulic systems, transformers, and several other industrial uses. In the past, when vehicle traffic in emerging nations rose, the volume of spent motor oil climbed steadily. Most used motor oil is produced in small quantities in a variety of settings, such as private houses, garages and small types of workshops. There is a few significant manufacturers of used oil, such as largest corporations, truck fleet firms, and railroads. Used hydraulic, cutting, motor, and gearbox oils are referred to as waste lubricating oil. In addition, it implies to the deterioration of a newly installed lubricating elements polluted by metals, carbon residue, ash, varnish, water, gums, and other contaminating impurities, Apart from the asphaltic substances originating from the engine bearing surface [2].

After a few thousand miles of driving, these oils need to be replaced and taken out of the automobile due to stress from significant service deterioration. Between 1.7 and 3.5 million tons of lubricating oils are annually collected in Europe and the United States. This considerable amount of used lubricating oil waste has an important effect on both the economy and the environment. The term "used lube oil" refers to any petroleum-derived or synthetic oil that is still present after being used for lubrication, cutting point, etc. After a while, the lubricating oil begins to lose its qualities and becomes unsuitable for use in machinery. Temperature accumulation causes the lubricating oil to degrade and lose properties like viscosity and specific gravity. Dirt and rusted metal fragments from the surfaces are also present in the lubricating lubricants. The lubricant loses its ability to lubricate and must be changed with new since it over-reduces favorable properties with repeated use. It's surprising to hear that base oil never ruins it just gets dirty. The accumulation of contaminants and chemical alterations in lubricating oil are the two primary reasons because it is no longer suitable for continuous use. Water and carbon dioxide are the main contaminants released during fuel burning. For every liter of fuel used, one liter of water is produced. When the engine is still hot, this typically exits through the exhaust; however, when the engine cools down gradually, it may stream down and gather in the oil. Rust and sludge production are the results. The result was the oil becoming black. Incomplete combustion, particularly during warm-up with a rich mixture form, is the cause of their creation [1]. Large amounts of water can be contaminated by a small amount of used lubricant. Waste lubricating oil is contaminated by impurities and residues left over from combustion and has several additives when used. The used oil is burned in kilns and other large incinerators, producing a lot of ash and toxins that pollute the environment. The used waste lubricating oils are produced from different sources and disposed of poorly. Because it contains contaminants, used lubricating oil cannot be disposed of carelessly. Regenerating and reusing used lubricants is becoming more popular as a reaction to both economic issues and environmental conservation. Proper lubrication is crucial for reducing energy costs in machines and automobiles. Inadequate lubrication led to engine overheating, a decrease in engine runtime, broken bearings, etc., which ensured that maintenance costs rose. By properly recovering and refining used oil waste, usable fresh oil and new oil are produced, lowering energy use and protecting the environment from contamination. The goal of refining is to get rid of pollutants and degraded additives while also bringing the oil's characteristics back up to par with SAE and ISO standards. Up to 2% lead may have been present in typical old engine oil in the past, but today any lead is likely to come from bearing wear and vary between 2 and 12 ppm. Again, particularly during startup, unburned gasoline or diesel might enter the lubricant. This enters the engine via the air-cleaner. Due to typical engine wear, composites of tiny silicate, wear metal, iron, copper, and aluminum particles are discharged. Some oil molecules will oxidize as byproducts of high-temperature oxidation, changing into complex and caustic organic acids. Used oil is categorized into four main groups based on average levels of 13.2% mono aromatics, 76.7% saturates, 3.7% di-aromatics, and 6.5% poly aromatic-polar material. New lubricant deteriorates over time. Thus, it needs to be changed periodically. After being extracted, the spent oil is disposed. To put it plainly, incorrect disposal of spent oil is a precious resource wasted. A gallon of old motor oil that cannot be collected leads to the need to drill for more oil and, in some instances, to increase oil imports. However, the majority of crude petroleum produced worldwide today contains relatively small of the distinct hydrocarbon component chains needed for motor oil use. Because of this, the process of refining crude fat to make virgin lubricating oil is labor-intensive, challenging, costly, and requires roughly three times the energy of refining old oil. In order to preserve lubricant-base oil at a minimum quality level equal to that created in its virgin state, it is possible to recover and "regenerate" it [3].

Whenever old motor oil has the potential to be recycled safely and effectively, lowering energy consumption and environmental impact, it is a severe environmental problem when it is disposed of illegally. The majority of spent motor oil is unfortunately handled incorrectly. Some of it drains into sewers and damages water treatment facilities or enters rivers directly. To destroy weeds, some is poured onto dirt roads or dumped directly onto the ground. Waste oil in large quantities is disposed of, potentially contaminating surface and groundwater levels in landfills. Diverse methods exist for recycling and recovering a wide range of waste oils, either immediately or following some kind of separation and refinement. According to the hierarchy of waste management methods, maintaining the oil's natural characteristics so that it can be directly reused is the best option. Its heating value could be recovered or used in other low-level applications, among other things, as alternative possibilities. It is possible to directly repurpose certain waste oil kinds, lubricants in particular. Waste oils can be utilized for the following treatments: as a lubricant base stock that is equivalent to refined virgin base oil or as a clean-burning fuel [4].

In order to produce a material with qualities similar to those of virgin oil, used oil recycling is necessary. Vacuum distillation with solvent extraction or hydrogen finishing are the next steps in the process, although they are not the only ones. Pre-treatment includes heating or filtering. Refining old lubricants might have benefits for the environment and budget. Refined waste oil produces base oil with less energy consumption than fuel produced from it after further processing. Refined oil can be made using only one-third of the energy required to process crude oil to produce virgin base oil from used oil. Refining oil is frequently regarded as the best option because it reduces waste, uses fewer resources, and has a minor negative impact on environmental pollution [5]. The notion of reused lubricating oil was first presented in 1930. Engine lubricants were made by treating and reblending spent lubricating oils, which were first burned to provide energy. As environmental restrictions tighten and the necessity for ecological preservation grows, it has become increasingly essential to dispose of waste oils properly and recycle them. The early oil industry employed very different technology for oil refinement than modern refinement techniques. With horizontal cylinder stills used by individuals such as Samuel M. Kier, only 5 to 6 barrels of oil could be held at a time. The use of stills allowed refiners to raise the oil's temperature progressively. They retained just lamp oil or kerosene and eliminated other distillates, such as petrol, as the temperature rose. The process that crude oil goes through when it enters a modern refinery is known as fractional distillation. In order to be further refined, the different components of crude oil are separated by this procedure. Fractional distillation occurs when a mixture of various hydrocarbons, known as crude oil, is introduced to a high-pressure steam boiler. This tank raises the temperature of the oil to a boiling point, causing it to evaporate, just like boiling water does. It heats the crude oil to as much as 112 °F. A conduit allows the oil to turn into vapor before it enters the bottom of the distillation column. Many trays or plates are stacked inside the tall tank that holds the distillation column. It cools as it moves up the queue. Once the specific vapors have cooled to boiling temperatures, they condense on the plates or trays below. In the same manner, as water condenses on the exterior of a cold glass, the vapors condense into separated liquid phases. Following passage via pipelines, the liquid components are divided into several tanks. The fractions include fuels such as petrol, naphtha, kerosene, diesel, lubricating oils, heavy oils, and other materials. Old lubrication oil is put through processes like distillation or refining for lubricants or other petroleum components to provide a high-quality base stock. This technique has grown in wealthier countries [6].

1.2 LUBRICANT

A lubricant is an additive, typically organic, that is used to lessen friction between surfaces that are moving, which lowers the quantity of heat produced by those motion parts. It could also be used for various force transfers, moving foreign objects, and heating or chilling surfaces. Lubricity is a quality that can be used to lessen friction. Its primary purpose is to reduce friction and enhance the efficiency of a device. However, 90% of essential oil and less than 10% of additives are commonly found in lubricants. On the other hand, additives offer a variety of advantages, such as improved viscosity, enhanced age or contamination resistance, resistance to oxidation and corrosion, and more. They lessen wear and friction as well. Non-liquid lubricants include things like air cushions, plumbing tape made of powder, and other materials [7].

The following characteristics are usually found in a good lubricant:

i) Low freezing point and high boiling point
ii) A high index of viscosity
iii) High thermal stability
iv) Good hydraulic stability
v) Demulsibility
vi) Preventing corrosion
vii) A high level of good oxidation resistance.

1.2.1 Uses of Lubricant

Motor Oil: The most popular kind of car oil is known as motor oil. For optimal vehicle performance, several automakers advise changing the engine oil every 3,000 miles. But the engine oil has ingredients in it to prevent disintegration, lessen foaming, and prevent corrosion. Motors come in a variety of viscosity ratings. With a lower viscosity, the oil is thinner and flows more readily. A multi-grade motor oil like 5W-30 is recommended by the majority of automakers. One viscosity rating is intended for while the oil is cold, and the other is intended for when the oil is heated.

Gear Oil: Gear oil is used when lubrication at high temperatures is necessary. Gear oil, which generally has a viscosity level over 75 and is typically graded 75W-90, is used in vehicle manual transmissions and differentials.

Chassis Grease: It is most common to utilize this kind of car grease. The steering and suspension joints are use it. Greasing suspension parts periodically and whenever squeaks and groans are audible will help to delay early wear. On components that need grease fittings and lubrication are present.

High-temperature Wheel Bearing Grease: This grease is arrangement to be used in high-temperature situations. In the wheel bearings of cars with disc brakes, this type of oil is utilized. Grease still has a component that makes surfaces slick even after drying.

White Grease: As a result of the potential for water infiltration in metal-to-metal applications, white grease is made to be water-resistant. Water cannot either dissolve or remove white grease. Typically, white grease is rated for high temperatures.

Electronic Grease: On electrical connections where heat shouldn't build up, electronic grease also known as heat-sink grease. This grease is incapable of conducting electricity.

Penetration Lubricants: It is used to grease and free stuck, corroded, and rusted nuts and bolts. When this lubricant has time to absorb, it functions best. Cleaning is done with a wire brush after allowing it to absorb.

Graphite: Graphite should be used to lubricate any components that shouldn't come into contact with oil. In door locks, graphite is widely used.

Transmission Fluid: Transmission fluid is a multifunctional lubricant that is slippery. Seals are cured, the gearbox is cooled, all moving components are lubricated, and corrosion is avoided. Transmission fluid is vividly colored to help you spot leaks more easily. Car should be moving along level, flat surface when transmission fluid is being checked. Transmission fluid is typically used in a four-wheel-drive car's drivetrain.

The term "used lube oil" describes any petroleum-derived or synthetic oil that is still present after being used for lubrication, cutting, etc. The lubricating oil degrades as a result of temperature buildup, which causes a reduction in properties like viscosity, specific gravity, etc. Lubricant oil may be refined as often as required, making lubricant oil re-refining a very tempting economic proposition while conserving the environment.

1.2.2 Lubricating Oil System

A system for lubricating the drive mechanism that includes an oil reservoir and a storage tank for lubricating medium and can hold a specific amount of lubricant at the drive mechanism. At the drive mechanism, a first pump is positioned to continuously replenish the oil reservoir with a supply of lubricating medium in order to maintain a specific level therein while the drive mechanism is in operation.

By providing oil to the engine's moving parts, the lubrication system can lower surface friction. The lubricating system significantly impacts the lifespan of an automotive engine. The oil fling that the crankshaft rotation distributes lubricates the cylinder walls and piston-pin bearings. An automatic lubrication system, also known as a centralized lubrication system, distributes predetermined amounts of lubricant to various parts of an operating machine. Even though these systems are usually entirely automated, a centralized lubrication system still requires a manual pump or button activation. Two distinct categories of the system that share many of the same components can be distinguished.

Oil Systems: Oil systems are mostly utilized by CNC milling machines and other stationary production equipment

Grease Systems: Mobile equipment like trucks, mining machines, or construction machinery are the main uses of grease.

Even though their principal uses are mostly stationary for oil and mobile for grease, they can both be used in different ways. Some manufacturing equipment that is stationary will have grease systems.

1.2.3 Classification of Lubricants

The different lubricant types depend on the base oil.

Mineral Oil Based Lubricants: A lubricating base oil made from crude oil is referred to as "mineral oil" in this context. The American Petroleum Institute (API) has classified it as a variety of lubricant essential oils [8].

Group I: Using solvent or catalytic dewaxing, solvent extraction, and hydro-finishing techniques to produce a product that is either 90–120 percent saturated or has more than 0.03% sulfur. Class I base oils typically include 500 SN (solvent neutral), 150 SN (solvent neutral), and 150 BS (bright stock). Between 103 and 108 on the viscosity index.

Group II: Sulfur 0.03%, saturates > 90%, and an SAE viscosity index of 80 to 120 contain & manufactured using catalytic-based or solvent dewaxing procedures and hydrocracking. Due to the nearly complete saturation of all hydrocarbon molecules, Base oil in Group II exhibits exceptional anti-oxidation properties. It has a viscosity index of 113 to 119 and a watery white color.

Group III: Specialized processes, such as iso-hydroisomerization, generate sulfur 0.03%, saturates > 90%, and SAE viscosity index > 120. Base oil or slax wax left over after the dewaxing procedure might be used to make it. Based on the most common compositions with a viscosity index of 140 or higher, these can also be categorized into three groups:

a) Paraffinic
b) Naphthenic
c) Aromatic

Group IV: Polyalphaolefins (PAO)

Group V: Each of other substances, except naphthenic, PAG, and esters. The lubricant industry frequently expands this language for this group:

Synthetic oils based lubricants: Synthetic hydrocarbons, which are ultimately sourced from petroleum, can also be used to make petroleum-based lubricants [8]. These comprise:

i) Polyalpha-olefin
ii) Synthetic esters
iii) Polyalkylene glycols
iv) Phosphate esters
v) Alkylated naphthalenes
vi) Silicate esters
vii) Ionic fluids
viii) Multiply alkylated cyclopentanes

Solid lubricants:

PTFE: When coating something like kitchen utensils, polytetrafluoroethylene (PTFE) is commonly used to give a non-stick surface. Due to its chemical inertness and temperature range up to 350 °C, it is a valuable constituent in specialized greases. When exposed to high pressures, PTFE powder or solids are not very useful because of their softness and propensity to flow away from the site of contact. Then, metal, alloy, or ceramic lubricants have to be utilized [6].

Solid Inorganic: Molybdenum disulfide, tungsten disulfide, hexagonal boron nitride, and graphite are examples of inorganic materials used to make solid lubricants. In certain instances, their lubricity remains unaffected even at elevated temperatures. The employment of certain materials may be restricted due to their limited aversion to oxidation (molybdenum disulfide, for example, deteriorate s at temperatures above 350 °C in air but at 1100 °C in lowering conditions).

Metal Alloy: Pure metals, metal alloys, and metal composites can be employed as bearing and sliding surface components alone or as grease additives. Surfaces are plated with cadmium and gold, which improves their ability to slide and resist corrosion. As sliding bearings or as a standalone lubricant for sliding surfaces, , tin, lead, zinc alloys, and differents bronze alloys are utilized [8].

Aqueous Lubrication: There are several technological applications for aqueous lubrication. At liquid-solid interfaces, brush polymers with a high degree of hydration, like PEG, can act as lubricants [7]. These polymer films have a very low coefficient of friction, which helps to keep surfaces apart and high fluidity at the brush-brush interface, even at high compressions [9].

Bio-Lubricants: Plant oils and other sustainable resources are used to make bio-lubricants. Generally, they are fats called triglyceride esters, which can come from either plants or animals. For use as lubricant base oils, compounds produced from vegetables are preferred. It includes castor oil, high-oleic canola oil, palm oil, sunflower seed oil, and rapeseed oil derived from vegetables. The most often used kind is tall oil derived from trees. Hydrolyzing a range of vegetable oils yields acids, which are subsequently combined in a certain way to form synthetic esters. A further naturally occurring lubricant is lanolin, a wool grease that has a water-repelling property [8]. Whale oil has been used historically as a lubricant and as an additive to automatic gearbox fluid to reduce friction by certain persons through the last decades of the 20th century [9]. Bio-lubricants made up about 840,000 tonnes (1% of UK lubricant sales) every year in 2008.

1.3 ADDITIVES OF LUBRICATING OIL

The oils produced by traditional refining are not ideal for use as lubricants. As a result, lubricants are chemically enhanced and finely refined. The following ingredients, at a concentration of 12–15 weight percent, are essential in getting the properties of the final oil condition [10]:

Antioxidants: Unaccompanied by improvements, the base oil, even a sophisticated one, would quickly oxidize during use, increasing its viscosity and causing the production of varnishes, deposits, and corrosive oxidized products. A rise in temperature of 10°C doubles the oxidation rate of a hydrocarbon, to be more precise.

Detergents: Detergents prevent deposits on engine surfaces at higher temperatures and maintain the clean lubricant distribution system. Colloidal calcium or magnesium carbonates can be added to these additions to provide an alkalinity reserve. Even when 16-carbonate is added in levels up to 35% of the additive's mass, this colloidal dissipation is fully limpid, and its oil solution is a perfectly stable condition. The alkalinity reserve counteracts the acids produced when fuel or oil is oxidized. These additions are organic magnesium or calcium salts in acids [10].

Dispersing Additives Unaccompanied by Ash: The dispersing additives were developed because keeping everything that might collect in the lubricating circuits in a refined suspension was essential. The alkenylsuccinimides that these firestones are supposed to be sold as have an oleophilic component that is a polybutene radical with a molecular mass that varies from 800 to 1,500 for surfactants. The development of additives devoid of ash improved this property.

Antiwear Additives: There is a risk of fracturing the oil coating and subsequent rapid deterioration of surfaces as the pressure between surfaces increases. This can be avoided by adding additives to the oil, which are subsequently absorbed onto the contact surface and form a sturdy protective coating. These ingredients are:

a) Polar chemical compounds of the alcohol, fatty ester, fatty amine, or acid types that could desorb at temperatures above 150°C.

b) Organic substances that contain lead, zinc, phosphorus, chlorine, nitrogen, oxygen, or sulfur.

Viscosity Modifiers: As an antioxidant and effective antiwear additive, zinc dithiophosphates have a viscosity index (VI) oil range from 95 to 105. They can be obtained by producing traditional or unconventional base oils (by mild hydro-refining). The multi-grade oils that are used in autos do not correlate to this VI range. The production oil should be sufficiently differentiable at high temperatures while fluid at low ones. By selectively increasing the viscosity at high temperatures, the addition increases the VI and, for instance, changes the virtually mono-grade 15W20 oil to the grades 15W40 or 15W50. Alkylpolymetacrylates, which are relatively expensive, or more usually olefin copolymers or hydrogenated diene/styrene copolymers, are the two types of additives that are frequently utilized.

Pour-point Depressant Additives: These additions prevent the paraffin wax crystals from forming, which form in the oil at lower temperatures. Low molecular weight polymetacrylates have 17 applications. A similar effect is produced by several drugs that improve VI, as indicated in the previous sub-section.

Anticorrosion and Antirust Additives: These are inhibiting substances, either nitrogenous or oxygenating:

a) The majority of the oxygenated inhibitors are long-chain carboxylic acids.
b) Fatty amines and the byproducts of them make up the bulk of the nitrogenous inhibitors.
c) Another group of substances with anti-rust properties include detergent additives and dispersants. Ferrous and ferric hydroxides are produced when water and airborne oxygen react with iron, causing rust. Acids are created when fuel or oil oxidizes, and sulfur compounds are the primary cause of corrosion.

Antifoam additives: The antifoam ingredient added to the oil is relatively little (mg/kg) and is used to reduce the oil's tendency to foam, caused mainly by detergents and dispersion agents. Products with low molecular weight, including silicone and alkyl polymethacrylate, are used because they concentrate at the interface between liquid and air and do not dissolve in oil [11].

1.4 FUNCTIONS OF LUBRICANTS

It takes a lot of skill to properly lubricate contemporary, complicated machinery. Industrial lubricants need to perform a variety of additional tasks in addition to their typical roles in reducing wear, friction, and heat [12].

a) Lubricant, or the creation of a liquid film between two highly loaded moving parts.
b) Act as a coolant to eliminate frictional heat, which is frequently very high and produced both within and outside the machine.

c) Acquire and transport pollutants that come from both internal and external sources.

d) In many applications, it functions as a hydraulic medium.

e) Limit wear on heavily loaded parts when the fluid coating is extremely thin (boundary lubrication).

f) Prevent precision parts composed of different metals from rusting and corroding.

g) Provide defense against sludge and varnish buildup in the lubricating system.

h) Prevent problems by avoiding aeration and foaming.

i) Prevent or speed up the production of emulsions in moist systems.

j) Possess the ability to distinguish water that comes from breathing air or other external sources.

1.5 TYPES OF LUBRICATING OILS

i. Automotive sector

a. Engine oils

  i. Petrol (Gasoline) engine oils

  ii. Diesel engine oils

b. Automatic transmission fluid

c. Gearbox fluids

d. Brake fluids

e. Hydraulic fluids

ii. Tractor sector

a. Universal Tractor Transmission Oil – UTTO

b. Super Tractor Oil Universal – STOU – includes engine

iii. Other motors

a. Two Stroke engine oils

iv. Industrial

a. Hydraulic oils

b. Air compressor oils

c. Food Grade lubricants

d. Gas Compressor oils

e. Gear oils

f. Bearing and circulating system oils

g. Refrigerator compressor oils

h. Steam and gas turbine oils

v. Aviation

a. Gas turbine engine oils

b. Piston engine oils

vi. Marine

a. Crosshead cylinder oils

b. Crosshead Crankcase oils

c. Trunk piston engine oils

d. Stern tube lubricants

1.6 PROPERTIES OF LUBRICANTS

A wide range of lubricants' characteristics affect both their chemical and physical characteristics. The optimal lubricant to use in a given situation can be chosen by understanding these features. There are many qualities, but the following are the most crucial ones:

Viscosity: The "internal resistance to flow" of a lubricant Lower viscosity lubricants have a consistency that is more similar to water and flow, whereas higher viscosity lubricants are thick and do not. The picture below shows the viscosity of four different oils, as seen in ref. Figure 1.2. The ball sinks more quickly in the thinner, lower-viscosity oil than it does in the blends with greater viscosities.

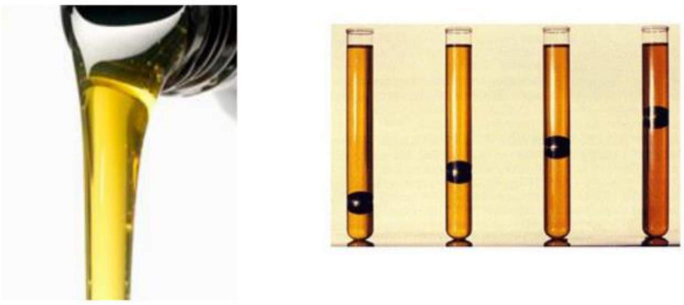


Figure 1.2 Viscosity of Difference Lubricating Oil [7]

Viscosity Index: The viscosity index calculates the rate at which viscosity changes with temperature. To put it another way, how much viscosity alters with temperature.

Oxidation Stability: When oxygen and lubricating oil are mixed, oxidation is the result. Acids, water, and high temperatures all contribute to the rate of oxidation. As temperatures rise, the lifespan of a lubricant decreases, resulting in varnish and sludge.

Pour Point: The lowest temperature that allows a lubricant to pour or flow like a liquid .This can vary based on the testing setting.

Demulsibility: A lubricant's capacity to dissociate from water is known as demulsibility.

Flash Point: The point at which lubricants will heat up and react with air to ignite, but not to hold a flame.

1.7 BASIC PERFORMANCE REQUIREMENTS FOR LUBRICATING OIL

(i) Having an appropriate viscosity and favorable viscosity-temperature characteristic.

When the viscosity is low, the internal leakage of the pump increases and a high density will increase the pressure loss of the working system. Consistency is too soft, which reduces volume efficiency, resulting in decreased system pressure and increased wear and tear. Because there is a significant temperature differential between the hydraulic system's operating temperature and the ambient temperature, a temperature change will inevitably result in a change in oil viscosity. As a result, the oil's temperature and thickness must be as low as possible.

(ii)The essay is well-lubricated.

With the hydraulic system's operating pressure. Power, automation, and the shrinking of hydraulic parts are all ongoing improvements. As a result, when the hydraulic system starts and stops, the sliding components are mostly in the boundary lubrication state. To stop wear and abrasion, antiwear compounds are frequently added to oils. Meet the lubrication needs to increase the wear resistance of oil products.

(iii) Excellent stability.

The following characteristics of stability are important: thermal stability, oxidation stability, corrosion resistance, shear stability, diazepam hydrolysate, low temperature stability, and storage stability.

(iv) Good anti-foam and air release.

Air may be mixed with the hydraulic system for a variety of reasons, and it can be found in the hydraulic oil in two different states: mixing and dissolving. Cavitation in hydraulic oil and air dissolved in oil can both occur. It alters the hydraulic oil's viscosity and compressibility when suspended in oil as a bubble.

(v) It shall be set on the adaptability of the sealing material.

The major issue of hydraulic system leakage necessitates the use of hydraulic oil to ensure that gaskets are sealed and other plastic components are not eroded. An attribute that prevents contraction or expansion.

(vi) It was positive for overthinking.

Insoluble colloids in oil may impact hydraulic oil's filterability. asphaltene effects and pollution particle effects. Precision standards for hydraulic control components are becoming more stringent as hydraulic technology advances. The pump clearance is relatively limited due to the high pressure. This makes the gadget more sensitive to contaminants in the oil. Before oil enters the control element, it must be filtered since small contaminants can lead to abnormal wear and failure of hydraulic components. This necessitates having a good filter on the hydraulic oil. Formerly flame-resistant. Non-toxic. easily managed, etc.

1.8 ADVANTAGE OF LUBRICATING OIL

Lubrication enhances the longevity, consistency, and efficiency of equipment by reducing wear, friction, heat overload, rust, corrosion, contamination, and other issues. Equipment breakdowns and failures that could be expensive are prevented in large part by lubrication. Lubricating systems have five advantages:

Friction: In order to improve operation and add a layer of protection against friction, lubricants work best when applied to machine parts. In order to prolong its lifespan and minimize downtime due to component failure and breakdown, the lubrication system coats metals.

Corrosion: The remedy for preventing rust and corrosion in equipment and parts is lubricant. Systems for industrial lubrication contribute to the durability and corrosion resistance of industrial equipment.

Temperature Control: To maintain the systems at the proper temperature continuously of the lubrication systems, which are employed for smooth operation, also dissipate heat and divert system fluid to be cooled.

Efficiency: Mechanics and equipment operate more efficiently when properly lubricated. Not only does that lubrication reduce wear and tear but also friction.

Maintenance & Repair: An effective lubrication system will help extend the life of machinery and utilize it for extended periods of time without causing a reduction in output, malfunction, or breakdown.

1.9 PERFORMANCE EVALUATION OF LUBRICATING OIL

A lubricant performance test by itself helps analyze a particular lubricating oil property that is listed in Table 1.1. When combined with other tests in the right way, they determine the desired or actual performance profile of a particular lubricating oil.

Table 1.1 Physical Properties of Lubricating Oil [12]

Types of Lubricating Oil	Physical Properties				
	Kinematic Viscosity(cSt)		Viscosity Index	Pour Point	Flash Point
	40℃	100℃			
Engine oil	-	4.1-6.6	>90	<-5	>190
Two Stoke oil	-	5.6-7.8	>95	<-5	>70
Automatic gear oil	-	13.5-15.5	>85	<-5	>200
Industrial gear oil	28.8-35.2	-	>90	<-10	>200
Hydraulic oil	9.0-11.0	2.5 Typical	>75	<12	>125
Turbine oil	28.8-35.2	5.0 Typical	>90	<-6	>160
Refrigerator Compressor oil	28.8-35.2	5.7 Typical	>90	<-20	>200
Air compressor oil	28.8-35.2	5.6 Typical	>90	<-10	>200
Mineral base oil	29.0-31.0	-	>100	<-9	>204

1.10 DETAILS OF WASTE LUBRICATION OIL

The resource known as waste lubricating oil contains contaminants, so it cannot be thrown away carelessly. Waste lubricant recycling and regeneration is becoming more popular as a response to both environmental conservation and economic issues [13].

Waste oil management is becoming more crucial in industrial and urban environments. The relationship between the quantity of automobiles and industries and the production of waste oils is demonstrated. Most lubricating oils derived from petroleum are intricate blends of hydrocarbon compounds. Most of them are composed of alkanes, which have slightly longer branches, and mono cycloalkanes and monoaromatics, which have numerous short chapters on the ring. These hydrocarbon molecules typically have molecular weights between 250 and 1000 for low-viscosity oils and more viscous lubricants. There are twenty to thirty-four carbon atoms. The moving parts of engines and other machinery are greased using thick liquid fats. This group also includes another semi-solid, grease. Lubricating grease, automotive lubricant, and industrial lubricant are the three primary categories into which liquids are divided. Combining lubricating oil with additives and foreign materials, like metal powder, chips, and other particles, increases the risk of ageing, degradation, failure, mechanical fault, and decreased performance [14].

To increase performance in such situations, the oil is changed. Natural resources should be preserved in addition to preventing environmental damage by collecting and recycling wasted, used, or waste oils. Considering the vast amounts produced worldwide by transportation and industrial operations, waste oil treatment is very crucial. Improper handling, treatment, or disposal of these waste oils could have a negative impact on the environment [15].

With the potential to address technical, financial, and environmental issues related to recycled used oil recycling, several novel treatment technologies have been developed in recent decades. The fact that one liter of waste oil that has been reprocessed into fuel contains roughly 8000 kJ of energy enough to light a 100 W bulb for a full day is further evidence of this point made in Reference [13].

Both the environment and the economy may gain from the effective recycling of waste lubricant, which might help lower environmental pollutants and greenhouse gas emissions [11].

When utilized in service, lubricating lubricants facilitate simpler motion of connected parts and protect rubbing surfaces. These function as a medium to drain excessive heat accumulation from the moving surfaces during this operation. Viscosity, specific gravity, and other characteristics of the lubricating oils are reduced as a result of further temperature buildup. Lubricating oils accumulate metal fragments and dirt that have worn off surfaces. Because of an excess decline in desired properties with prolonged use, the lubricating oil loses its lubricating qualities and needs to be replaced with a new one. Lubricating oil disposal has grown to be a significant issue due to the vast amount of engine oil consumed. Numerous countries are now tackling the issue of discarded or used lubricating oil-related environmental degradation in their environments. Every year, for instance, the United States produces roughly 2 billion gallons of oil. The need to recover these important hydrocarbon resources while lowering the pollution caused by spent lubricating oil has prompted governments and companies to come up with workable solutions. These days, more people are paying attention to recycling spent lubricants [16].

This is primarily due to its environmental concerns, but it is also partially caused by the worry that the world's oil reserves are running low. The concept of recycling spent lubricants has been around since the 1930s, and it gained significant traction during World War II due to the limited availability of crude oil, which prompted the repurposing of everything, including lubricants. Due to environmental concerns regarding resource conservation, interest in recycling has remained vital. However, it is recognized that the total amount of oil spills at sea and offshore pales in comparison to the pollution created by discarded lubricating oils. The focus on waste recovery has heightened interest in re-distilling this spent lubricating oil to get it back into its original, useable lubricant. Refining or distilling discarded lubricating oil yields a high-quality base stock for lubricants and other petroleum products. Re-distilling or refining is the term for this process. Numerous Western nations have created various techniques for repurposing used lubricating oil. In affluent countries, this technique is now widely used; in some, it can account for as much as 50% of a country's lubricant demands [17].

The fundamental idea stays the same and makes use of several of the fundamental actions listed below:

a) Using settling, remove water and solid particles.
b) Gums, greases, etc. can be removed with sulfuric acid treatment.
c) Acid neutralization using an alkaline treatment.
d) Rinsing with water to eliminate "soap."
e) Contacting clay to remove impurities and bleach the oil.
f) Using stripping to remove volatile oils and moisture.
g) Filtering to get rid of particulates like clay.
h) Conforming to the requirements.

The primary goal of this research is to produce high-quality lubricating oil from spent oil through the process of re-refining it, which will minimize the need to import lubricant and reduce pollution to the environment. Waste lubricating oils primarily consist of the basic oil, carbon soot, metallic fragments, oxidation products, and deteriorated additives. To provide the lubricants certain performance properties, a lot of additives are added [18]. The main additives are anti-foaming agents, increases in viscosity index, demulsifying or emulsifying agents, stickiness improvers, corrosion inhibitors, rust inhibitors, friction modifiers, antioxidants, detergents, anti-wear components, metal deactivators, and components that withstand high pressure. These additives change with usage, losing their properties and making the lubricating oil unusable. Furthermore, as a result of component wear and tear, metal processing and lubricating lubricants absorb different metal fractions during operation. The waste oil also picks up some pollutants during usage or storage, including dust, water, unburned fuel, carbon, and chlorinated solvents [19].

1.11 IMPORTANCE OF USED OIL REFINING

Re-refining in Lubricating Oil Recovery
Re-refining in Dedicated Grass-root Unit
Reprocessing in Primary Refinery
Reprocessing to Fuel
Burning Untreated
Disposal

Figure 1.3 Waste Oil hierarchy [12]

Refining trash into virgin lubricating oil could be a good way to minimize hazardous waste emissions into the environment. There are numerous methods for recycling and recovering a wide range of waste oils, either directly or after some sort of separation and purification. Preserving the original qualities of the oil to enable direct reuse is the first option, as shown in Figure 1.3, in the waste management hierarchy. More options include recovering its heating value and using it in other, lower-level applications. Certain waste oils, especially lubricants, can be processed back into use immediately. Waste oils after treatment can be utilized as a base stock for lubricants, like refined virgin base oil, or as clean burning fuel. Because of the vast amounts produced worldwide, the possibility of direct reuse, reprocessing, regeneration, and the negative consequences on the environment if improperly managed, processed, or disposed of, the management of spent oil is especially crucial [12].

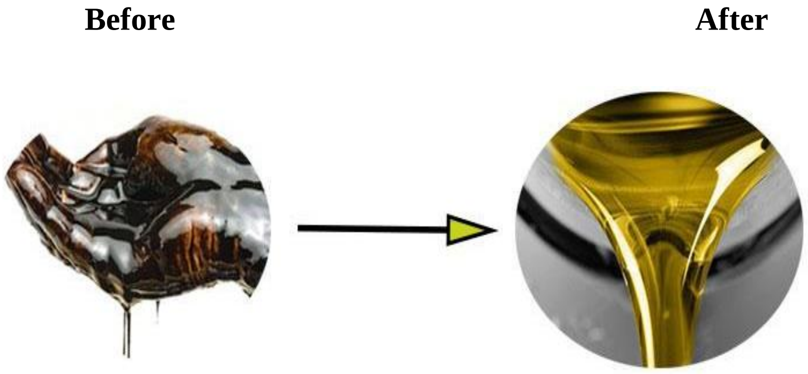


Figure 1.4 Refined Lubricant Oil [14]

The qualities that make used oil important as a lubricant and a perfect material for recycling remain even though it is unclear. Regarding Figure 1.4, there are three methods of refining again: distillation, basic dehydration/filtration, and furnace burning for destruction. After analysis and comparison of the properties obtained from previous work, the parameters of the treated oil were compared to those of virgin oil [13]. These properties included water content, specific gravity, viscosity, flash point, pour point, sulfur, and metal content. Viscosity should be the primary consideration when selecting lubricating oils. Higher viscosity corresponds to a stronger oil coating because the two parameters are roughly inversely correlated. It is possible for contamination or oxidation to cause used oil to become more viscous. The best way to extract water from spent oil is through refining. Distillation at temperatures higher than water's boiling point is mostly to blame for this and moving parts wear down spent oil, which results in sulfur. Compounds with a low melting point and high shear strength are formed when sulfur and metal combine. Mineral acids that lead to engine corrosion are created when sulfur compounds in gasoline oxidize in internal combustion engines that use lubricating oils [14].Water infiltration can lead to a number of issues with lubricating oils, including corrosion, which is closely related to water intrusion. Water can displace oil during application at contacting surfaces, lowering lubrication levels and activating surfaces that could serve as catalysts for the oil's own breakdown [15].

The specific gravity of virgin oil is higher than processed oils and lower than used oil. The specific gravity of the contaminated oil may differ from that of the pure base oil, depending on the type of contamination. The used oil will have a lower specific gravity than new or re-refined oil if it becomes tainted by water from fuel dilution or engine combustion. There may be benefits to the economy and ecology from reusing used lubricants [17].

Reusing waste oil as fuel requires more energy than refining it to create base oil. Refined oil is made from used oil, using only one-third of the energy needed to refine crude oil and make virgin base oil. Because of this, re-refining is usually considered the most excellent option for minimizing waste, protecting the environment, and conserving resources [11].

1.12 WASTE LUBRICATING OIL REFINING TECHNOLOGIES

Three main techniques are available for recycling waste lubricating oils: burning, reprocessing, and re-refining.

Reprocessing:

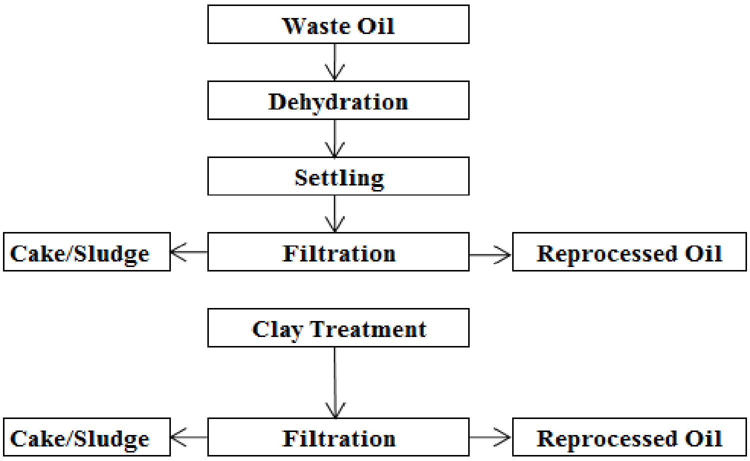


Figure 1.5 Flow Chart of Reprocessing of Used Lubricating Oils [13]

According to ref. Figure 1.5, the goal of reprocessing is to provide a final fuel oil with a low water and basic sediment content that won't clog boiler tubes, clog burners, or result in sediment buildup in customer tanks. Filtration, or a mixture of these procedures, is therefore necessary for the process. Unfortunately, additional treatment procedures like distillation and clay contact would lessen the competitive advantage of waste oil processors since it would not be able to eliminate all chemical impurities from the oil [13].

Refining:

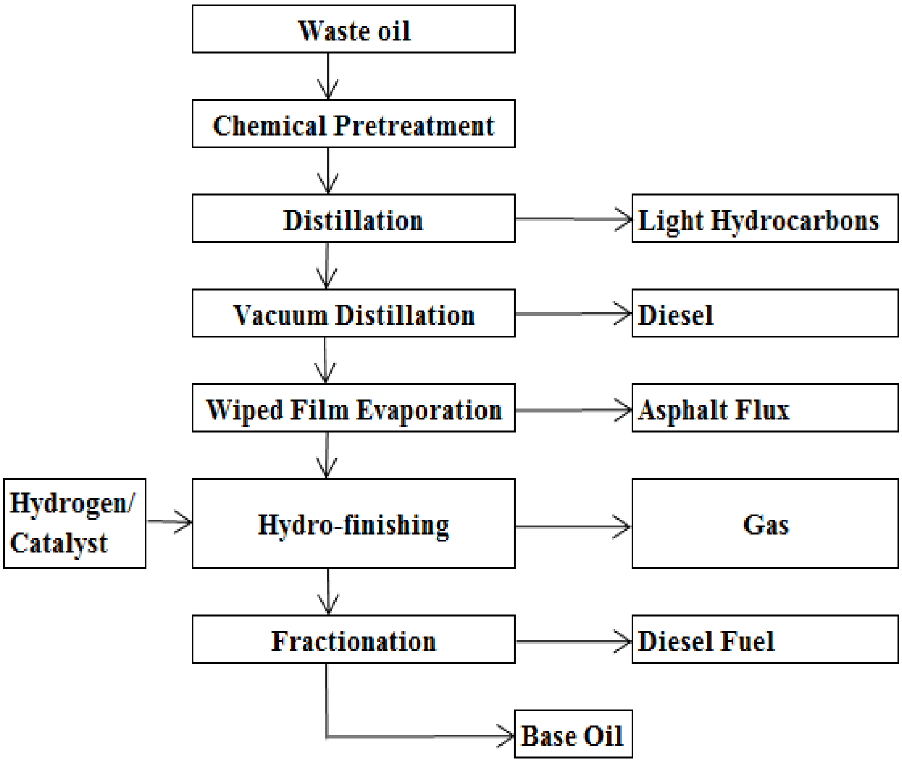


Figure 1.6 Flow Chart of Refining of Used Lubricating Oils [18]

For recycling used oil, several re-refining techniques have been proposed over time. To provide premium base stock for lubricants or other petroleum products, spent lubricating oil is subjected to distillation or refining procedures, as shown in Figure 1.6. In affluent nations, this approach is now used far more frequently; in certain cases, it accounts for up to 50% of the nation's lubricating oil needs [18]. Different western countries have devised different methods for treating spent lubricating oil so that it can be reused. It calls for turning used oil into a product that resembles virgin oil in all respects. Heat treatment or filtration is typically the first step in the process, followed by vacuum distillation with clay or hydrogen finishing, solvent extraction with clay and chemical treatment with hydro-heating. The re-refining process can be less polluting and more economical for small-scale enterprises with a capacity range of 10,000–30,000 tons when vacuum distillation is followed by clay contracting. The residual by-product is baled in thick plastic sheets and properly compacted before being disposed of in landfills. A reputable recycling company's presence may help improve the trust factor [19].

1.13 LUBRICATING OIL PURIFICATION AND RECOVERY

There are four methods for waste oil recovery, those are

a. Distillation Method,
b. Activated Charcoal Clay,
c. Fuller’s Earth Method and
d. Acid Clay Method.

Distillation: The constituents or chemicals from a liquid combination are extracted through distillation, which uses selective boiling and condensation. A partial separation that raises the concentration of particular components in the mixture can occur from distillation, or it can lead to an almost total separation. The four main categories of applications for distillation are as follows: industrial distillation, distillation on a laboratory scale, distillation of herbs for perfumery, and distillation of medicinal and food ingredients [20].

Simple Distillation: In a simple distillation, a condenser receives the vapor right away. As a result, the distillate's composition is exactly the same as that of the vapors at the specified temperature and pressure, not pure.

Fractional Distillation: In a packed fractionating column, vaporization-condensation cycles must be performed in order to separate the components. One technique for distilling chemicals that are heat-sensitive is steam distillation.

Vacuum Distillation: In accordance with the standard testing procedure we used for the distillation process, the principle of vacuum distillation is to drown out the atmospheric air from the apparatus to distil or heat the flammable liquid at a minimum temperature higher than the desired temperature to avoid forming vapor due to the heating process followed by a stripping process.

Vacuum Distillation that is Sensitive to Air: Certain chemicals are both air-sensitive and have high boiling points. One can employ the above-mentioned basic vacuum distillation system, in which an inert gas is used to replace the vacuum when the distillation process is finished.

Short Route Distillation: This type of distillation is typically carried out at low pressure and includes the distillate traveling a short distance often only a few centimeters.

Zone Distillation: This method of distillation involves partially melting refined substances in a moving liquid zone and condensing vapor in the solid phase at the condensate pull in a cold area. It is done in a lengthy container.

Distillation Method: Flow Chart

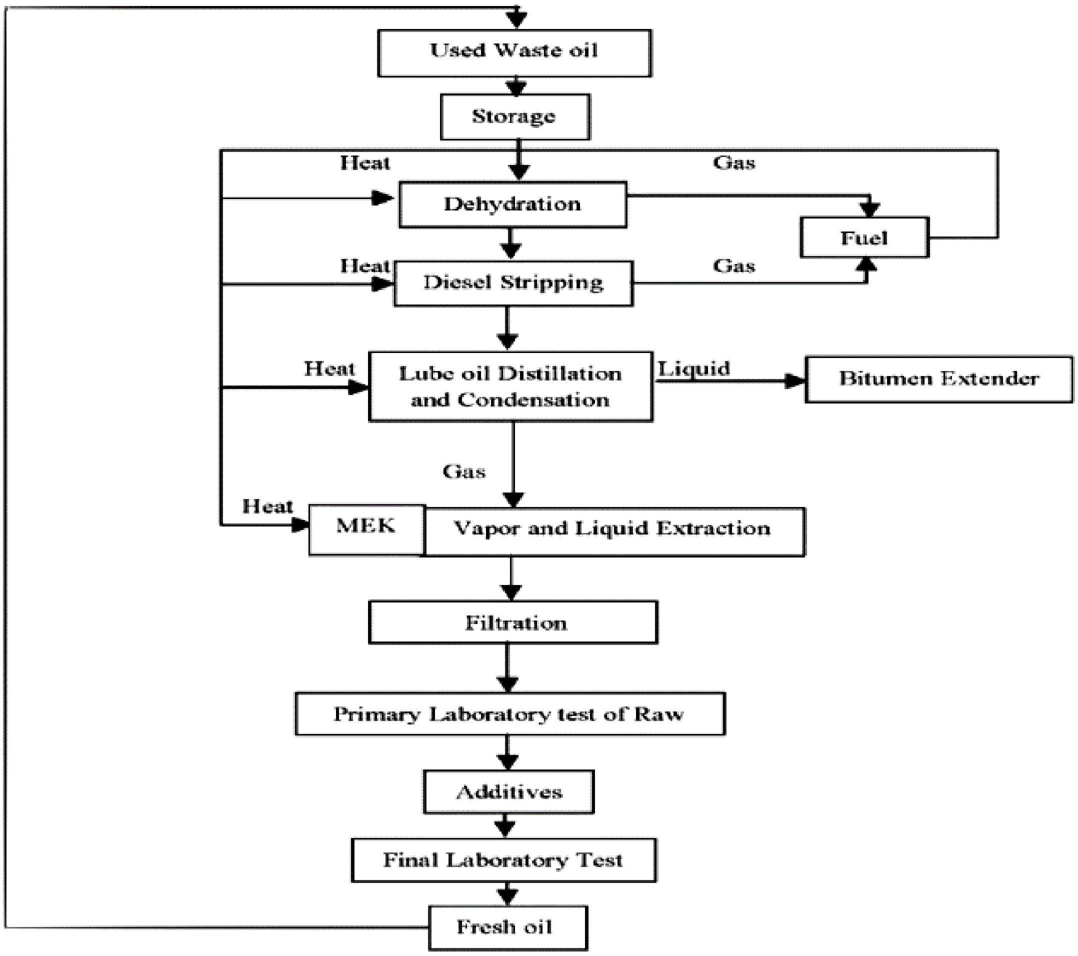


Figure 1.7 Distillation Method to Refining of used Lubricating Oils [20]

In order to remove any moisture from the material, air distillation was done first. As seen in above Figure 1.7, distillation is a unit operation where heat energy is used to separate the constituents of a liquid combination. Such separation is essentially caused by variations in the vapor pressure of distinct constituents at the same temperature. However, two hundred milliliters of used oil were added to the vacuum distillation flask. To lessen the foam encounter, the pressure was gradually increased. To extract the dissolved gases, gentle heating was used. A very black, waxy residue was left behind after the distillate was weighed. In order to cure this lube oil stream, 30 grams of clay were packed into a blocked funnel, and the lube oil was allowed to flow through the clay bed before being disposed of vacuum filtration is this. The process of separating a solid from a liquid suspension using a porous media or screen to hold the solid while allowing the liquid to pass through is known as filtration, however vacuum filtration also exists. Vacuum filtration is the term used to describe filtration processes that use atmospheric pressure downstream and less than atmospheric pressure upstream of the filter medium [20].

Activated Charcoal Clay:

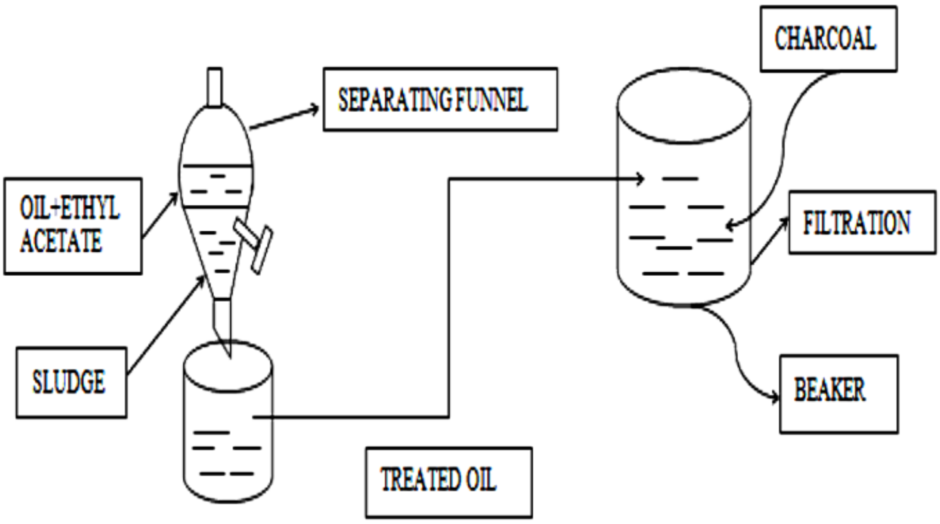


Figure 1.8 Activated Charcoal Clay Method to Refining of used Lubricating Oil [21]

A shaker was used to thoroughly mix the waste lubricant. 200 milliliters of ethyl acetate were placed in a separating funnel along with 400 milliliters of old lubricant. For a whole day, the solution was kept at room temperature. There is a two-layer configuration and sludge that was removed makes up the bottom layer [21].

According to above reference Figure as shown 1.8, the upper layer is made up of a solution that has been activated charcoal-treated for 30 minutes. For adsorption, charcoal is employed. Adsorption is the phenomenon of chemical substance enrichment on a solid surface and clay then performed vacuum filtering. The fundamental operation of filtration is the separation of a solid from a suspension in a liquid with the aid of a porous medium or screen that holds the solid and permits the liquid to flow through; however, vacuum filtration also exists. When air pressure is applied to the downstream side of the filter media, and less than atmospheric pressure is applied to the upstream side, the process is called vacuum filtration. Oil is used after filtering to calculate properties [21].

Fuller’s Earth Method:

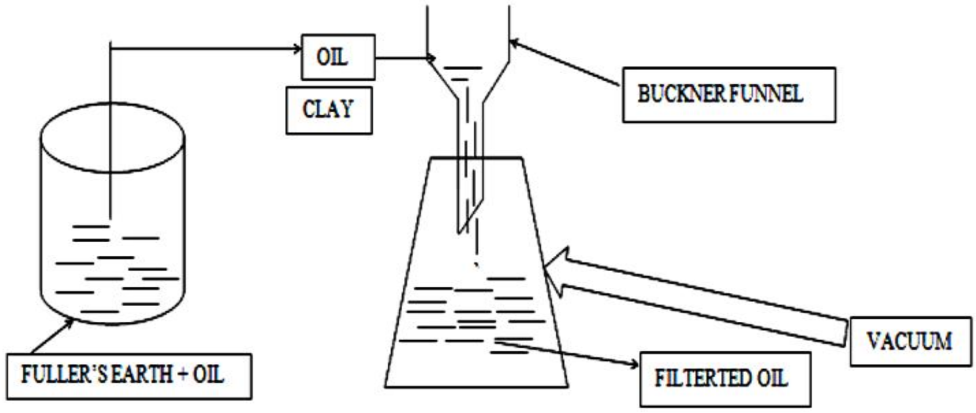


Figure 1.9 Fuller’s Earth Method to Refining of used Lubricating Oils [22]

Centrifugation is used to filter the waste oil for 30 minutes at 1000 rpm. The liquid part was removed using a decanter. Fuller's earth was applied to the decanted liquid for one hour, as shown in above Figure 1.9. Fuller's earth is utilized for adsorption purposes because of the phenomenon of chemical material enrichment at solid surfaces. Clay then completed the vacuum filtration [22]. The process of separating a solid from a liquid solution using a porous medium or screen to hold the solid while allowing the liquid to flow through is known as filtration, but vacuum filtration also exists. Vacuum filtration is the term used to describe filtering processes that use atmospheric pressure downstream and less than atmospheric pressure upstream of the filter media and oil may have its color improved by using clay.

Acid Clay Method: Using centrifugation for 20 minutes at 1800 rpm, the material was further filtered. The suspended particulates decanted off and settled in the waste oil at the flask's bottom. The decanted liquid was thermally pre-treated, as ref. below Figure 1.10 illustrates, to break down some of the ingredients and lessen the acid's burden. Measuring 100 milliliters of pre-treated oil, 10 milliliters of 98% concentrated H_2SO_4 were added, and the mixture was vigorously stirred in a separating funnel [23].

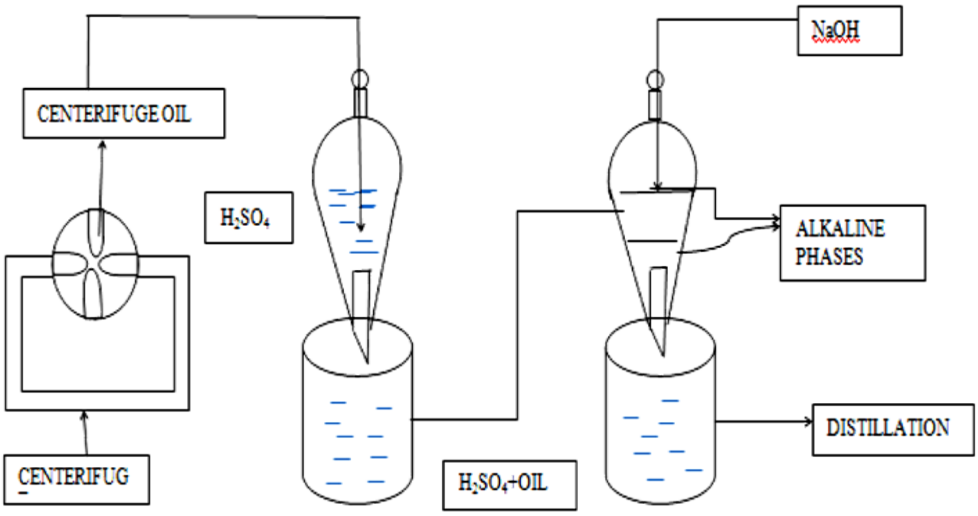


Figure 1.10 Acid Clay Method to Refining of used Lubricating Oils [23].

Agitation is the process of forcing material into a tank or vessel in a circulating pattern. After allowing the material to settle for 48 hours, two layers or phases were created, and the sludge was taken out of the bottom of the separating funnel. Subsequently, a 100ml of 10% NaOH solution was added to neutralize the acid and left to settle and half an hour, calmly. The bottom-forming alkaline step was eliminated, and hot water was used to wash the lubricant. An elemental burner was used to heat the oil, and a vacuum pump was attached [23].

1.14 BENEFITS AND DRAWBACKS OF USED OIL RECYCLING

Benefits: Potentially dangerous substances found in used oil include dioxins and furans, heavy metals, polyromantic hydrocarbons, and chlorinated hydrocarbons. These substances are recognized as mutagens and carcinogens. The most ecologically friendly way to handle waste lubricating oil is through high-end refining to recover base oil for reuse. Any used oil manufacturer that values its environmental credentials and reputation should use this technique [24].

a) Refined lubricant manufacture requires 60% less energy than crude lubricant production.
b) Used oil recycling has the energy potential to produce enough electricity to power a typical home.
c) It may be used to make a wide range of goods with petrochemical bases.
d) A long-term, environmentally sustainable solution.
e) Lower the quantity of lubricating oil imported.
f) An excellent replacement for lower-quality fuel.

Drawbacks:

a. Due to inadequate laboratory facilities, the qualities of the used lubricating oil were not examined.
b. The lubricating oil collection system is only intended to handle the three designated oils. Needs a sophisticated method for collection.
c. A strong market is necessary for lubricant that has been re-refined.
d. Requires a significant financial investment.
e. A reliable recycling firm is needed for the product to be commercially viable when choosing the re-refining option.
f. It is expensive to dispose of end waste remnants properly.

1.15 DISPOSAL AND ENVIRONMENTAL IMPACT

An estimated 40% of all lubricants find their way into the environment. However, burning, recycling, filling landfills, and releasing waste into water are typical disposal methods. Even a tiny amount of oil can contaminate large amounts of water, so most countries strictly regulate landfill disposal and water discharge. Most regulations permit a certain amount of lubricant to be present in waste streams, and businesses annually spend hundreds of millions of dollars treating their waste fluids to get them down to permissible levels [25].

Using oil as fuel to generate power is usually governed by regulations due to the relatively high quantity of additives it contains. Burning produces ash that is full of hazardous chemicals, mostly heavy metal compounds, and airborne pollutants. Lubricant burning is thus limited to specialized facilities with access to landfill sites that are authorized to handle hazardous ash and equipped with sophisticated scrubbers to eliminate airborne contaminants. Regrettably, most lubricant that finds its way into the environment comes from people throwing it down drains, onto the ground, and onto landfills as garbage. In addition to spills brought on by mishaps, additional direct pollution sources include pipeline leaks, roadway runoff, and natural or artificial disasters. Because base stock and crude oil are becoming more expensive, recycling is becoming a viable option because of filtering technology and practice developments. Usually, a variety of filtering techniques recover the basic oil while removing additives, oxidation products, and particles. In the process, the oil could be refined. Following that, this base oil is handled just like virgin base oil; however, as recycled oils are often seen as inferior, there is a great deal of resistance to using them [26].

Base quantity though the cost-effectiveness of fractionally vacuum-distilled old lubricant relies on several aspects, it offers better qualities than all natural oils. However, used lubricant may also be sent into refineries to be combined with crude oil. Again, there is strong opposition to this application since the procedure can severely poison or deactivate the vital catalysts due to the additives, soot, and wear metals. Therefore, the primary barrier to recycling remains the collection of fluids, even when the cost of performing filtering (soot removal and additive removal) and re-refining (distilling, isomerization, hydrocrack, etc.) is prohibitive. Refineries require a continuous supply of fluids monitored in cisterns and rail tanks. It is occasionally essential to get rid of any residual lubrication. The best course of action in such circumstances is to return it to the manufacturer to be processed as part of subsequent batches [27]. Because they have a great potential to seriously pollute water, lubricants also have a significant negative environmental impact. Furthermore, lubricant additives often include substances that are harmful to both plants and animals. Additionally, hazardous oxidation products may occur in utilized fluids. Although particularly hazardous additives may have a deleterious effect on lubricant persistence in the environment, the base fluid still plays a major role in this regard. Because lanolin lubricants are non-toxic, they are a safe and environmentally friendly solution for both users and the environment [25].

1.16 CONTAMINANTS IN USED OIL AND ITS EFFECTS:

Some sorts of impurities cause the automobile lubricating oil to lose its efficacy while the vehicle is operating [27]. These pollutants fall into the following categories:

Extraneous Pollutants: Metallic particles from the engine and the ambient air both add foreign pollutants. Dust, grime, and moisture are airborne contaminants. Given that air may cause the oil to froth, air itself may be regarded as a pollutant. The following are the pollutants found in the engine:

1. Metallic fragments from engine wear.
2. Carbon flakes left over from the incomplete combustion of gasoline.
3. Metal-corrosion products include metallic oxides.
4. There is a cooling system water leak.
5. Engine crankcases may become contaminated with water, which is a result of burning fuel.

The Consequences of Deteriorating Oil: As oil deteriorates, a variety of products are created. Among these significant goods [28], a combination of water, oil, sludge, dust, and carbon particles left behind when fuels burn too partially. Sludge might stay in colloidal dispersion in the oil or deposit on different engine components. Engine components can develop a stiff or sticky substance called lacquer when high-temperature operation is applied to sludge in the oil. Compounds of oil oxidation that stay in the oil and cannot be filtered out, resulting in oil-soluble compounds that build up on engine components. Depending on the operating circumstances of the engine, there are significant variations in the amount and distribution of engine deposits. Rather than lubricating oil, incomplete combustion products from the fuel are primarily responsible for carbonaceous deposits at low crankcase temperatures. However, the lubricating oil may be the reason for the rise in sludge and lacquer deposits at high temperatures.

Impact of Pollutants in Oil: Contaminants that may arise during operation have an impact on the lubricating oils characteristics. The following are the consequences of the pollutants [29]:

a) Water is even in small quantities, rusts steel and iron. Additionally, the water causes the formation of emulsions, or water sludge, which may block pump valves, other oil handling equipment, and oil passageways. Another factor in foaming issues is water.

b) Solid dirt, dust, grit, and metal pieces that the lubricant stirred up: These impurities result in excessive wear, scoring on the bearing surface, and sometimes even failure from metal fatigue seizing.

c) Sludge and lacquers: The deposits of sludge block tiny oil passageways and clearances. Varnishes and lacquers stick valves and prevent the oil pump from running continuously.

d) Liquid pollutants, such as engine exhaust residue and thin lubricating oils, may even lower their viscosity below a safe threshold. Heavy oil contaminants cause viscosity to rise and obstruct oil circulation. Heat transfer capability and the lubricating valve are impacted by this.

1.17 MANAGEMENT OF USED OIL

a) **Utilizing Oil Management is Required:** One of the biggest sources of pollution in the world is used oil, chiefly due to improper handling, high toxicity levels, and large amounts of production. Positive effects on the environment and economy will come from a well-organized waste oil management system.

- **Environmental Concerns:** Oil, in whatever form, has the ability to do damage to the surroundings. When oil residue settles on the bottom of aquatic habitats, it coats the substrate and any living things that may be there. Water covered with an oil layer may slow down photosynthesis by preventing light from penetrating the water. Reduced oxygen generation also results from decreased photosynthesis. The oxygen transfer from the air through the water's surface may also be impeded by the oil coating. Oil may quickly seep into the soil particles below the surface and cause issues for both macroscopic invertebrates and soil microorganisms. This oil may eventually find its way into a lake or other body of water, or even the water table.
- **Economic Impact**: By collecting and reusing spent motor oil, it can lessen the reliance on imported oil by saving energy. Refined old oil may provide 2-1/2 gallons of superior lubricating oil from a single gallon. However, to make the same

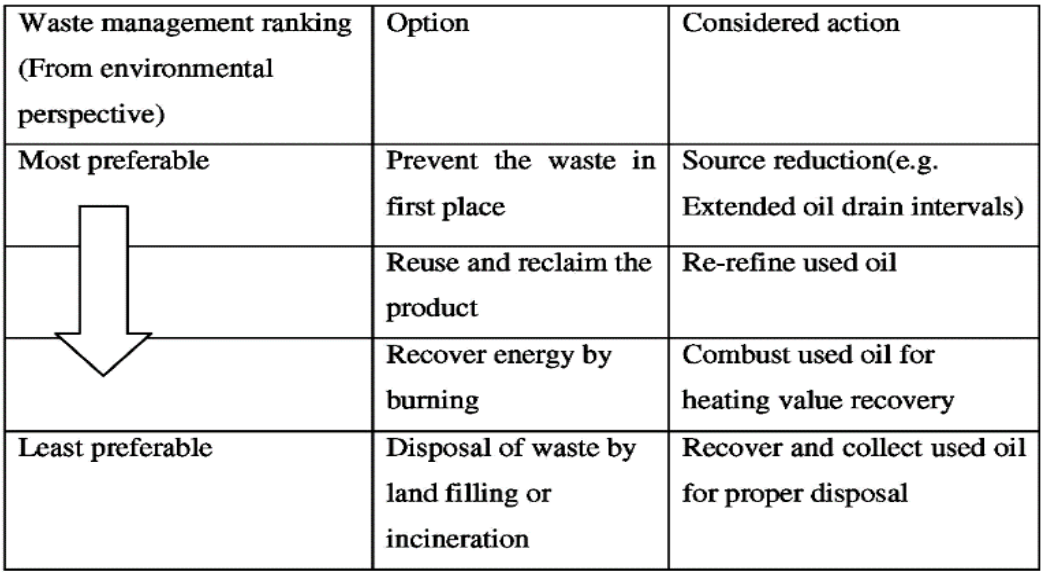
2-1/2-quart volume, 42 gallons of crude oil must be refined (even if the 42 gallons of crude are used to make many other goods).

- **Effects on Human Health:** When ingested, inhaled, or come into contact with the skin, pollutants in used oil may cause a wide range of ailments and diseases in humans and other species.

b) Used Oil Management Options:

To minimize the amount of waste oil produced, as indicated by Table 1.2, the first stage in the waste oil management hierarchy is to employ efficient engines and enhance lubricating oil quality. It is necessary to refine old oil again to make it suitable as a lubricant. Refining comes second among the options since it saves a substantial amount of foreign currency and is a green process. Re-refining is immensely beneficial because our country depends on imports of virgin lubricating oil [30].

Table 1.2 Showing the Hierarchy of Used Oil Management [30]



Waste management ranking (From environmental perspective)	Option	Considered action
Most preferable	Prevent the waste in first place	Source reduction(e.g. Extended oil drain intervals)
	Reuse and reclaim the product	Re-refine used oil
	Recover energy by burning	Combust used oil for heating value recovery
Least preferable	Disposal of waste by land filling or incineration	Recover and collect used oil for proper disposal

The third option is to reprocess the used oil to make it suitable for use as fuel. Usually, in order to remove sludge and suspended particles, used oils used for fuel must undergo treatments, including settling. By eliminating carbon, heavy metals, sludge, and suspended particles, this kind of straightforward treatment may significantly raise the material's quality. The collection and appropriate disposal of old oil are given the least priority.Utilized lubricating oil is now processed largely for sale as lubricating oil and utilized mostly for fuel purposes in Bangladesh. Since burning used oil as fuel releases dangerous air pollutants, it should be illegal to do so. The lubricating characteristics of mainly treated lubricating oil are only partly restored, and using this oil might cause engine malfunctions and reduce engine life [31].

1.18 SPECIFIC OBJECTIVES AND POSSIBLE OUTCOME

Specific Objectives:

1. To find out the causes of deterioration of Tribological properties for different lubricants.
2. Performing experiments and collecting the experimental data for analyzing & improving the Tribological behavior of used lubricants with different additives.
3. Cost analysis.

Possible Outcome:

1. Analyzing & regaining of lubricants properties to increase recycling lubricants that has a significant impact on both economical & environmental aspects.

1.19 DETERIORATION OF LUBRICATING OIL PROPERTIES

Lubricating oils degrade during use primarily owing to two factors: contamination and oxidation-induced physical and chemical changes [32]. Water, unburned gasoline, fuel combustion products, and airborne dust and wear products are frequent pollutants in engines. The primary reasons are oil degrades include.

Degradation: When oxygen molecules interact with oil molecules, oxidation takes place. This may result in a rise in viscosity as well as the formation of silt, sludge, and varnish. Depletion of the additives and a breakdown in the basic oil may also happen in certain situations. Increase the acid number as soon as the oil starts to oxidize. Additionally, the equipment may develop corrosion and rust.

Heat Disintegration: Temperature is one of a lubricant's primary issues. A lubricant's main job of separating the moving elements of an engine must be accompanied by heat dissipation. This indicates that the lubricant can be heated above the stable temperature that is advised. The chemical reaction is thought to double with every 10°C rise in temperature. Thus, the life of oil is reduced by 50% for every 10°C rise. When using the oil, try to keep it as cold as possible to prolong its life and lessen the likelihood of thermal breakdown.

Pressure-Sensitized Thermal Failure: When an air bubble travels from a low-pressure location to a high-pressure area within a system, pressure-induced thermal breakdown takes place. This is found in all lubrication industries, but hydraulic systems exhibit it the most prominently. Pressure-induced thermal decomposition causes the oil's air bubble to heat up, quickly frying and oxidizing the surrounding oil molecules.

Increased Depletion: Many additive packages are designed to serve specific functions and are used up over the oil's life. To assess the state of the lubricant and pinpoint the causes of the additives' depletion, oil analysis is essential for monitoring additive levels.

Pollution: Dirt, water, air, and other contaminants may have a significant impact on the rate of disintegration. Fine metal-filled dirt has the potential to act as a catalyst, igniting and accelerating the lubricant's deterioration process. Oxygen may be found in air and water, which combines with the oil to cause lubricant oxidation. Once again, oil analysis might be useful in keeping an eye on the amount of contaminants in your lubricant.

1.20 OUTLINE OF THE METHODOLOGY:

- Collecting reused lubricants & analyzing data through the preparation and other information.
- Applying experimental method.
- Developing the process for regaining of Tribological behavior of used lubricants.

Drawing conclusion and recommendation for the chemical laboratory & workshop.

The methodology of recycling lubricants & measuring performance system schematically shown in Figure 1.11.

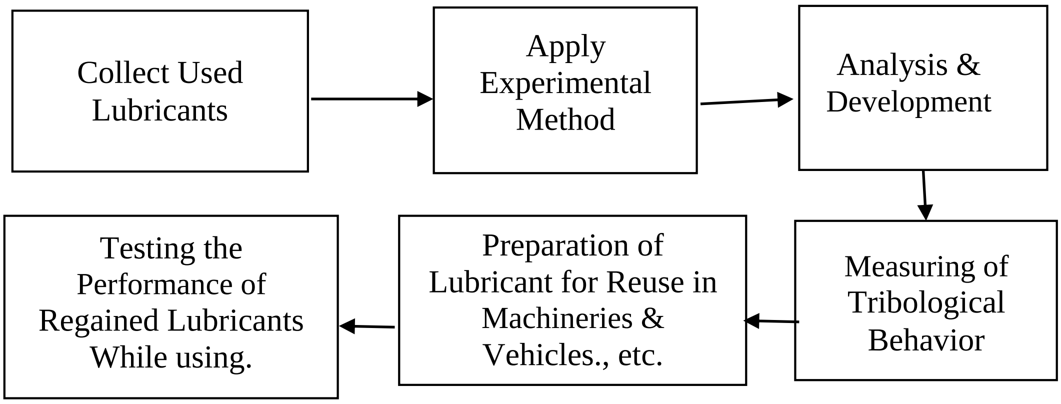


Figure 1.11 Recycling Lubricants - Preparation & Measuring System

CHAPTER II

LITERATURE REVIEW

A material with a high pollution level used in lubrication oil must be managed carefully. Improper disposal of waste lubricants into the ground or water streams, including sewers, can lead to environmental contamination. It will be advantageous to recycle those old lubricants and lower the cost of petroleum. The main uses of lubricating oil are to reduce friction between moving elements of different machinery or equipment, minimize material wear, and increase fuel and energy-efficient equipment efficiency. Furthermore, lubricants prevent corrosion, lower heat, and maintain machine cleanliness. Used engine, transmission, hydraulic, and cutting oils are called waste lubricating oil. After a few thousand kilometers or hours, oil changes or removals are necessary for cars and other machinery. The massive amount of waste lubricant oil significantly impacts economic and environmental factors. The release of hazardous metals and other pollutants into the environment by those lubricants, whether burned as low-grade fuel or released into the land, water, or air, could result in significant contamination. The best course of action is to recover the tribological characteristics of lubricants using non-toxic and affordable materials. Utilizing the most recent technological advancements, scientist Chongqing Fason has created a waste lubricant oil distillation factory. It can extract sulfur, base nitrogen, and metallic compounds from distilled oil during the refining process. Depending on the client's needs, the final product of distillation could be modified into golden diesel fuel or new base oil [33].To restore tribological behaviour, numerous studies on lubricants have been carried out.

Researchers in Nabil M. Abdel-Jabbar et al. (2010) [34] looked at the waste lubricating oil re-refining adsorption method using various adsorbent materials. Date palm kernel powder, acid-activated date palm kernel powder, egg shale powder, and oil adsorbent were among the adsorbent materials used. Investigations were conducted on adsorption over a fixed amount of adsorbent under ambient conditions. Waste oil was successfully adsorbed using natural adsorbents, including powdered date palm kernels, oil adsorbent, egg shale powder, and demulsifiers and stabilized condensate. The date palm kernel powder method of processing waste oil appears appealing.

Another team of researchers looked into the recycling and reuse of spent oil (S. Dhinesh and Kumer et al. 2017 [35]). However, the Ministry of Environment and Forests has designated spent oil as hazardous waste. The Indian government insists on its appropriate management to prevent significant environmental threats and to reap financial benefits. Virgin oil could be avoided by recovering or repurposing spent oil as base oil. After the old oil has been refined, its viscosity index and other characteristics are enhanced by adding appropriate additives. Cars require regular oil changes; spent oil can be recovered and recycled further. The economy and environment may benefit from the reuse of spent lubricants. It requires less energy to reprocess waste oil for fuel than to refine it again to produce base oil. Refined oil is made from used oil, using only one-third of the energy required to refine crude oil and make virgin base oil. As a result, re-refining is frequently seen as the best choice regarding resource conservation, waste reduction, and environmental harm reduction.

According to A. E. Elsayed et al. (2016) [36], this study examined the effects of two distinct solvent mixes on activated alumina as an adsorbent material to create lubricating oil: A (xylene+butanol+methanol) and B (xylene+butanol+isopropanol) followed by bleaching. In this study, spent oil was centrifuged at 1500 rpm for 30 minutes and then allowed to settle for an hour. The oil was filtered through a Buncher funnel using a vacuum pump to eliminate contaminants. The amount of sludge removed from the used oil is a crucial experimental measurement of the re-refining process. As the solvent-oil ratio rises, the pace at which sludge is removed also increases. In all situations this investigation looked at, the ideal solvent-oil ratio was discovered to be 3:1 at 70°C. Recycling old oil with two solvent combinations (A and B) enhances the base's physico-chemical characteristics. This has to do with getting rid of the contaminants' components.

According to Temitayo E. Oladimej et al. (2018) [37], it has been discovered that disposing of used lubricating oil (ULO) locally can pollute the air, land, and water. Because of the spread of diseases, pollution shortens people's lives. According to published research, treating used oil is among the simplest methods of preventing corrosion. In addition to reducing pollution, one key benefit is converting trash into money. An extensive review of the various techniques for handling spent lubricating oil was conducted for this research. While unavailable in poor nations, integrated technological methods are widely employed in industrialized countries. Although the processes used in these technologies produce less pollution, they still need expensive and complex equipment.

P.M. james et al. (2016) [38] explained the extremely toxic butane content is another experimental procedure in used motor oil. Reusing motor oil is necessary since the fossil fuels from which lubricating oil is produced are drying up. Several methods are utilized to refine spent lubricating oil and remove additives, fuels, water, and macro pollutants to reuse motor oil. This project involves several analyses, testing, and contaminants to ensure that the re-refined oil is fit for engine use.

On an experimental basis, used motor oil used oil gathered by NAFTAL and kept at the port of Algiers is analyzed and treated by F. Danane et al. (2014) [39]. It conducted experiments in the lab to create a suitable re-refining procedure for this. The outcomes of these analyses enabled us to distinguish between the several regeneration processes, which include pretreatment, chemical agent-assisted metal removal, and a final treatment that involves bentonite passage and filtration. The engine oil left over at the end of the procedure is an essential oil ready to be used again. This process has allowed us to remove most contaminants and optimize various parameters. As a result, repurposing or refining spent lubricants is essential to their future usage as a valuable energy source that reduces both environmental pollution and energy consumption. The results of the final examinations show that thanks to the suggested procedure's effectiveness, it produced finished engine oil with much-enhanced properties comparable to base oil.

However, spent oil waste produced by autos and other related businesses poses a risk to the environment (Naveed Anwar et al., 2012 [40]). The current study aimed to evaluate the benefits and drawbacks of the widely used acid/clay approach for recovering spent oil. Samples of waste oil were heavily polluted and tampered with water and soil. Only a few tests, such as those measuring copper strip corrosion, water content, sediments, and flash points, were carried out to comprehend the features of the waste oil product that is currently on the market, even though no standard criteria or parameters are available for comparison. Analysis results, however, showed a poor reflection. These findings demonstrated the need for enhanced processing techniques because the product is not environmentally friendly. More investigation is required to determine the effects of air pollution from burning or using recovered and waste oil on human health, particularly occupational health and safety. Lubricating oils are designed to keep machinery cleaner and perform better under demanding operating conditions. They are made with compounds called "Additives" and base oils (virgin oil). Next, hydrated sodium silicate is used to neutralize the acidic substance.

S. E. F. Hegazi et al. (2017) [41] discussed the recycling spent engine oil treated with acetic and formic acid. A recycling procedure was created, and in the end, the outcomes were on par with some of the traditional techniques. This means that recycled oil may be used again in automobile engines if the necessary additives are added. Using (acetic acid or formic acid) has the benefit of not reacting with base oils or reacting very minimally. Unlike sulfuric acid, which reacted strongly with the utilized oil, glacial acetic and formic acids, we had little interaction with base oils. This demonstrates unequivocally that the oil's natural structure is unaffected by acetic and formic acids. Moreover, recycling used oil is greatly benefited by the application of formic and acetic acids. This innovative method of recycling spent motor oil did not release harmful pollutants into the atmosphere, such as sulfur dioxide. Furthermore, compared to sulfuric acid, glacial acetic acid and formic acid do not negatively affect processing machinery as much. To move this method to the commercial stage, more study is needed. While several variables have been examined in this research, many more, including pressure, temperature, mixing, centrifugation speed, settling time, and adsorbent type, still require further research.

According to N. B. Selukar and S. M. Wagh et al. (2014) [42], waste lubricating oil occurs whenever lubricating oil is used for a specific purpose and is used in work. Since waste lubricating oil pollutes the atmosphere when it burns and harms living things, it should be collected and recycled to lessen its negative impact on the environment and subsurface and surface waters. Reusing old lubricating oil is wise for any nation, especially for India, since it will help protect our natural resources and foreign exchange. As an alternative energy source, mineral waste lubricating oil sources especially engine oils have garnered much interest.

Shri Kannan C. and others (2014) [43] discussed the many ash and toxins are released into the atmosphere while burning used oil in kilns and incinerators, polluting the environment. Refining used oil can reduce pollution and yield items with more excellent value. Refining spent lubricant minimizes the need for virgin base oil to produce new fat. Re-refining aims to eliminate deteriorated additives and impurities, restoring the oil's characteristics to meet SAE (Society of Automotive Engineers) guidelines. Many automotive components, including engines and gearboxes, are lubricated by lubricating grease. Lubricating oil's primary purposes are to lower friction and act as a medium for heat transfer. Additionally, it removes metal-worn parts and prevents corrosion. To repurpose it, the spent engine oil is gathered and purified. Vacuum distillation and solvent extraction are the steps in the treatment process. The use of additives increases the lubricating oil's efficiency. Fresh lubricant and refined lubricating oil have comparable properties. The following values were recorded in order: 910 kg/m^3, 0.910, 167 Cp, 51, 260°C, 323°C, -10°C, 70°C, 14°C, and 10.05 mg/g for density, specific gravity, viscosity, viscosity index, pour point, cloud point, fire point, aniline point, and TAN. These properties improved to 884 kg/m^3, 0.884, 266 Cp, 81, 276°C, 313°C, -22°C, 105°C, 11°C, and 0.53 mg/g after refining, in that sequence.

According to M. Yu et al. (2012) [44], given the high concentration of heavy metals, organic compounds, and persistent organic pollutants in used oil, the Chinese government should enact legislation and taxes to promote the development of used oil treatment and recycling. Other nations have assisted in recycling used oil by utilizing technology, public policy, and producer liability.

Lubricant Condition Monitoring (LCM), according to J. M. Wakiru et al. (2018) [45], is a crucial condition monitoring method since lubricant testing provides a wealth of information. This study examines current research directions and the evolution of LCM-based maintenance decision support techniques, focusing on their use in equipment prognosis and diagnostics. It also looks at methods that can be used to extract knowledge from LCM data to support maintenance decision-making, as well as the technical and functional elements of lubrication—a brief discussion of potential LCM future trends in the context of maintenance decision-making rounds off the study.

Lubricating oils are viscous liquids that are used to lubricate moving components in engines and other machinery, according to J. D. Udonne (2011) [46]. The main goal of this research project is the comparative analysis of four techniques for recycling spent lubricating oils- distillery and clay, acid treatment and clay, and activated charcoal and clay. In contrast to 92.8 cs for fresh lube oil, test findings indicated that viscosity increased from 25.5 to 86.2 for distillation and 89.5 for activated/clay treatments. The acid therapy produced the best outcomes, while other data showed varying degrees of improvement.

In V. Kapustina et al. (2014) [47], the primary system components and their interconnections are identified as Finland's waste oil management system and are examined through systems thinking. The findings demonstrate improved performance, with the rate of waste oil collection rising by 30% and the treatment and recovery system's environmental performance rising by 70% during the previous six years. Analyses of comparable systems can be made using this format.

M. Rahman et al. (2008) [48] studied contrasts various waste oil end uses and creates a method for recovering the fundamental characteristics of the base oil. To recover waste oil gathered from multiple sources, a pilot scale setup of the standard acid-clay approach was developed, and experimental runs were carried out to modify the process variables. This empirical investigation indicated that 62 and 66 per cent of the recovered base oil was recovered.

According to Boughton et al. (2004) [49], there are three main approaches to managing the 1 billion gallons of wasted oil produced annually in the US: it can be repurposed as base oil, either sold as raw fuel oil or refined into marine diesel fuel. The environmental benefits and impacts of each management choice in a product end-of-life scenario are quantified and analyzed in this article using the life-cycle assessment (LCA) methodology. The results showed that heavy metals-related toxicity comes out on top when management techniques are compared. For example, burning spent oil for fuel has 150 times higher potential effects on human and terrestrial toxicity than recycling or distillation. Poor markets and low profitability should not influence the selection of the employed oil management system to proceed with the market for untreated fuel oil.

J. Zhu et al. (2012) [50], this research thoroughly analyses the features of the current lubricating oil condition monitoring solutions. The methods are examined and divided into four groups: optical, chemical, physical, and electrical (magnetic). A collection of essential attributes for oil health monitoring, diagnostics, and prognostics are used to evaluate each solution's characteristics and sensing technique. A comparative analysis is carried out involving numerous distinct solutions.

J. George and associates (2017) [51] active lubricant condition monitoring is an excellent predictive technology that can lower maintenance costs and increase system reliability for mechanical systems. It entails utilizing software to collect and process data, integrating a microcontroller for wireless communication, and analyzing oil degradation parameters. Alternative actuation systems might be implemented to minimize system component damage or maintenance.

J. Artif and associates (2019) [52], this study examined the most recent laws, announcements, rules, guidelines, and specifications about lubricants used in Bangladesh's oil industry. It reported on the base oil recovery process from waste lubricants and its management system to identify opportunities to introduce adulterated and substandard lubricating oils into the local market. In Bangladesh, lubricating oil adulteration is widespread and damages engine longevity. Controlling adulterations requires rules for law enforcement and sanctions. The infrared spectrum test is more reliable in identifying contaminated lubricating oil than other tests. Hazardous waste is being disposed of unscientific across the nation due to a lack of regulatory oversight, which puts the environment and human health in significant danger.

The science and technology of interacting surfaces in relative motion and related fields and activities is known as tribology (S. Mia et al., 2017 [53]). Tribological research has been conducted in Bangladesh regarding industrial applications and gear mechanisms, bearings, conveyors, roller mechanisms, and workshop machinery. The maintenance departments within their respective industries often perform daily, weekly, monthly, or as-needed machine maintenance. Although mineral oils and greases are commonly used as lubricants, severe pressure lubricating oil is crucial. To increase the functionality and lifespan of Bangladeshi machinery, industry application and research cooperation are required.

Waste lubricating oil is a resource that cannot be disposed of carelessly since it contains contaminants, according to M. Falconer et al. (1986) [54]. It is tainted with various additions and contaminated with residues and pollutants from the burning process. Pollution of the environment is caused by the incorrect generation and disposal of spent lubricating oils, which come from various sources. Refining is required to remove pollutants and deteriorated additives, bringing the oil's qualities back up to SAE requirements so that waste lubricants can be recovered and used again.

According to S. Baskar et al. (2014) [55], three lubricating oils were used in a pin-on-disc wear tester to examine journal-bearing material's wear and friction behaviour. A maximum load of 200 N and sliding speeds ranging from 2 to 10 m/s were used for wear tests. The findings demonstrated that the journal-bearing material varied based on the lubricating oils and sliding conditions, with SAE 20W40 and CMRO showing more significant wear and CMRO having a lower friction coefficient. SEM was used to evaluate worn surfaces, and wear mechanisms was covered.

Waste lubricating oil is a resource that cannot be disposed of carelessly since it contains contaminants, according to M. Diphare et al. (2013) [56]. Reusing and regenerating waste lubricants through recovery methods like burning, reprocessing, and re-refining is becoming increasingly popular. This research compares and analyses regenerative technologies to lay the groundwork for policy creation and recovery technique selection.

Three brand-new phosphorus-free triazine derivatives, ZOO, ZOS, and ZDION, were created and tested for their capacity to suppress corrosion, their ability to withstand heat, and their tribological behaviour in rapeseed oil by X. Zeng et al. (2006) [57]. While ZOS has the best extreme pressure, antiwear, and friction-reducing properties, ZDION shows poor antiwear performance. The synthetic additives enhance the tribological behaviour of the base stock containing them in the rubbing process because of their capacity to adsorb and react with the steel surfaces. This protective film comprises iron oxide, sulfate, sulfide, and organic compounds containing N and O.

X. Zeng and other associates (2004)[58] developed ashless, non-phosphorus, oil-soluble substance made of sodium octyl mercaptan and cyanuric chloride in tetrahydrofuran. An EP wear test machine and a four-ball wear tester assessed its tribological characteristics. The results demonstrated that while OT shows more extreme pressure properties, OTT performs better than OT as an anti-wear and friction-reducing additive.

C. R. Yang et al. (1999) [59] report that dynamic friction and wear behaviour are investigated in a reciprocating friction drive system using a 0.45% carbon steel pair. The results show that the lubricant shearing-induced fluid friction during the first slip period dominates the traction force variation and produces a positive slope g. The wear is most significant in the transition zone. However, because of the Hertzian contact action, the wear is only caused at a more significant average load and is indifferent to the friction zones. The stick time has no bearing on the static friction force.

E. Vidović et al. (2014) [60] revealed the government rules and modifications to lubricant composition and qualities are causing significant changes in the lubricant business. This study categorized the most common rubber varieties used in seals and how they react to mineral base, aliphatic, aromatic, and chlorinated hydrocarbon compounds. Comparing seven different elastomer kinds demonstrated how esters and additives affect how seals swell. It was discovered that adding ester results in improvement while adding swelling additives significantly affects the swelling/shrinking of group III base oils, with the final impact roughly matching that of group I oils.

The friction testing of elastomers in lubricated contact by S. Verma et al. (2012) [61] is examined, covering practical matters like contact mechanics, material response to loading, contact edges, oil absorption, cleaning, and specimen geometry. According to the findings, using mineral oil or synthetic ester yields comparable outcomes.

R. I. Taylor et al. (2000) [62] shows that the research explores the distinctions between fuel economy oils for heavy-duty diesel engines and passenger car engines and how using fuel economy lubricants can minimize friction and improve fuel efficiency. It also incorporates realistic losses owing to air and tire rolling resistance to forecast the benefits of fuel consumption under various speed and load conditions.

The jerky motion referred to as "stick-slip" was researched by J. B. Sampson et al. (1943) [63] using the stick-slip equipment constructed in this lab. Different combinations of unlubricated metals have had their motion during the slip compared. Several common scenarios have had the friction change with velocity determined. Assuming that the kinetic friction is roughly constant, most slip traces are symmetrical about their inflection point. Nonetheless, there is proof that the variance returns to its higher static value when the sliding surfaces come to rest. Several theories of conflict are examined in these data.

The effects of oil contaminants such as diesel and soot on the properties and tribological behavior of oils in the boundary lubrication regime in VDVP will be investigated in this work by F. M. Salehi et al. (2016) [64]. This has been accomplished by evaluating the tribological performance of various oils using ball-on-disc and pin-on-plate test rigs. This study employed a range of surface analysis methodologies to comprehend the impact of every impurity on the wear and friction behavior of contacts. Carbon black

(CB), sometimes called soot substitute, causes pollution and increases component wear. Wear is increased by the antagonistic interactions between ZDDP and other additives based on phosphorus, sulfur and CB. Moreover, this study demonstrated how ageing and diesel pollution can change an oil's overall characteristics and, in some situations, lessen wear and friction.

A. A. Polycarpou et al. (1996) [65] designed a two-component, two-dimensional friction model for a lubricated line contact. It comprises the following: average load, sliding velocity, fluid properties standard to sliding direction, and instantaneous separation of the sliding bodies. The model was derived from unstable friction experiments with time-varying sliding rates and constant normal loads. It applies to quasi-steady, unstable, continuous, and intermittent sliding and records the instantaneous fluid shear and solid friction components.

The examination of new engine oils using engine testing is covered by Y. Nakamura et al. (2015) [66] to determine whether they impact engine fuel efficiency. The primary technologies used are additive technologies, which, depending on the lubrication condition of the valve train, pistons, cylinders, and bearings, offer the optimal settings for the viscosity modifier, friction modifier, and HTHS viscosity. Engine tests were utilized to evaluate the impact of the increased fuel efficiency after rig testing confirmed the friction modifier's capacity to reduce friction. This study is expected to further the use of mineral oil-based 5W-30 engine oil in heavy-duty diesel engines.

M. Mofidi and associates (2011) [67] explained the elastomeric seals may fail due to abrasion from sliding against rough surfaces. This study examined the two body abrasive wear of sealing elastomers in lubricated and dry conditions. The results showed that depending on the material, oil, abrasive size, average load, and test duration, abrasive wear may increase or decrease in the presence of lubricants. Lubrication has a more significant effect on increased abrasive wear when utilizing fine abrasives.

In this study, E. Matas et al. (2015) [68] investigate the effects of three distinct additive types' concentration levels and chemical compositions on wear coefficient and friction for mineral base oils and synthetic ester base fluids. The study employed a factorial experimental design to assess wear rates in mixed and boundary lubrication scenarios. It was discovered that the extreme-pressure (EP) additive outperformed both of the evaluated antiwear (AW) additives regarding wear reduction. The reference mineral oil blend was the only one where a synergistic impact between the three addition combinations was noticed. According to this study, the conventional "AW" and "EP" labels on widely used additives are not very helpful for creating lubricants based on the ester.

The ECE R49 test cycle, a 12-litre normally aspirated Euro I representative engine, and ultra-low sculpture gasoline were used in the Jefferd et al. (1983) [69] study. The findings demonstrated a substantial difference in the legally required emissions depending on the lubricant formulation. Compared to SAE 10W-40, a premium part-synthetic heavy-duty diesel engine oil, two fully synthetic brands with superior performance requirements produced higher particulate matter by over 20%.

As reported by Z. He et al. (2002) [70], Nitrogen-containing heterocyclic compounds are utilized more frequently because of their superior thermal stabilities, anti-oxidant, anti-corrosion, and anti-wear qualities. They are also considered innovative, potentially excellent, multifunctional, ash-free lubricating oil additives. This work offers insightful and representative results on the molecular structures and tribological characteristics, the impact of various active ingredients, and their mechanism, all of which will aid their development.

According to C. Gao's (1995) [71] dynamical analysis for a pin-on-disk sliding system and the consideration of meniscus formation at the sliding interface, stick-slip motion occurs when the initial growth rate of the static friction force is more excellent than half the product of the substrate speed and the spring constant. Furthermore, an inverse relationship is shown between the saturation substrate speed and the entire growth time of the dynamic friction force. An increase in the thickness of the surface liquid layer results in a bigger slip-slip amplitude, a more robust mechanical speed, and a more substantial saturation speed. It also causes an increase in the initial growth rule and the ultimate static friction force.

The study conducted by Comfort (2003) [72] investigates the origins and effects of friction in heavy-duty diesel engines. Another objective is to examine each component system from the perspective of fundamental mechanics. Using a Stribeck diagram, several lubricated friction regimes will be demonstrated, emphasizing loading and relative velocities. The study's second part will examine the impact of lubricant on the friction of specific engine components and provide data obtained with oils that meet military and commercial requirements.

According to J. Booth (2008) [73], international regulations mandate lubricant formulators to create additive packages that minimize wear across service intervals, boost fuel efficiency, and lessen environmental effects. This thesis investigated the potential of electrostatic charge monitoring, which is responsive to surface chemistry variations, to provide information about additive-surface behavior and its relationship to tribological performance. Tribological test equipment was equipped with electrostatic sensors to replicate the tribo-contacts of the engine valve-train, manual transmission synchronizer, and automatic transmission clutch. Distinct oils produced distinct charge signals, suggesting that lubricant chemistry significantly impacted charge creation. X-ray photoelectron spectroscopy (XPS) analysis and friction data showed that the dispersant dominated the tribofilm composition when friction modifier (FM) and dispersant additives were used to lubricate a simulated wet clutch contact. The fight for surface sites is a highly dynamic process, as demonstrated by the electrostatic charge data, which cycled between the levels of the FM and dispersant alone. Examining additive-surface charge behaviors led to more interesting tribological findings. The influence of surface chemistry on film formation was determined by XPS of steel and brass simulated synchronizer contacts lubricated with polysulfide and potassium borate. The same film composition and structure were obtained by seeding the borate additive into the oil and, consequently, the connection instead of starting with a mixture. The kind of additive-surface adsorption and interactions between additives and contaminants can be detected by electrostatic monitoring. Electrostatic sensors can detect tribofilm kinematics; however, no real-time method currently employs this technique. Long-term lubricant development may shift toward formulation that is charge-informed.

The introduction of a 5W-30 oil as the initial and service fill for Ford products in Europe was prompted by the low viscosity friction of modified oils, as reported by J. Bennett et al. (2000) [74], showing promise in lowering internal engine friction and enhancing fuel efficiency. Using five 5W-20 candidate oils and evaluating their fuel efficiency and emissions benefits, a pilot study was conducted to analyze the possible advantages and problems of switching to 5W-20 in diesel engines. A chassis dynamometer was used to test the most promising car options to verify any changes in regulated emissions and calculate the net fuel economy advantage. A reciprocating rig was also used to evaluate the candidates' friction coefficient to forecast the fuel efficiency increase. There may be a benefit to reducing fuel consumption and CO2 emissions; however, the cost benefits of using a low-viscosity oil would have to be weighed against the fuel economy gain.

This scientific work by W. Balasooriya et al. (2018) [75] aims to investigate the effects of swelling-induced ageing on the surface damage mechanisms and tribological properties of hydrogenated nitrile butadiene rubber (HNBR) in contact with different liquids. The HNBR had less surface temperature and coefficient of friction (COF) when swelled with a standard IRM 903 solvent, but it had more wear than the unswollen specimen, according to the results. The bulk mechanical characteristics nearly recovered under de-swollen conditions, but the surface properties were still severely compromised.

S. D. Publishing and T. Agargaon (2009) [76] Modern science has made The development of numerous electronic intelligence systems possible. These systems are developed using FLC (Fuzzy Logic Controller). The washing time of an innovative washing machine has been determined using two inputs and one output. A mathematical comparison of the defuzzification approaches' performances has been conducted using MATLAB.

Yan Bin Sun and associates (2022) (77) Five friction couples are evaluated using an SRV tester at room temperature for friction and wear behaviour. The friction couples are silicone oil 114(114SO), a linear perfluoroalkyl polyether Z-25, polyalphaolefin (PAO), and multiply alkylated cyclopentane (MAC). The test results show that MAC exhibits superior anti-wear and friction reduction properties than the other three liquid lubricants when GCr15 steel friction couple materials are lubricated at lower loads than Si3N4 and GCr15 stainless steel friction couple materials.

According to S. K. Sharma (2023) [78], this work focuses on the tribological behavior of bioinspired materials and surfaces, which can lower greenhouse gas emissions and energy waste. The notable reduction aided the creation of anti-wear and anti-adhesion characters in noise, friction, and drag from imitating bio-inspired characters. Studies demonstrating the improvement in the frictional characteristics were also included.

Vegetable oils have significant potential as ecologically friendly lubricants due to their exceptional lubricity, biodegradability, good viscosity-temperature characteristics, and reduced evaporation loss, as discussed by B. K. Sharma and companions (2007) [79]. However, their poor cold-flow behavior and limited thermo-oxidative stability limit their application. This research offers a systematic way to enhance their oxidation behavior by identifying an appropriate combination of additives. Using a rotary bomb oxidation test (RBOT) and pressure differential scanning calorimetry (PDSC), the synergism between antioxidants and antiwear additives was examined on four antioxidants and three antiwear additives in vegetable oils. Based on the results, the dialkyl dithiocarbamate antioxidant outperformed diphenylamine and inhibited phenol.

N. A. Raof and associates (2022) [80] satisfied the needs of modern machinery that must adhere to strict international standards, biodegradable lubricants made of renewable feedstocks, such as trimethylolpropane ester (TMPE), have been created. This analysis concentrates on creating plant-based TMPE formulations for various uses, such as hydraulic and heat transfer fluids, drilling fluid, insulating fluid, food-grade lubricant, and motor oil. Nevertheless, they face difficulties such as low capacity to support a load, hygroscopic characteristics, and a significant potential for harmful emissions.

Y. M. V. Markine and associates (2017) [81] explained that the finite element (FE) model with real wheel-rail profiles can be checked against the CONTACT model by comparing the slip-adhesion area, shear stress, and other results obtained by the two models. The confirmed FE model is used to perform a series of simulations that simulate the effects of various operational patterns (e.g., varying friction, traction, etc.) on the surface and subsurface tribological responses of wheel-rail interaction. Most explicit FE simulation results are consistent with CONTACT results; nevertheless, an increase in traction and friction might cause stress concentrations from below the surface to rise to the surface.

The "weeping" lubrication mechanism of articular cartilage serves as an inspiration for the engineering, production, and application of low-friction polymer surfaces, as explored in T. Khosla et al. (2016) [82]. Two new approaches to decrease friction in aqueous environments are investigated based on surface texturing and microspheres. Low friction is achieved by shifting the lubrication process to the hydrodynamic/mixed domain when fluid is between two shearing surfaces. These surfaces' tribological characteristics are investigated under various applied loads and shear velocities. Conventional boundary lubricants may offer a novel way to achieve previously unheard-of low friction when paired with an optimum surface texture. This thesis provides a preliminary demonstration of the concept for coating total joint replacement implants that could lower friction in an aqueous solution by employing surface texturing of soft polymers and microspheres. Subsequent investigations aim to ascertain how magnetic field intensity, particle concentration, and size affect magnetic iron-core HCS efficacy.

The study carried out by Tiago Cousseau (2013) [83] looked into the operation of grease-lubricated rolling contacts as well as the effect of grease composition on rolling bearing performance, especially in the early stages of grease life. It includes measuring the friction torque of rolling bearings, analyzing how operating conditions affect film thickness and traction behaviour, and researching the mechanisms that lubricate grease throughout its life. There is a strong correlation between grease performance and grease characteristics. It also includes a brief analysis of degraded fats to help readers better understand how grease works in its later stages of life.

CHAPTER III

MATERIALS AND METHODOLOGY

3.1 INTRODUCTION

The main objective of this project work is to distinguish the physical and chemical properties of fresh lubrication lubricants from discarded used oil. Design and build the suggested system using the distillation method compared to the current system. They are using new lubrication oils for machinery results from testing, analyzing, and monitoring outcomes for different states.

Details of the components and experimental analysis of waste lubricating oil refining. Various waste lubricating oil kinds were utilized in this instance. Lubricating oil waste was placed in the system storage. External heaters constructed of nickel wire were used to heat the system storage. The dehydration process lowered the amount of water in the oil by heating the waste lubricating oil. Fewer gasses can be heated to make fuel.

Diesel is stripped using heat and a small amount of gas to make fuel. A liquid bitumen extender follows heating to complete the lube oil distillation and condensation process. The next step is to blend the new raw base oils in vapor and liquid form using MEK. After appropriate filtration, this is sent to a laboratory to analyze the known oil condition. Fresh oils are made from used lubricating oil used in industrial machinery or automobile engines to guarantee proper raw base oils from the system, adding necessary additives and again forwarding to the laboratory for recognized soil conditions [84].

3.2 REQUIRED MATERIALS AND EQUIPMENTS

Waste Lubricating Oil:

Both Fresh and Waste lubricating oils, Six sample -two from each items used & fresh were collected from M/S. Eastern Trade Syndicate in Chittagong, Bangladesh. As ref. Figure 3.1 those samples are heavy duty mono grade engine oil SAE 40, hydraulic oil ISO VG and gear oil ISO VG 150.

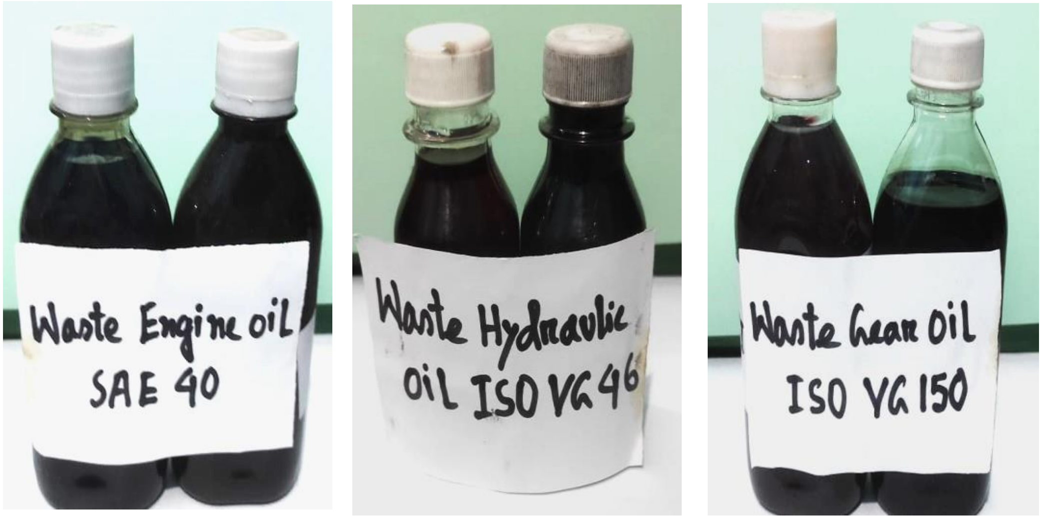


Figure 3.1 Sample of Waste lubricating Engine Oil SAE 40, Hydraulic Oil ISO VG 46 and Gear Oil ISO VG 150.

Storage:

A storage can have straight or slanted sides and usually has a handle or bail as ref. Figure 3.2, its local meaning is identical to bucket. With a capacity of 20 L and made of Plastics.

Figure 3.2 Storage as a Pail of Plastic Container.

Electric Burner:

As ref. Figure 3.3 ,Walton Crystal Glass 9-Stage 2100 Watt Electric Burner WIS30 induction burner has strong power 2100 watt, suitable for all heating methods with 9 stage power settings super heat resistant, with a grade black crystal glass plate, overload and timer function, interior high temperature protection, waterproof preset and child lock function.

Figure 3.3 Walton Crystal Glass 9-Stage 2100 Watt Electric Burner WIS30

Methyl Ethyl Ketone (MEK) reagent

The chemical formula for methyl ethyl ketone (MEK) is CH3C(O)CH2CH3. This white liquid ketone smells harsh and sweet, like acetone and butterscotch. It is widely manufactured industrially and found in trace amounts in the natural world. It is frequently used as an industrial solvent and is soluble in water. 2-Butanol can be oxidized to create MEK. Copper, zinc, or bronze catalyze the dehydrogenation of 2-butanol as follows: CH3CH(OH)CH2CH3 → CH3C(O)CH2CH3 + H2.

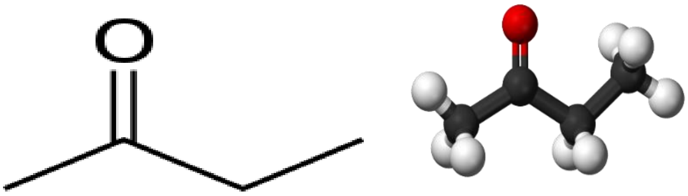


Figure 3.4 Methyl Ethyl Ketone (MEK) bonding structure.

Figure 3.5 Methyl Ethyl Ketone (MEK)

MEK is a popular and efficient solvent that is used in processes with vinyl films, gums, resins, cellulose acetate, and nitrocellulose coatings. Because of this, it is used in producing textiles, plastics, paraffin wax, and home goods, including paint remover, lacquer, varnishes, glues, and denaturing agents for denatured alcohol. It is also used as a cleaning agent. MEK is marketed as "model cement" and is used to join the components of scale model kits since it dissolves polystyrene and many other plastics. In this instance, it's acting as a welding agent even though it's frequently considered an adhesive [85].

MEK can react and start flames with most oxidizing compounds. It is somewhat explosive; all it takes for a solid reaction to occur is a tiny flame or spark. Foam resistant to alcohol, dry agents, or carbon dioxide should be used to put out MEK flames. Humans cannot tolerate concentrations in the air that are high enough to catch fire because of the vapor's unpleasant properties.

Waste Lubricating Oil Filter:

This filter element reduces the likelihood of expensive engine repairs by capturing impurities in the oil. It's a well-known fact that dirty oil can cause severe damage to the engine. This oil filter element is specially designed and manufactured to make your Hastings oil filter operate at its peak again and minimize the possibility of costly downtime and repairs by removing damaging contaminants from the oil. Some particles adhere to the filter media as the oil flows through the reference Figure 3.6 [86].

Figure 3.6 Hastings Waste Oil Filter [86]

While some particles become stuck in the filter media due to the pressure of the oil as it passes through the filter, other particles adhere themselves to the media surface without clogging the media pores. Hastings products, on the other hand, excel in both areas, meaning you obtain optimal oil filtration even during extended oil change intervals, while some oil filters trade filtration efficiency for dirt-holding capacity and vice versa. Where applicable, the nitrile gasket will withstand high temperatures and provide a consistent seal that prevents leaks. To ensure this oil filter element meets OE specifications, the manufacturer tested it according to SAE HS806 test procedures that are the industry standard for lube filtration.

Specifications of Waste Lubricating Oil Filter:

Brand	: Hastings
Part Number	: LF328
UPC	: 768370025053
Filter Type	: Full-Flow
Inner Diameter (in)	: 1.59"
Inner Diameter (mm)	: 40.5 mm
Length (in)	: 5.5625"
Length (mm)	: 141.3 mm
Outside Diameter (in)	: 3.9375"
Outside Diameter (mm)	: 100.0 mm

Additives:

HiTEC 8744X Heavy Duty Engine Oil Additives:

To meet the demands of today's heavy-duty diesel fleets, HiTEC 8744X was created. It offers the following advantages to customers: API CH-4 solution with cost optimization in Group II base stocks superior performance in critical areas such as wear resistance and field-proven technology over 40,000 kilometers in harsh situations [87].

Technical Data of HiTEC 8744X Heavy Duty Engine Oil Additives:

Appearance	: Dark brown viscous liquid.
Specific Gravity at 15.6/15.6°C	: 0.985
Flash Point, °C (PMCC)	: 135 min
TBN, mg KOH/g	: 89
Viscosity at 100°C, cSt	: 140

HIPER 1500 Hydraulic Oil Additive:

In addition to having excellent oxidation stability, Hiper 1500 is an ash less additive package made explicitly for R&O oil hydraulic fluids. It also has improved air release properties, resistance to oxidation, anti-foam characteristics, extended anti-rust performance, increased extreme pressure, excellent anti-wear performance, improved filtration, and corrosion inhibition properties. Additionally, the product's demulsibility is excellent. At room temperature, the maximum handling temperature is 75°C, and the shelf life is 24 months.

Technical Data of HIPER 1500 Hydraulic Oil Additive:

Appearance : Light brown, clear, low viscosity liquid.

Nitrogen : 0.8 to 1.0%

Viscosity @ 40 ºC Approx. : 70 cSt

Density @ 29.5 ºC Approx. : 0.920 mg KOH /gm

Flash Point, COC :> 140 ºC

HiTEC 317 Industrial Gear Oil Additive:

In addition to having excellent oxidation stability, Hiper 1500 is an ash less additive package made explicitly for R&O oils hydraulic fluids. It also has improved air release properties, resistance to oxidation, anti-foam characteristics, extended anti-rust performance, increased extreme pressure, excellent anti-wear performance, improved filtration, and corrosion inhibition properties. Additionally, the product's demulsibility is excellent. At room temperature, the maximum handling temperature is 75°C, and the shelf life is 24 months.

Technical Data of HiTEC 317 Industrial Gear Oil Additive:

Appearance : Clear amber liquid.

Density @ 15ºC, g/ml : 1.025

Specific Gravity at 15.6/15.6°C : 1.027

Flash Point, °C (PMCC) : 82 min

Kinematic Viscosity at 100ºC, mm^2/s: 15

Laboratory Glass Test Tubes

Standard laboratory glassware components include test tubes made of finger-length glass tubing closed at the bottom and open at the top.

Figure 3.7 Laboratory Glass Test Tubes

Sample Collection:

Waste lubricating oil was used for refining in this research work. Waste lubricating oil of different types, Heavy-duty diesel engine oil SAE 40, Industrial hydraulic oil ISO VG 46, and Industrial gear oil ISO VG 150 were collected from the Eastern trade syndicate, Chittagong, Bangladesh. Each type was collected about 20 ltr. An electric burner and vacuum distillation heated those samples.

Figure 3.8 Sample of Engine Oil SAE 40, Hydraulic Oil VG 46 & Gear Oil ISO VG 150.

3.3 EXPERIMENTAL PROCEDURE

Lubricating oil was treated for contaminants after waste was collected. Because hydrogen breakdown compounds in engine oils reduce the viscosity of engine oil and water compounds in engine oils render the combustion process ineligible and reduce the power of a combustion stroke, the process is carried out to remove these compounds from engine oils.

The motor oil is heated to 1200°C in a glass beaker; at this point, the water molecules burn off as vapour, and the oil turns into a light clay-like muck. This is the primary step in the engine oil refining process, which involves various distillation techniques. We are refining the spent engine oil using vacuum distillation. The vacuum distillation plant is then continually fed with dehydrated oil, precisely like the fractions that occur during the distillation of crude oil. Engine solvent is distilled into several fractions under light fuel and diesel. The process begins at the first boiling point of 202°C and reaches its maximum heating value at 470°C. About 15% of the spent engine oil will be converted to gasoline. 10% of bitumen carbon wears metal aromatic compounds, and 75% of engine oil will be produced from the bulk residue of engine oil, given the used engine oil. Using the filtering procedure during the refining phase, the engine oil's original colour is restored, and macro particles are eliminated. Many additives improve the engine oil's viscosity, flash, and pour points. To give the engine oil a consistent physical quality, MEK is the addition of choice. 8% of the additive is added to the 92% engine oil to increase the rate.

3.4 DESCRIPTION OF RELATED TEST METHOD

ASTM D 445

This test method determines the kinematic viscosity of liquid petroleum products, both transparent and opaque, by measuring the amount of time it takes for a volume of liquid to flow under gravity using a calibrated glass capillary viscometer. The dynamic thickness can be calculated by multiplying the measured kinematic viscosity by the density of the liquid. Applying this test method to beverages where shear rates and shear stress are proportional is its primary goal. A fixed volume of fluid must take a certain amount of time, measured in seconds, to flow under gravity through the capillary of a viscometer that has been calibrated, heated to a precisely controlled temperature, and powered by a repeatable head. This test method also measures the fuel oil's kinematic viscosity and non-Newtonian characteristics. The recorded flow time multiplied by the viscometer's calibration constant yields the kinematic viscosity [88].

Test Method	Equivalent Test Method	Test Purpose
ASTM D 445	IP 71-1, SO 3104,DIN 51562, JIS 2283 and AFNOR T60-100	Kinematic Viscosity of transparent and opaque liquids

ASTM D 2896

Achieving better outcomes with some substances, such as nitrogenous polymeric compounds and very over-based oil additives, is possible. Acidic and base salts (soaps), essential salts of polyacidic bases, organic and amino compounds, inorganic bases, and salts of heavy metals are among the components that can be regarded as having basic properties. Used and new oils can both be tested using this procedure. A mixture of glacial acetic acid and chlorobenzene dissolves the sample. Then, a potentiometric titrimeter is used to titrate the mix using a per chloric acid solution in glacial acetic acid. It uses a calomel reference electrode coupled to the sample solution through a salt bridge and a glass indicating electrode. An inflexion in the resulting curve represents the endpoint, which is determined by plotting the meter readings against the corresponding volumes of titrating solution. Sodium acetate titrant is utilized in a back titration modification when specifically used oils fail to exhibit any inflexion in the standard titration.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 2896	IP 276, ISO 3771 and JIS K 2501	Base number potentiometric per chloric acid titration

ASTM D 95

The sample is heated under reflux with a water-immiscible solvent, which co-distills with the water in the model. Condensed solvent and water are continuously separated in a trap, the water settling in the graduated section of the web and the solvent returning to the still.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 95	IP 74, ISO 3733,DIN 51582, JIS K 2275, and AFNOR T60-113	Water in petroleum products by distillation method

ASTM D 92

All petroleum products' fire points and flash, except fuel oils and those with an open cup flash below 175°F (79°C), are determined using this test procedure. An exact level of sample is added to the test cup. Upon approaching the flash point, temperature rises steadily and slowly. A tiny test flame is shined across the cup at predetermined intervals. The flash point of a substance is defined as the lowest temperature at which vapours above its surface ignite. The test is resumed once the test flame is applied, and the oil ignites to burns for at least five seconds. It's known as the fire point temperature.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 92	IP 36, ISO 2592, DIN51376, JIS K 2265, and AFNOR T60-118	Flash point by Cleveland open cup

ASTM D 2270

The widely used and widely acknowledged viscosity index is used to assess the variation in kinematic viscosity induced by temperature changes in petroleum products between 100 and 40°C. An arbitrary number known as the viscosity index is used to calculate the temperature-dependent variation in a petroleum product's kinematic viscosity. The influence of temperature on the kinematic viscosity of oils with similar viscosities decreases with increasing viscosity index. Based on their kinematic viscosities at 40 and 100°C, this article describes how to calculate the viscosity index of petroleum-based materials and products, such as lubricating lubricants [89].

Test Method	Equivalent Test Method	Test Purpose
ASTM D 2270	IP 226, ISO 2909 and AFNOR T60-136	Viscosity index

ASTM D 97

Its pour point indicates the lowest temperature at which petroleum oil is helpful for some uses. The pour point is typically lower than the cloud point (Test Method D 2550). Following initial heating, the sample is cooled at a predetermined rate, and its flow properties are checked every three degrees Celsius. The pour point is the lowest temperature at which oil movement is noticed.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 97	IP 15, ISO 3016,DIN 51597, JIS K 2269, and AFNOR T60-105	Pour point

ASTM D 6304

This test method uses an automated device to directly determine the amount of water in the entrained petroleum products and hydrocarbons within the range of 10 to 25 000 mg/kg. Additives, base and automatic gearbox fluids, lubricating oils, hydrocarbon solvents, and other petroleum products can all be tested using this methodology. This test method can determine the water concentration from mg/kg to per cent level by carefully selecting the sample size. This test procedure is subject to the typical chemical interferences in Karl Fischer titrations. Both volumetric and gravimetric sample injection techniques can be used in the titration vessel. After the sample has been automatically titrated, the device shows the result. A water vaporizer accessory can heat dense materials in the evaporation chamber for analysis. The vaporized water is transported into the Karl Fischer titration cell by a dry inert carrier gas.

Test Method	Test Purpose
ASTM D 6304	Water in petroleum products and lubricants by coulometric karl fischer titration.

ASTM D 1500

Considering consumers can quickly notice the colour, determining the colour of products of petroleum is a crucial aspect of their quality, mainly employed for manufacturing control. The degree of material fineness can sometimes be inferred from its colour. An indication of potential contamination with another product could be a deviation outside a product's known colour range. Though it shouldn't be applied arbitrarily in product specifications, colour is only sometimes a good quality indicator. Petroleum products, including heating oils, lubricating oils, diesel fuel oils, and petroleum waxes, can all be visually identified by colour using this test procedure. Refined items with an ASTM colour lighter than 0.5 are suitable for Test Method D 156 use. Glass discs ranging from 0.5 to 8.0 are used to compare the liquid sample in the test container under a standard light source. If the sample colour lies between two classic colour and there is no exact match, the higher of the two colour is reported.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 1500	IP 196,ISO 2049, DIN 51578, JIS K 2580, and AFNOR T60-104	Color

ASTM D 1298

After the sample is heated to the recommended level, it is roughly the same temperature when transferred to a cylinder. After being dropped into the model, the proper hydrometer is left to settle. When the temperature reaches equilibrium, the hydrometer scale is read, and the sample's temperature is noted. If necessary, the cylinder and its contents may be placed in a bath that is kept at a constant temperature to prevent excessive temperature variation during the test.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 1298	IP 160, ISO 3675, DIN 51757H, JIS K 2249H, and AFNOR T60-101	Density and relative density, specific gravity

ASTM D 874

When the sample is carbonised, the remaining residue is called sulfated ash. Sulfuric acid is then added to the residue and heated until its weight remains constant. To determine how much known metal-containing ingredient is present in new oils, utilise the sulfated ash. When no phosphorus is present, zinc and tin (stannic) become their oxides, while calcium, barium, magnesium, sodium, and potassium become their sulphates. Phosphorus present with metals either entirely or partially persists in the sulfated ash as metal phosphates; however, sulphur and chlorine do not interfere. The findings can be inconsistent when samples containing zinc are partially converted to oxide, as zinc sulphate slowly breaks down to its oxide at the method's ignition temperature. In this experiment, magnesium behaves differently from the other alkali metals. The data should be interpreted cautiously if magnesium additives are present. Low results could be obtained from molybdenum samples because the ashing temperature may not allow molybdenum compounds to recover fully. Oils with ashless additives can only use this test method on sulfated ash levels less than 0.02 per cent. Sulfated ash content of 0.005% is the method's lowest limit. Lead-containing and used engine oils are not meant to be analysed using this test method.

Moreover, Test Method D 482 should be utilised when analysing nonadditive lubricating lubricants instead of this protocol. The sulfated ash values obtained through experimentation may not match the values determined from elemental analysis due to the different inter-element references that were previously discussed. The formation of such nonsulfated species depends on the temperature at which the oil is ashed, the amount of time the oil is ashed, and the composition of the metal compounds in the oil. Because sulfated ash values are not a reliable indicator of the overall amount of metallic compounds, they should typically only be included in product specifications if the customer and seller know this. Until carbon and ash are left, the sample is fired and burnt. Following a cooling period, sulfuric acid is applied to the residue heated to 775°C to oxidise the carbon fully. After cooling, the ash is heated to 775°C until it reaches a consistent weight and is again treated with sulfuric acid.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 874	IP 163, ISO 3987, DIN 51575, JIS K 2272, and AFNOR T60-143	Ash sulfated ash from lubricating oils and additives.

ASTM D 482

Petroleum products containing ash may contain extraneous materials like dirt, rust, or metallic compounds that dissolve in water or oil. This test method does not apply to petroleum products that contain additives that produce ash, such as certain phosphorus compounds, lead-containing lubricating oils, or used engine crankcase oils. Some sample types, including distillate oils, may only include some of the elements that produce ash in a quantifiable manner. Under all such circumstances, Test Method D 874's sulphate dash process should be applied. The sample is burned in an appropriate receptacle until only carbon and ash are left. A muffle furnace is used to heat this carbonaceous residue to 775°C, after which it is cooled and weighed to turn it into ash.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 482	IP 4, ISO 6245, JIS K 2272 and AFNOR M07-045	Ash from petroleum products.

ASTM D 2622

This test method can be used to analyze a variety of fuels, including diesel, jet fuel, kerosene, residual oil, naphtha, other distillate oil, lubricating base oil, hydraulic oil, crude oil, unleaded gasoline, M-85, and M-100. This process has, at minimum, been tested in the range of 3 mg/kg and 5.3 mass% of sulfur concentration. Higher sulphur content samples can be tested with the appropriate dilution. Volatile substances, such as high vapour pressure gasoline or light hydrocarbons, may not exceed the stipulated precision limits of the test technique due to the selective loss of lightweight materials during analysis. Analytical errors may occur when the elemental composition of the samples—sulfur excluded—deviates significantly from the standards. The standard and sample matrices must match precisely to maintain the same carbon-to-hydrogen ratio with this approach. Methanol content is 100% in M-100 and 85% in M-85 fuels, respectively. Their high oxygen concentration absorbs a substantial amount of sulfur K_ radiation. To compensate for this, calibration standards that match the samples or correction factors must be used. Compared to traditional sulphur test methods, this technology offers improved precision, reduced sample preparation needs, and high throughput. It can be used to determine sulfur in a range of concentrations. But compared to other methods, the equipment required is significantly more expensive. An X-ray beam is directed towards a sample, and the peak intensity of the sulphur K_ line at 5.373 is recorded. At 5.190 Å, the peak intensity is lower than the background intensity. The obtained net counting rate is compared to an equation or calibration curve generated to calculate the sulphur concentration in mass per cent [90].

Test Method	Equivalent Test Method	Test Purpose
ASTM D 2896	DIN 51400 T6 and JIS K 2541	Sulfur determination sulfur by wavelength dispersive X-Ray fluorescence _WD-XRF

ASTM D 322

While the engine usually operates, some fuel may dilute the engine oil. On the other hand, severe performance issues could arise from excessive fuel dilution. A distillation-based test technique (Test technique D 322) and a gas chromatography-based test method (Test Method D 3525) are available for this job. The sample and water mixture are kept in a glass container with a reflux condenser installed that empties into a graded trap fastened to the still. The still's contents are heated to a boiling point. The model's vaporized diluent is liquefied in the condenser. Excess water runs back to the still while the diluent collects at the top of the trap. The boiling procedure is continued until all of the diluent has been recovered in the web and boiled out. They record something on audio.

Test Method	Equivalent Test Method	Test Purpose
ASTM D 322	DIN 51400 T6 and JIS K 2541	Gasoline diluent in used engine oils distillation method.

ASTM E2412

The standard procedure for Condition Monitoring of Used Lubricants by Trend Analysis using Fourier Transform Infrared (FT-IR) Spectrometry is the ASTM E2412 test method. It covers using FT-IR to monitor base stock degradation, contaminant buildup, and additive depletion in hydraulic fluids, machinery lubricants, and other fluids used in regular machinery operations. When paired with viscosity, TA, and TBN information, ASTM E2412 results can provide a comprehensive and in-depth analysis of the oil's quality. The wavenumber for this test method and various lubricant kinds spans from 3000 to 1090 cm^{1}; however, the path length of the employed cell and the spectral resolution will determine the precise absorbance intensity. For lubricants based on petroleum, the maximum absorbance varies from 3000 to 2800 cm^{1} (or a transmittance value near 0%T). The maximum absorbance varies from 1390 to 1090 cm^{1} (or a transmittance value near 0%T) for lubricants based on the ester.

Test Method	Test Purpose
ASTM E2412	Condition monitoring of used lubricants

NAS 1638

In the 1960s, the National Aerospace Standard (NAS) 1638 was created to aid in managing hydraulic fluid contamination levels in hydraulic components. Not only did NAS 1638 become the industry standard for the aerospace sector, but it also spread to many other industries. SAE 4059 is the most recent iteration of NAS 1638. However, in recent years, the ISO 4406 standard has primarily surpassed NAS 1638 in numerous industries. The techniques for determining particle counts or levels of solid contamination in a fluid are the main emphasis of both ISO 4406 and NAS 1638. The classes relate to the maximum number of particles in each size class in 100 millilitres. The classification values for previous specifications based on Hiac particle counts are displayed in the table below; however, this standard was declared invalid in 2001. According to Appendix A.2 [91], most users employ a single code number that the largest particle count in each size bin determines.

3.5 DESCRIPTION OF APPARATUS USING TESTING PURPOSE

Kinematic Viscosity Bath

Many petroleum products are designed and chosen with kinetic viscosity in mind. Capillary viscometers that have been calibrated are used to monitor flow in a vacuum or under gravity at carefully controlled temperatures. Convenient, precise measurements of glass capillary viscometry are made possible by a constant temperature bath with sophisticated temperature control circuitry and an integrated timing function within the Touch Screen Control Panel and displayed at 0.1 seconds and accurate to 0.01%. Temperature control of the microprocessor from room temperature to 150 °C (302 °F). Integrated digital timing, as shown in Figure 3.9, makes it simple to measure sample efflux times. Allows viscometer constants to be entered for automatic computation and viscosity unit or second display. Set point and actual bath temperature are shown on two digital screens with a precision of 0.1 °C / 0.1 °F that are calibrated to 0.01 °C / 0.01 °F. Choose between a Celsius or Fahrenheit temperature scale. Complies with DIN 51550, FTM 791-305, NF T 60-100, IP 71, 319, ISO 3104, ASTM D445, D2170, D6074 and D6158 standards. Date of Machine Calibration: January 1, 2019.

Figure 3.9 KV4000 Kinematic Viscosity Bath with Integrated Digital Timing

Dual-Bath Kinematic Viscometer

Concerning Figure 3.10, the CAV® 4.2 Dual-Bath Kinematic Viscometer is engineered to quantify the kinetic viscosity of both transparent and opaque liquids in compliance with IP 71, ISO 3104/3105, and ASTM D445/D446 specifications. The CAV® 4.2 is a fully automated benchtop viscometer with dual baths and two 14-position sample handles for unattended D445 processing. Two Ubbelohde-style tubes, one for each tub, with customizable options, have a viscosity range of 100 times between 0.5 mm²/s (cSt) and 10,000 mm²/s (cSt) at temperatures between 15 °C and 150 °C. Testing of hydraulic and formulated oils, base stocks, additives, gasoline, light and heavy fuels, paraffin, and gasoline and testing of gas and other powers like paraffin and gasoline are typical applications. The calibration date is January 1, 2019.

Figure 3.10 CAV 4.2 Dual-Bath Kinematic Viscometer

Metrohm 888 Titrando with Touch Control

High-end titrator with built-in buret drive includes a combination "Ecotrode plus" pH glass electrode, 900 Touch Control, 801 Stirrer magnetic stirrer, and exchange unit (20 mL). It also features USB ports, one galvanically separated measurement interface (which can be used for intelligent electrodes called "iTrodes"), and four MSB connectors. 12.12.18 is the date of calibration. The TBN (total base number) shown below in Figure 3.11 is assessed using this device.

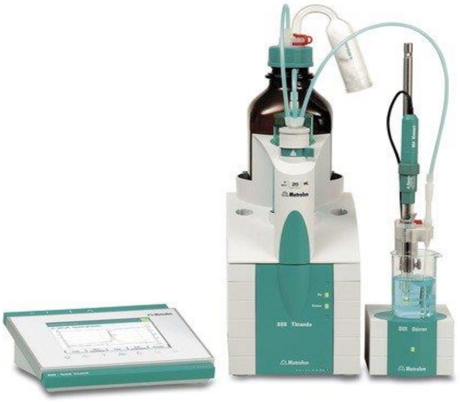


Figure 3.11 Metrohm 888 Titrando with Touch Control

Metrohm 798 MPT Titrino

As ref. Figure 3.12, the 798 MPT Titrino is an all-purpose titrator with LCD graphical display. Titration curves can be observed in real-time. Titration modes of the 798 MPT Titrino are constant or – depending on the titration curve –variable dosing of the titration reagent and Endpoint-Titration. The operator is almost free to define his titrations. All operating modes of the Titrino can be combined to perform extensive analytical sequences. The 798 MPT Titrino provides the opportunity to store, transfer and upload applications and results via memory card. Data exchange with a PC is possible with the Metrodata VESUV Software. With MetrodataTiNet Software complete remote control, data acquisition and evaluation via PC is enabled. Calibration date is 12.12.18. This apparatus using to test TAN (total acid number).

Figure 3.12 Metrohm 798 MPT Titrino

Metrohm 899 Coulometer

A DIN A4 paper sheet and the 899 Coulometer occupy less room on the lab table, as seen in Figure 3.13 below. The coulometer maintains performance without sacrificing size or compactness. It is possible to pinpoint the exact amount of water, even the trace. The scope of delivery includes indicator electrodes and generator electrodes without diaphragms. Ten µg to 200 mg of absolute water is the recommended measuring range. Coulometry is the best technique for determining the water content in liquids, solids, and gases within the trace range. Moreover, coulometry does not require titer determination because it is an absolute procedure. 12.12.18 is the calibration date. This device is used to measure the per cent pollution of water.

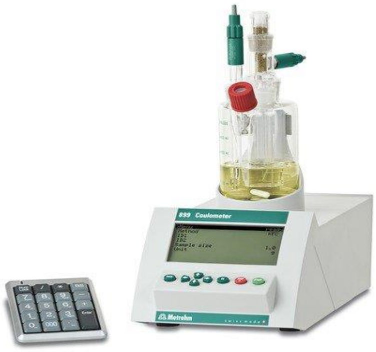


Figure 3.13 Metrohm 899 Coulometer with generator electrode without diaphragm

Koehler Cleveland Open Cup Flash Point Tester

Except for fuel oils and goods having an open cup, all petroleum products flash below their respective flash and fire points of 79°C (175°F). Through ASTM D92 and applicable guidelines. They concern flash points more significant than 79°C (175°F) and calculate flash and firing points using the Cleveland Open-Cup technique. It has an applicator for testing flames, a brass test cup, a heating plate, a thermometer support, and an electric heater. At predefined temperature intervals, the applicator pivots to apply a test flame and is correctly aligned according to specifications. The hinged thermometer support raises to make placing and removing the test cup easier. The integrated comparison bead and needle valve can change the flame size. They are equipped with step-less variable heat control and a 1000W nickel-chromium heater to repeat the temperature rise rate by specifications precisely. 12.12.18 is the calibration date. Figure 3.14 below shows a flash and fire point testing apparatus.

Figure 3.14 Koehler Cleveland Open Cup Flash Point Tester

ICP-OES Spectrometers

ICP-OES Spectrometers: Figure 3.15 shows the first and only ICP-OES (ICP-AES or ICP plasma) spectrometer available from SPECTRO GENESIS. This equipment is truly a "plug & analyses" one, meaning setting up a procedure in advance is unnecessary. All typical industrial and environmental applications, including sewage sludge, soil, oil, and diesel fuel additives, as well as biodiesel, wear metals, and wastewater, are covered by these factory procedures. The application package that includes the sample introduction system, sample preparation guidelines, and method documentation is included with the SPECTRO GENESIS ICP-OES right out of the box. It conforms to all applicable national and international standards. With a daily analysis capacity of up to 700 samples, simultaneous spectrum capture in the 175-770 nm wavelength range provides a solid alternative to sequential ICP and FAA analysis. A minimal 0.5 l/min optic purge achieves low running costs without requiring a water chiller. Faster out of the gate: the new LDMOS generator takes less than 10 minutes to warm up, as opposed to the previous model's more than 30 minutes. Spectropheneis ICP-OES offers customers who are fearless in learning more about ICP the advantages of state-of-the-art CCD ICP technology in a reliable, reasonably priced, and easy-to-use analytical instrument. This device offers a cost-effective substitute compared to sequential ICP and atomic absorption spectrometers. Two more pieces of ICP-OES equipment in SPECTRO's vast product line are SPECTRO ARCOS and SPECTROBLUE. Efficient ICP-OES (ICP-111-AB) Wear Metals Evaluation in Oil. ICP-OES Analysis of Soil and Sludge (ICP-47-AB). Biodiesel: ICP-OES Analysis (ICP-58-AB). Investigating Wet Solutions One uses ICP-OES (ICP-49-AB). Oils: ICP-OES Analysis (ICP-48-AB). Industrial wastewater is analyzed using ICP-46, ICP OES, and radial plasma observation. Using ICP-50 Elemental Analysis of ICP-OES Edible Oils and Fats. Through Stainless Steel Analysis of ICP-56. The ICP-57 ICP-OES was used to analyze brass alloys. They use ICP-112-AB, Smart Analyzer Vision Software-equipped SPECTRO ICP-OES Analyzers Compliant with 21 CFR Part 11. The calibration date is January 1, 2019. This instrument is employed in metal testing.

Figure 3.15 ICP-OES Spectrometers

Infrared Spectroscopy (FT-IR)

Referring to Figure 3.16, you may rely on our industry-leading infrared spectrometers and hardware for quick and precise FT-IR, FT-NIR, and FT-MIR analysis in a highly adjustable and adaptable arrangement. In the near, near-mid, mid-far, and far infrared wavelength ranges, molecular spectroscopy research is frequently used for the following purposes:

Chemicals and Materials: Analyze fuels, find impurities in products, troubleshoot manufacturing issues, and learn more about the characteristics of cutting-edge and new materials.

Pharmaceuticals: Examine and evaluate product formulations and packaging coatings; quickly determine the quality of formulated products, intermediates, and raw materials.

Food: Screen for known and unknown adulterants.

Environmental Safety: Determine and track the environmental hydrocarbon levels with accuracy. We also provide all the necessary consumables, such as windows and sampling cells, kits for desiccant, and introductory kits that help novice infrared researchers gain helpful experience with IR spectrometers and sampling. The date of calibration is January 1st, 2019. This equipment is used for FT-IR testing.

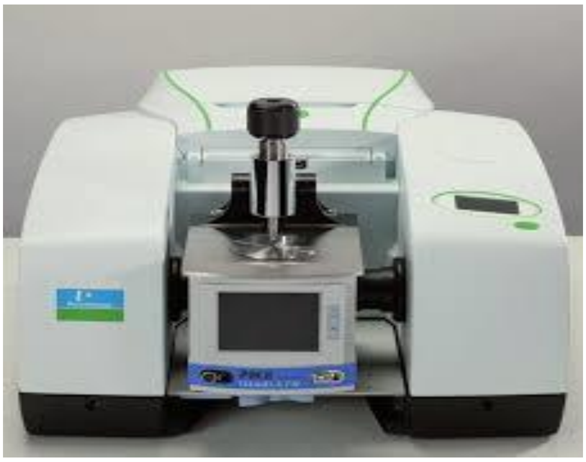


Figure 3.16 Infrared Spectroscopy (FT-IR)

Koehler Dual Twin Foaming Test Apparatus

In applications with turbulence, high-speed gearing, or extensive volume pumping, foaming of lubricating oils can result in cavitation, overflow, premature oxidation, and insufficient lubrication.

Figure 3.17 Koehler D892 and D6082 Dual Twin Foaming Characteristics Test Apparatus

A regulated amount of air is blasted into the sample at predetermined temperatures. Every time an aeration period ends, the resulting foam is measured at various times after that. Measured is the time it takes for the foam to collapse to "0" following the aeration phase. For four tests in compliance with ASTM D892 and ASTM D6082 control standards. Sequences I through IV can be controlled digitally using dual liquid baths. The necessary flow rate of 94 and 200 mL/min to the air diffusers is maintained by four flow meters. The Sequence I and III tests are required to be conducted at 24°C, which calls for using an external chiller. The date of calibration is January 1st, 2019. Utilizing the foaming test, as shown in above apparatus in Figure 3.17.

3.6 SAMPLING SYSTEM

Sampling Procedure

Considering the procedure, timing, and location of sample collection inside the lubricating system is crucial. This is because, during the sample, relatively little oil is extracted. The entire oil capacity, reaching 100,000 litres, is far more than the 250 ml sample. It is imperative to ensure that the sample accurately represents the total oil volume and to take the appropriate safety measures while sampling oils, which may be hot and confined in pressurised systems; wearing gloves and face protection is advised. In general, the following are essential considerations when obtaining representative oil sample acquisitions [92]:

a) Sample only while the equipment is functioning at room temperature; do not do so when the machine is motionless or cold or after adding a sizable amount of fresh oil.

b) Pull a sample from the engine's main supply line; if necessary, install specially designed, easily accessible sampling valves.

c) For each specific piece of equipment, always take a sample from the same spot.

d) Fill the sample via the sampling point after flushing a small amount of oil (0.5–1.0 litres) and without opening the sampling valve in between.

e) To prevent unneeded contamination, put the sample into the sampling vial directly whenever possible.

f) Save your dirty, dry sampling equipment solely on used oil samples.

g) Fill the sample vial to 90% capacity to prevent leaks, and make sure it is securely sealed before

h) Before sending the sample vial to the lab, ensure it is securely sealed and filled to 90% capacity to prevent leaks.

Sample Information

The label on the sample bottle needs to be precise and comprehensive in order to ensure that the sample will be examined right away. Important details consist of the ship or power plant name, the engine's exact name, the lubricant type, the engine type, the sampling date, and the number of service hours. Errors or omissions in labeling could prevent a proper evaluation and recommendation from being made and delay the sample's analysis. Ships regularly get analysis test kits that include all the tools and bottles needed to collect samples. Pre-paid express mail postage bags and pre-labelled sample vials are increasingly commonplace in many kits. The designated laboratory can receive the pieces packaged and couriered for testing, but it is important to make sure the pieces are properly marked. It should also be made very clear that the package includes used oil samples that are meant to be tested until they are destroyed and have a flash point higher than 60ºC. If not, there's a chance that the parts might be held up in shipment because of transport safety issues [93]. Nowadays, most laboratories are able to complete testing within 24 hours after receiving a sample, if necessary. If samples had to wait several weeks to arrive at the laboratory during transit, there would obviously be no need for such a quick turnaround. Sample bottles that have been pre-labeled make this process much simpler and minimize the possibility of mistakes. Nevertheless, caution must still be exercised to guarantee that the oil from the appropriate sampling point is included in the pre-labelled empty bottle that is utilized. It should be emphasized that accurate understanding of the machinery, its operating circumstances, and a variety of other supplementary information are necessary for the interpretation of the utilized oil analysis results in order to diagnose machinery conditions [94]. This can contain performance data, environmental data, and historical information from any known functional incidents that might have had an impact on the equipment that is currently in use. For an effective diagnosis, having good extra information from the engineering staff is crucial. It's also critical to understand that the outcomes of a single analysis do not yield a complete and accurate diagnosis.

Sampling Intervals

Monitoring each test parameter as a function of time or operation hours is essential to understand the oil analysis results properly. Therefore, graphs that may be plotted to illustrate an equipment's regular operating tendencies and, in turn, what future developments would be deemed "normal" can be created. The analyst can see any significant departure from these trends and then call attention to it so that the engine staff can investigate the situation immediately to find the cause. It is often difficult to interpret any analysis conducted outside of this paradigm [95]. The risk assessment results carried out during the maintenance review will determine the sampling frequency for oil-based Condition Monitoring (CM). Unless enough trends have been established to enable optimization and modify the sampling frequency as needed, gathering samples once a month is prudent. Note: When utilizing a condition monitoring instrument, like oil analysis, as a protective device—that is, to highlight the appearance of a known failure state—it is imperative to take care to ensure that the sampling frequency is smaller than the "mean time to failure." If this doesn't happen, there will be mistakes made without defense. Evidence from the past indicates that when failure types, like liner scuffing or bearing fractures, have exceptionally short "mean time to failure" profiles, the usefulness of used oil analysis for CM is diminished. Thus, it is crucial to collect oil samples to monitor outcomes periodically. These repairs should be spaced no more than three months apart, and they are typically stated by the oil supplier or OEM (Original Equipment Manufacturer).

CHAPTER IV
RESULTS AND DISCUSSION

4.1 EFFECT OF TEMPERATURE ON OIL VISCOSITY

Used Waste Engine Oil SAE 40

Here analysis three sample of Waste Used Engine Oil SAE 40 like S1, S2 & S3, where ASTM standard Temperature 40 ℃ & 100 ℃. Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.1.

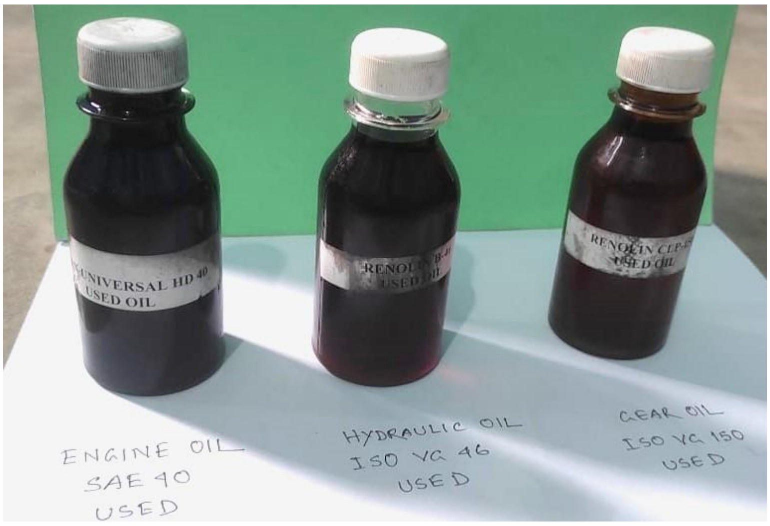
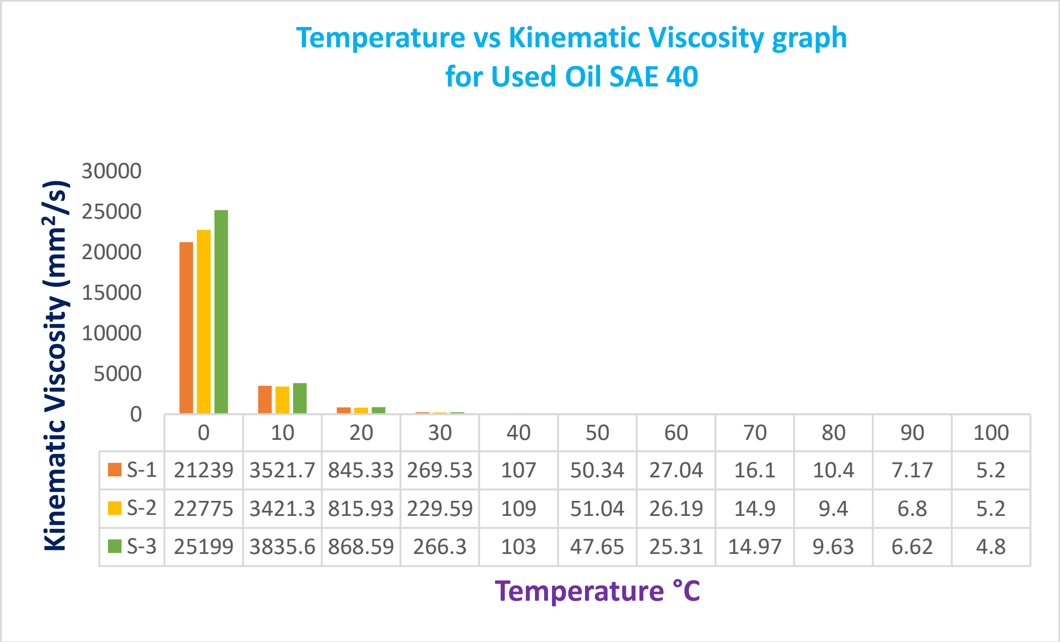


Figure 4.1 Sample of Used Engine Oil SAE 40, Hydraulic Oil ISO VG 46 & Gear Oil ISO VG 150.

Table 4.1 Viscosity of Used Waste Engine Oil SAE 40 at Different Temperature.

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	21238.9	22775.17	25198.5
10	3521.69	3421.29	3835.6
20	845.33	815.93	868.59
30	269.53	229.59	266.3
40	107	109	103
50	50.34	51.04	47.65
60	27.04	26.19	25.31
70	16.1	14.90	14.97
80	10.4	9.40	9.63
90	7.17	6.8000	6.62
100	5.2	5.2	4.8



	0	10	20	30	40	50	60	70	80	90	100
🟧 S-1	21239	3521.7	845.33	269.53	107	50.34	27.04	16.1	10.4	7.17	5.2
🟨 S-2	22775	3421.3	815.93	229.59	109	51.04	26.19	14.9	9.4	6.8	5.2
🟩 S-3	25199	3835.6	868.59	266.3	103	47.65	25.31	14.97	9.63	6.62	4.8

Figure 4.2 Kinematic Viscosity Variation with Temperature of Used Waste Engine Oil SAE 40 [A.10].

Used Waste Engine Oil (on Treatment) SAE 40

Here analysis three sample of Used Oil Engine Oil (on Treatment) SAE 40 like S1, S2 & S3, where ASTM standard Temperature 40 °C & 100 °C. Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.11.

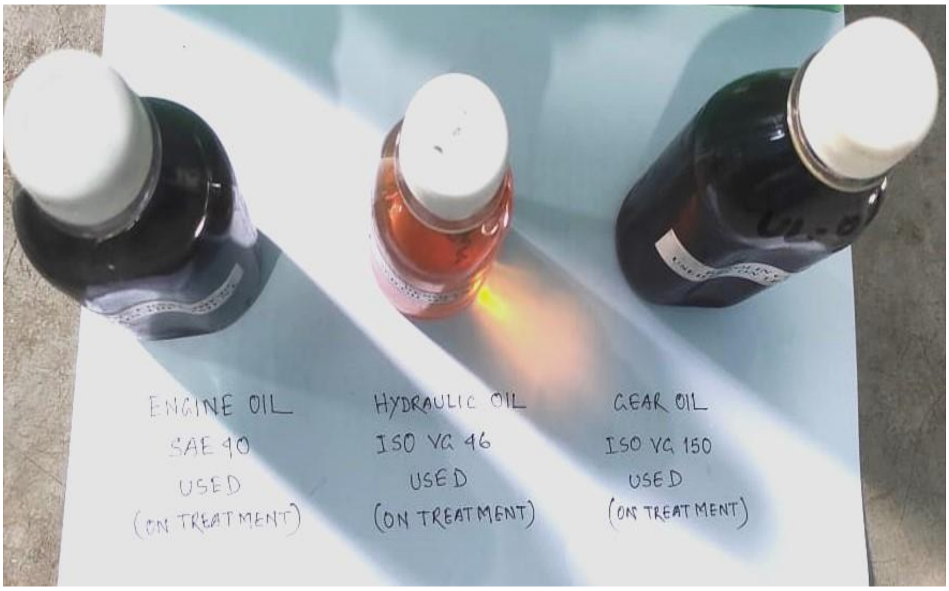
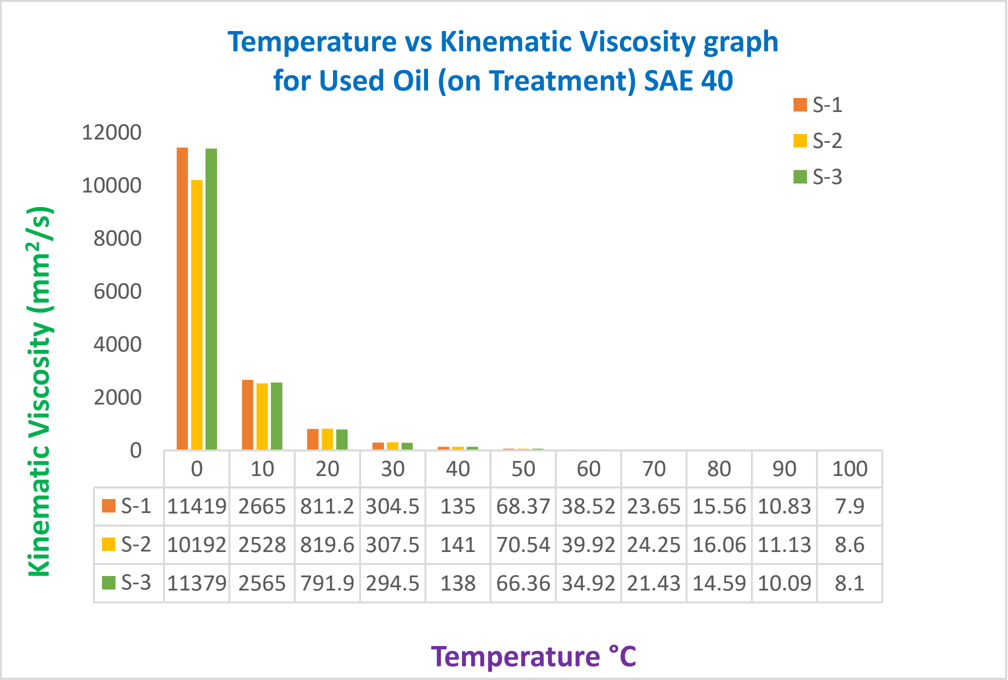


Figure 4.3 Sample of Used (on Treatment) Engine Oil SAE 40, Hydraulic Oil ISO VG 46 & Gear Oil ISO VG 150.

Table 4.2 Viscosity of Used Waste Engine Oil (on Treatment) SAE 40 at Different Temperature.

Temp °C	**S-1**(mm²/s)	**S-2**(mm²/s)	**S-3**(mm²/s)
0	11418.96	10192.2	11378.68
10	2665.35	2528.35	2565.39
20	811.2	819.6	791.9
30	304.48	307.47	294.48
40	135	141	138
50	68.37	70.54	66.36
60	38.52	39.92	34.92
70	23.65	24.25	21.43
80	15.56	16.06	14.59
90	10.83	11.13	10.09
100	7.9	8.6	8.1



	0	10	20	30	40	50	60	70	80	90	100
S-1	11419	2665	811.2	304.5	135	68.37	38.52	23.65	15.56	10.83	7.9
S-2	10192	2528	819.6	307.5	141	70.54	39.92	24.25	16.06	11.13	8.6
S-3	11379	2565	791.9	294.5	138	66.36	34.92	21.43	14.59	10.09	8.1

Figure 4.4 Kinematic Viscosity variation with Temperature of Used Waste Engine Oil (on Treatment) SAE 40.

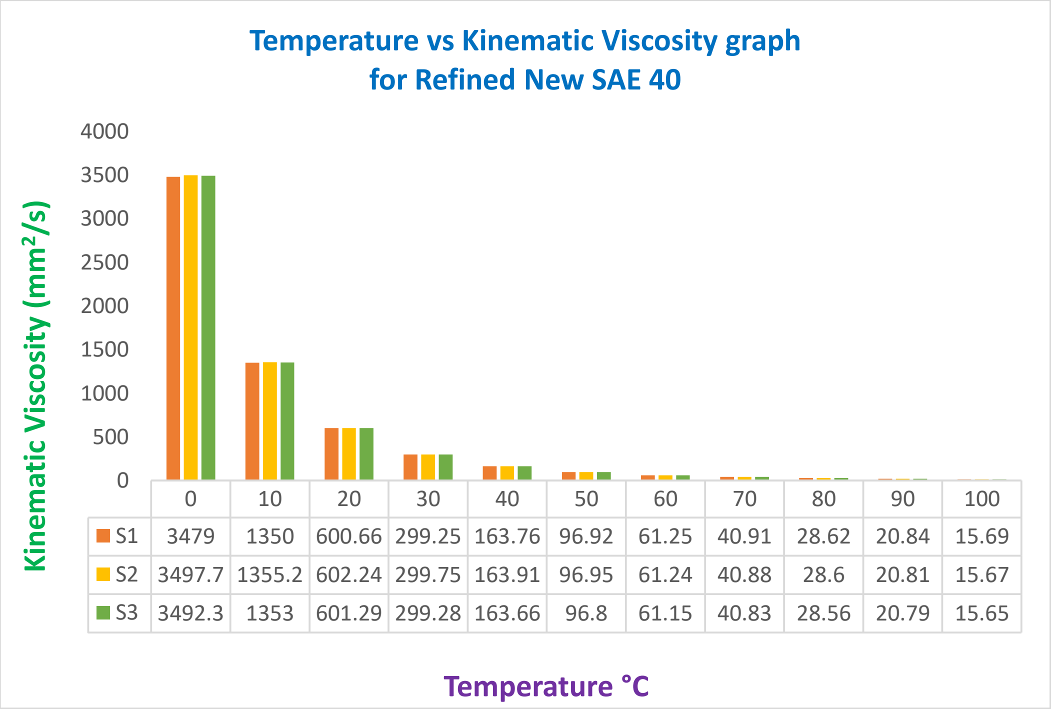
Refined Engine Oil SAE 40

Here analysis three sample of Refined Engine Oil SAE 40 like S1, S2 & S3, where ASTM standard Temperature 40 °C & 100 °C. Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.12.

Figure 4.5 Sample of Refined Engine Oil SAE 40, Hydraulic Oil ISO VG 46 & Gear Oil ISO VG 150.

Table 4.3 Viscosity of Refined Engine Oil SAE 40 at Different Temperature.

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	S-3 (mm^2/s)
0	3478.97	3497.7	3492.31
10	1349.97	1355.16	1353.03
20	600.66	602.24	601.29
30	299.25	299.75	299.28
40	163.76	163.91	163.66
50	96.92	96.95	96.8
60	61.25	61.24	61.15
70	40.91	40.88	40.83
80	28.62	28.6	28.56
90	20.84	20.81	20.79
100	15.69	15.67	15.65



	0	10	20	30	40	50	60	70	80	90	100
S1	3479	1350	600.66	299.25	163.76	96.92	61.25	40.91	28.62	20.84	15.69
S2	3497.7	1355.2	602.24	299.75	163.91	96.95	61.24	40.88	28.6	20.81	15.67
S3	3492.3	1353	601.29	299.28	163.66	96.8	61.15	40.83	28.56	20.79	15.65

Figure 4.6 Kinematic Viscosity variation with Temperature of Refined Engine Oil SAE 40.

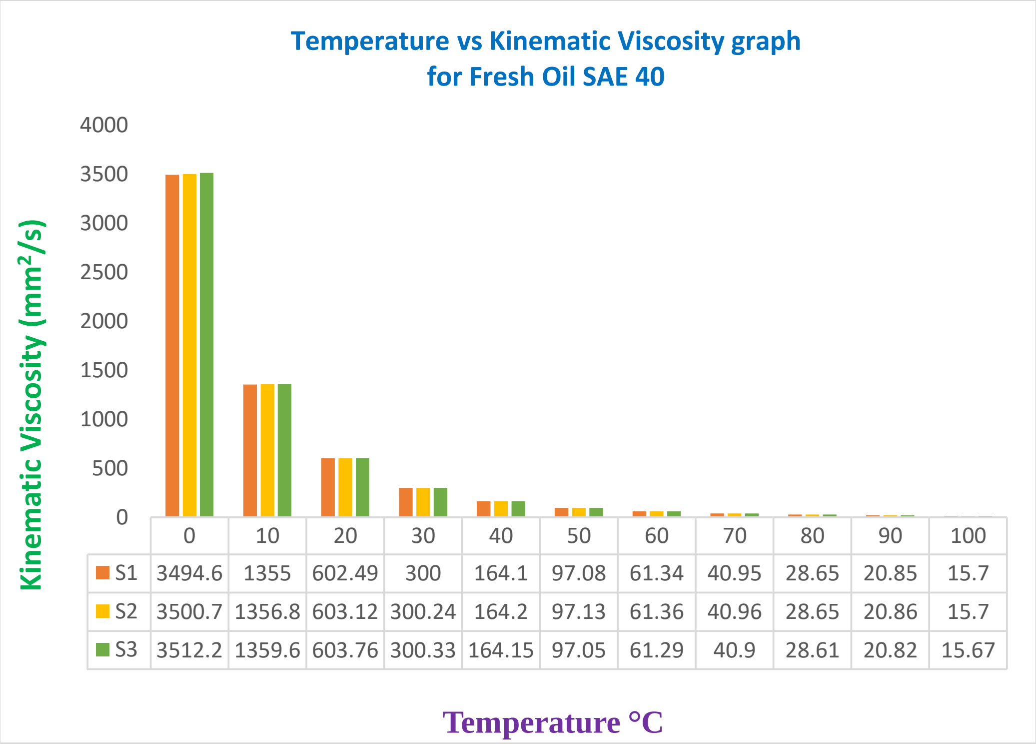
Fresh Engine Oil SAE 40

Here analysis three sample of Fresh Engine Oil SAE 40 like S1, S2 & S3, where ASTM standard Temperature 40 °C & 100 °C .Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.13.

Figure 4.7 Sample of Fresh Engine Oil SAE 40, Hydraulic Oil ISO VG 46 & Gear Oil ISO VG 150.

Table 4.4 Viscosity of Fresh Engine Oil SAE 40 at Different Temperature.

Temp °C	S-1 (mm^2/s)	S-2 (mm^2/s)	S-3 (mm^2/s)
0	3494.62	3500.65	3512.24
10	1354.96	1356.79	1359.56
20	602.49	603.12	603.76
30	300	300.24	300.33
40	164.1	164.2	164.15
50	97.08	97.13	97.05
60	61.34	61.36	61.29
70	40.95	40.96	40.9
80	28.65	28.65	28.61
90	20.85	20.86	20.82
100	15.7	15.7	15.67



	0	10	20	30	40	50	60	70	80	90	100
🟧 S1	3494.6	1355	602.49	300	164.1	97.08	61.34	40.95	28.65	20.85	15.7
🟨 S2	3500.7	1356.8	603.12	300.24	164.2	97.13	61.36	40.96	28.65	20.86	15.7
🟩 S3	3512.2	1359.6	603.76	300.33	164.15	97.05	61.29	40.9	28.61	20.82	15.67

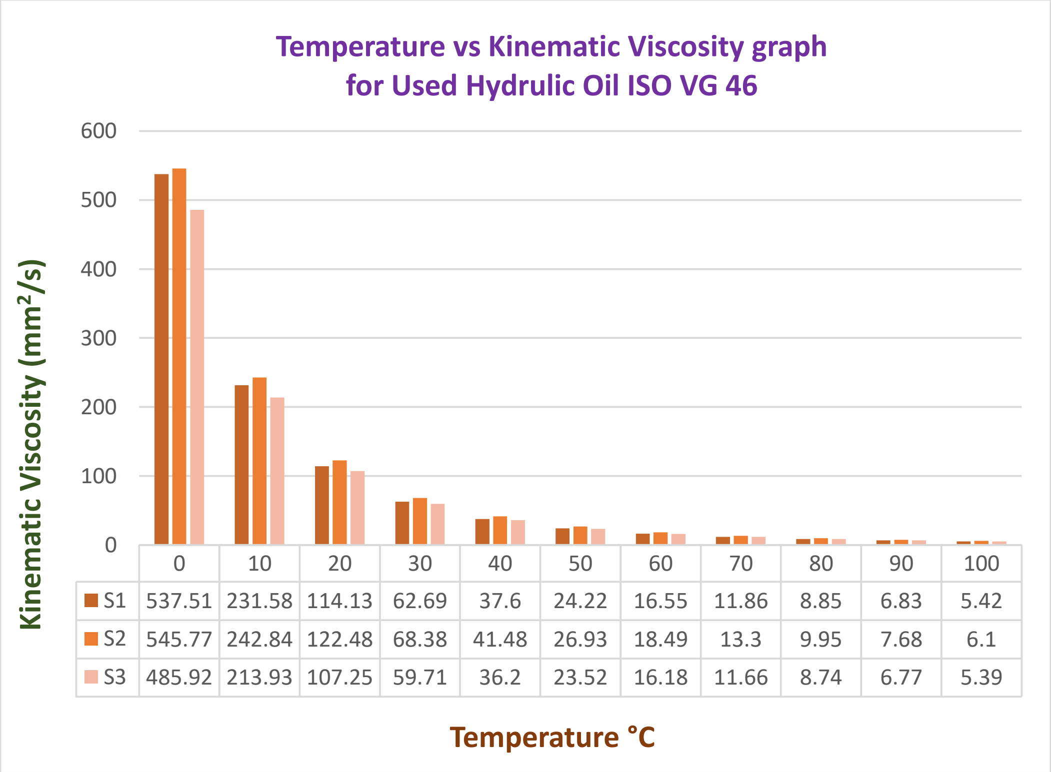
Figure 4.8 Kinematic Viscosity variation with Temperature of Fresh Engine Oil SAE 40.

Used Hydraulic Oil ISO VG 46

Here analysis three sample of Used Hydraulic Oil ISO VG 46 like S1, S2 & S3, where ASTM standard Temperature 40 ℃ & 100 ℃ .Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.14.

Table 4.5 Viscosity of Used Hydraulic Oil ISO VG 46 at Different Temperature.

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	537.51	545.77	485.92
10	231.58	242.84	213.93
20	114.13	122.48	107.25
30	62.69	68.38	59.71
40	37.6	41.48	36.2
50	24.22	26.93	23.52
60	16.55	18.49	16.18
70	11.86	13.3	11.66
80	8.85	9.95	8.74
90	6.83	7.68	6.77
100	5.42	6.1	5.39



	0	10	20	30	40	50	60	70	80	90	100
S1	537.51	231.58	114.13	62.69	37.6	24.22	16.55	11.86	8.85	6.83	5.42
S2	545.77	242.84	122.48	68.38	41.48	26.93	18.49	13.3	9.95	7.68	6.1
S3	485.92	213.93	107.25	59.71	36.2	23.52	16.18	11.66	8.74	6.77	5.39

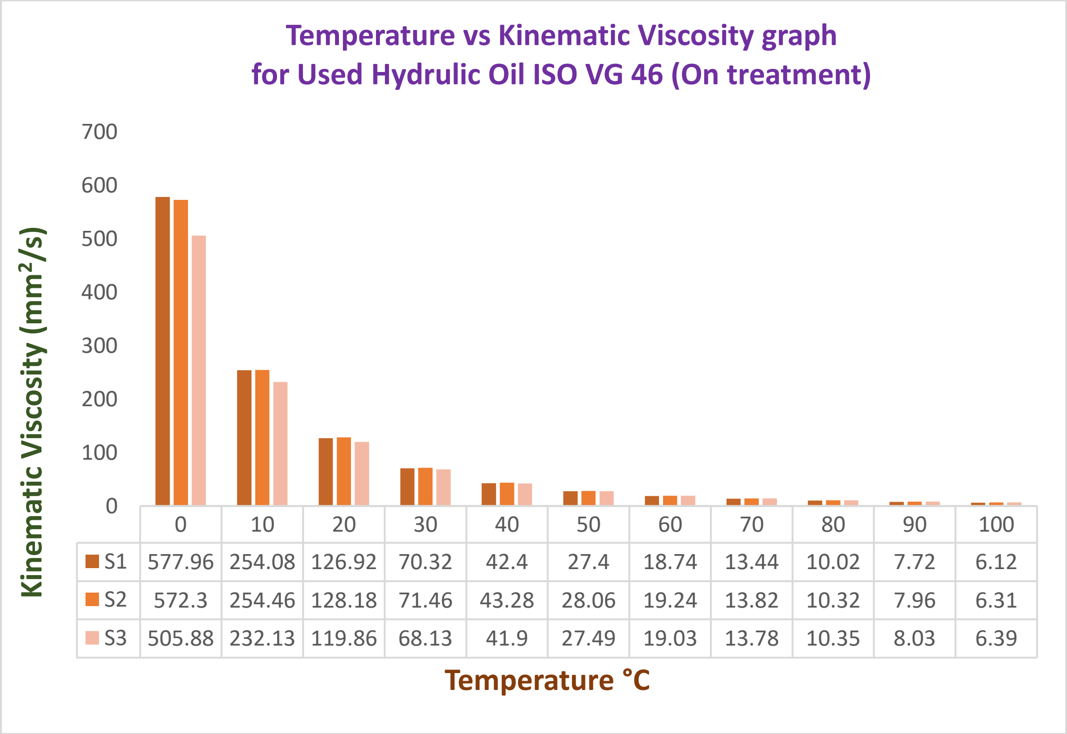
Figure 4.9 Kinematic Viscosity variation with Temperature of Used Hydraulic Oil ISO VG 46

Used Hydraulic Oil ISO VG 46 (on Treatment)

Here analysis three sample of Used Hydraulic Oil ISO VG 46 (on Treatment) like S1, S2 & S3, where ASTM standard Temperature 40 ℃ & 100 ℃ .Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.15.

Table 4.6 Viscosity of used Hydraulic Oil ISO VG 46 (on Treatment) at Different Temperature.

Temp °C	S-1 (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	577.96	572.3	505.88
10	254.08	254.46	232.13
20	126.92	128.18	119.86
30	70.32	71.46	68.13
40	42.4	43.28	41.9
50	27.4	28.06	27.49
60	18.74	19.24	19.03
70	13.44	13.82	13.78
80	10.02	10.32	10.35
90	7.72	7.96	8.03
100	6.12	6.31	6.39



	0	10	20	30	40	50	60	70	80	90	100
S1	577.96	254.08	126.92	70.32	42.4	27.4	18.74	13.44	10.02	7.72	6.12
S2	572.3	254.46	128.18	71.46	43.28	28.06	19.24	13.82	10.32	7.96	6.31
S3	505.88	232.13	119.86	68.13	41.9	27.49	19.03	13.78	10.35	8.03	6.39

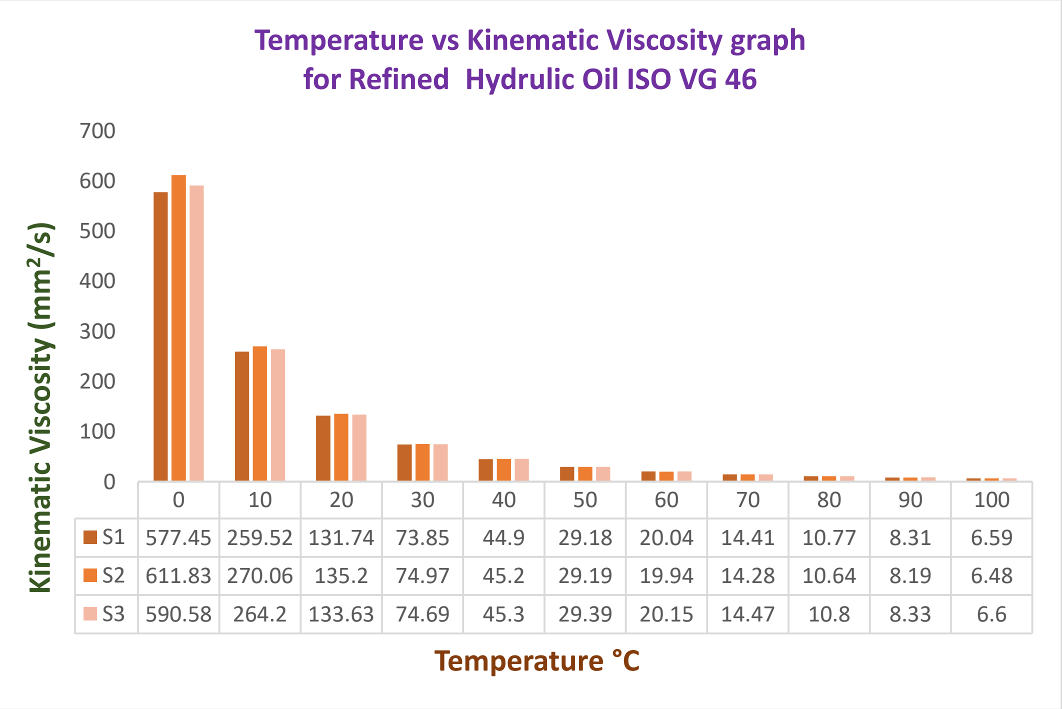
Figure 4.10 Kinematic Viscosity variation with Temperature of Used Hydraulic Oil ISO VG 46 (on Treatment).

Refined Hydraulic Oil ISO VG 46

Here analysis three sample of Refined New Hydraulic Oil ISO VG 46 like S1, S2 & S3, where ASTM standard Temperature 40 ℃ & 100 ℃ .Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.16.

Table 4.7 Viscosity of Refined Hydraulic Oil ISO VG 46 at Different Temperature.

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	577.45	611.83	590.58
10	259.52	270.06	264.2
20	131.74	135.2	133.63
30	73.85	74.97	74.69
40	44.9	45.2	45.3
50	29.18	29.19	29.39
60	20.04	19.94	20.15
70	14.41	14.28	14.47
80	10.77	10.64	10.8
90	8.31	8.19	8.33
100	6.59	6.48	6.60



	0	10	20	30	40	50	60	70	80	90	100
S1	577.45	259.52	131.74	73.85	44.9	29.18	20.04	14.41	10.77	8.31	6.59
S2	611.83	270.06	135.2	74.97	45.2	29.19	19.94	14.28	10.64	8.19	6.48
S3	590.58	264.2	133.63	74.69	45.3	29.39	20.15	14.47	10.8	8.33	6.6

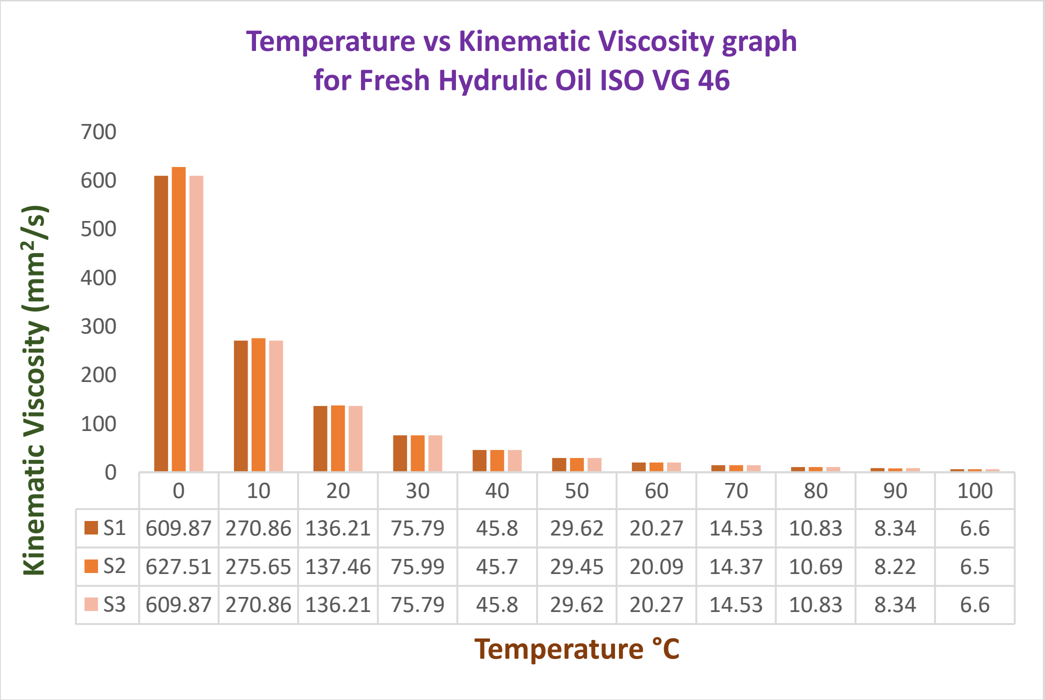
Figure 4.11 Kinematic Viscosity variation with Temperature of Refined Hydraulic Oil ISO VG 46.

Fresh Hydraulic Oil ISO VG 46

Here analysis three sample of Fresh Hydraulic Oil ISO VG 46 like S1, S2 & S3, where ASTM standard Temperature 40 ℃ & 100 ℃ .Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.17.

Table 4.8 Viscosity of Fresh Hydraulic Oil ISO VG 46 at Different Temperature

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	609.87	627.51	609.87
10	270.86	275.65	270.86
20	136.21	137.46	136.21
30	75.79	75.99	75.79
40	45.8	45.7	45.8
50	29.62	29.45	29.62
60	20.27	20.09	20.27
70	14.53	14.37	14.53
80	10.83	10.69	10.83
90	8.34	8.22	8.34
100	6.6	6.5	6.6



	0	10	20	30	40	50	60	70	80	90	100
S1	609.87	270.86	136.21	75.79	45.8	29.62	20.27	14.53	10.83	8.34	6.6
S2	627.51	275.65	137.46	75.99	45.7	29.45	20.09	14.37	10.69	8.22	6.5
S3	609.87	270.86	136.21	75.79	45.8	29.62	20.27	14.53	10.83	8.34	6.6

Figure 4.12 Kinematic Viscosity variation with Temperature of Fresh Hydraulic Oil ISO VG 46.

Used Gear Oil ISO VG 150

Here analysis three sample of Used Gear Oil ISO VG 150 like S1, S2 & S3, where ASTM standard Temperature 40 °C & 100 °C . Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.6.

Table 4.9 Viscosity of Used Gear Oil ISO VG 150 at Different Temperature.

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	3290.74	2983.96	3237.08
10	1287.77	1185.34	1271.07
20	577.01	537.73	571.09
30	289.14	272.25	286.81
40	159	151	158
50	94.48	90.38	94.03
60	59.92	57.66	59.7
70	40.13	38.82	40.02
80	28.15	27.35	28.1
90	20.54	20.02	20.51
100	15.49	15.15	15.48

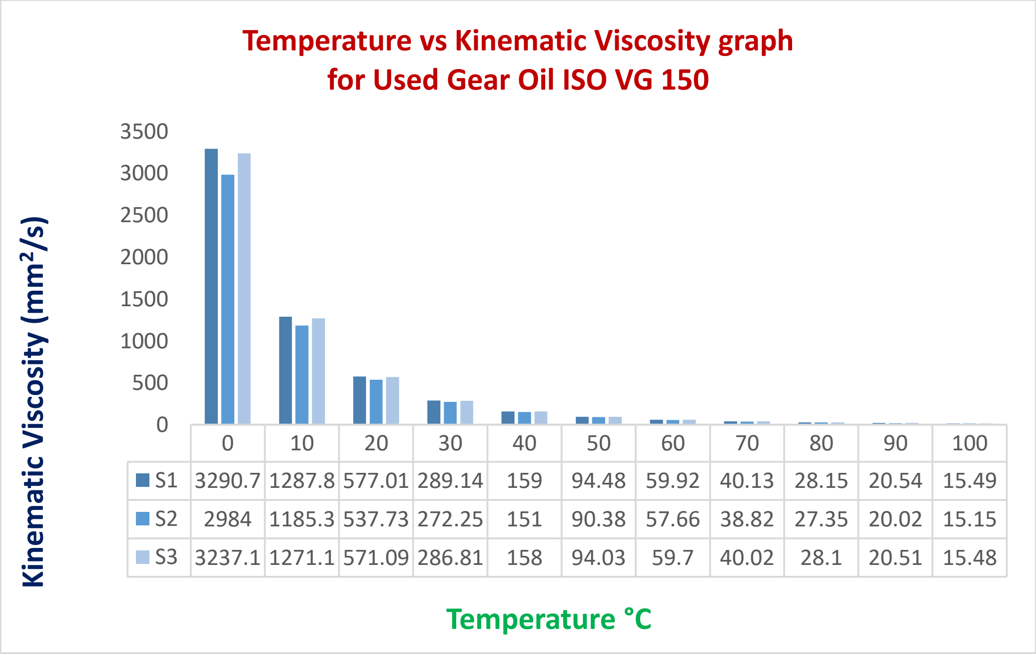


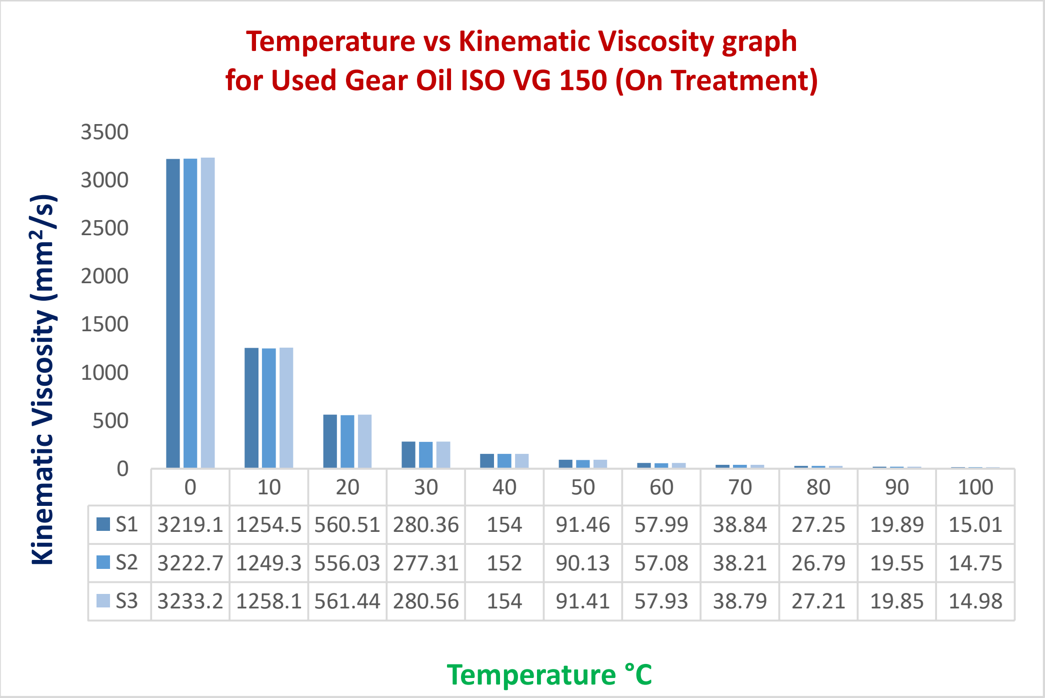
Figure 4.13 Kinematic Viscosity variation with Temperature of Used Gear Oil ISO VG 150.

Used Gear Oil ISO VG 150 (On Treatment)

Here analysis three sample of Used Gear Oil ISO VG 150 (On Treatment) like S1, S2 & S3, where ASTM standard Temperature 40 °C & 100 °C .Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.5.

Table 4.10 Viscosity of Used Gear Oil ISO VG 150 (On Treatment) at Different Temperature.

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	3219.11	3222.73	3233.22
10	1254.51	1249.34	1258.08
20	560.51	556.03	561.44
30	280.36	277.31	280.56
40	154	152	154
50	91.46	90.13	91.41
60	57.99	57.08	57.93
70	38.84	38.21	38.79
80	27.25	26.79	27.21
90	19.89	19.55	19.85
100	15.01	14.75	14.98



	0	10	20	30	40	50	60	70	80	90	100
S1	3219.1	1254.5	560.51	280.36	154	91.46	57.99	38.84	27.25	19.89	15.01
S2	3222.7	1249.3	556.03	277.31	152	90.13	57.08	38.21	26.79	19.55	14.75
S3	3233.2	1258.1	561.44	280.56	154	91.41	57.93	38.79	27.21	19.85	14.98

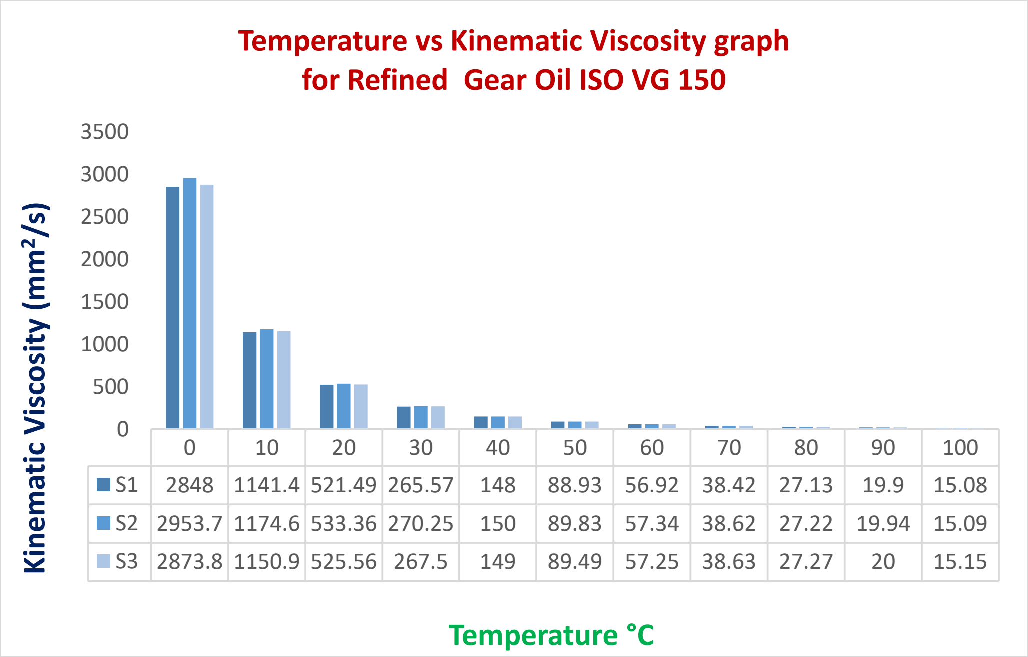
Figure 4.14 Kinematic Viscosity variation with Temperature of Used Gear Oil ISO VG 150 (On Treatment).

Refined Gear Oil ISO VG 150

Here analysis three sample of Refined New Gear Oil ISO VG 150 like S1, S2 & S3, where ASTM standard Temperature 40 °C & 100 °C . Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.7.

Table 4.11 Viscosity of Refined Gear Oil ISO VG 150 at Different Temperature.

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	2848.03	2953.7	2873.84
10	1141.35	1174.6	1150.94
20	521.49	533.36	525.56
30	265.57	270.25	267.5
40	148	150	149
50	88.93	89.83	89.49
60	56.92	57.34	57.25
70	38.42	38.62	38.63
80	27.13	27.22	27.27
90	19.9	19.94	20
100	15.08	15.09	15.15



	0	10	20	30	40	50	60	70	80	90	100
S1	2848	1141.4	521.49	265.57	148	88.93	56.92	38.42	27.13	19.9	15.08
S2	2953.7	1174.6	533.36	270.25	150	89.83	57.34	38.62	27.22	19.94	15.09
S3	2873.8	1150.9	525.56	267.5	149	89.49	57.25	38.63	27.27	20	15.15

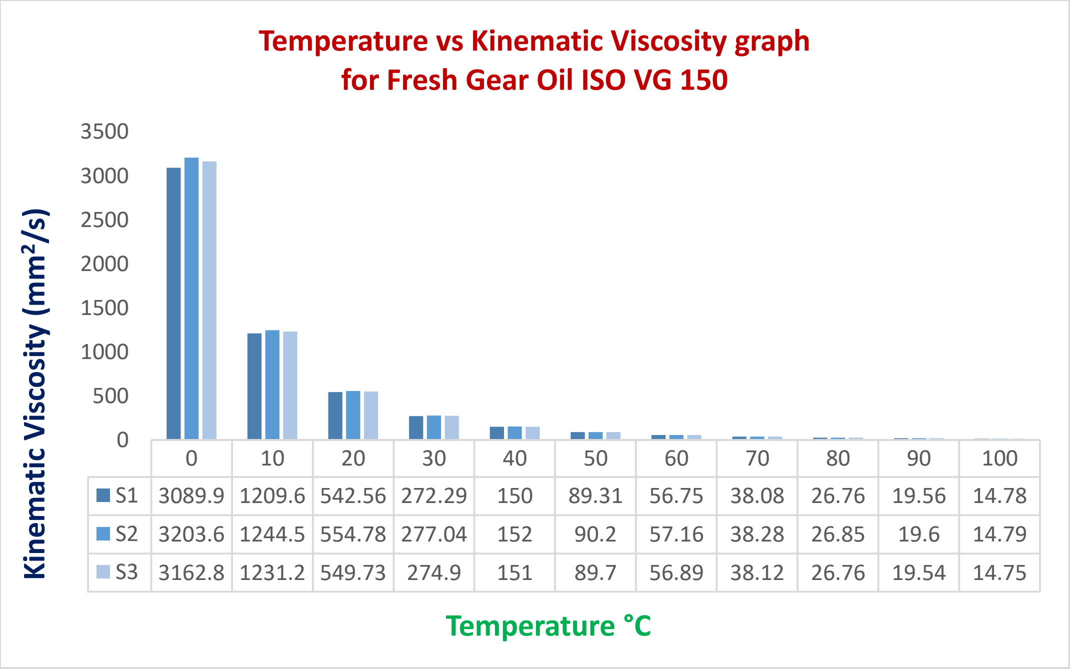
Figure 4.15 Kinematic Viscosity variation with Temperature of Refined Gear Oil ISO VG 150 [A.8].

Fresh Gear Oil ISO VG 150

Here analysis three sample of Fresh Gear Oil ISO VG 150 like S1, S2 & S3, where ASTM standard Temperature 40 °C & 100 °C .Viscosity of engine oil decreasing by increasing temperature as shown in Appendix A.9.

Table 4.12 Viscosity of Fresh Gear Oil ISO VG 150 at Different Temperature.

Temp °C	**S-1** (mm^2/s)	**S-2** (mm^2/s)	**S-3** (mm^2/s)
0	3089.86	3203.63	3162.77
10	1209.61	1244.52	1231.15
20	542.56	554.78	549.73
30	272.29	277.04	274.9
40	150	152	151
50	89.31	90.2	89.7
60	56.75	57.16	56.89
70	38.08	38.28	38.12
80	26.76	26.85	26.76
90	19.56	19.6	19.54
100	14.78	14.79	14.75



	0	10	20	30	40	50	60	70	80	90	100
■ S1	3089.9	1209.6	542.56	272.29	150	89.31	56.75	38.08	26.76	19.56	14.78
■ S2	3203.6	1244.5	554.78	277.04	152	90.2	57.16	38.28	26.85	19.6	14.79
■ S3	3162.8	1231.2	549.73	274.9	151	89.7	56.89	38.12	26.76	19.54	14.75

Figure 4.16 Kinematic Viscosity variation with Temperature of Fresh Gear Oil ISO VG 150.

4.2 TECHNICAL COMPARISON BETWEEN REFINED AND FRESH BASE OILS.

SAE 40 engine oil is made with additives, base oil (SN 500), and SBS 150.Additives and base oils (SN 500, SN 70/150) are used in the production of hydraulic oil (ISO VG 46). Base oils (SN 500, SN 150 and SBS 150) and additives are utilised in the production of ISO VG 150 Gear Oil.

Solvent Neutral (SN) 500 Base Oil

Base Oil SN 500 is classified as a light-grade base oil that falls within the top range of Grade I base oil standards. The manufacturing of lubricants is its primary application. It is a Group I base oil that has been refined using solvents. Foundation Oil SN 500 is a foundation stock for various industrial lubricants, including greases, hydraulic oils, transformer oils, engine oils, gear oils, gearbox fluids and metalworking fluids.

Table 4.13 Using Base Oil SN 500, Refined and Fresh Engine Oil (SAE 40) Technical Comparison

Parameters	Test Methods	Fresh engine oil	Refined engine oil
Appearance	Visual	Bright & Clear	Bright &Clear
Color	ASTM D 1500	L 2.0 – 2.5	L 1.5 – 2.2
Density @ 30° C	ASTM D 1298	0.885 – 0.890	0.801– 0.850
Kinematic Viscosity @ 40°C	ASTM D 445	97.5 – 102.0	94.5 – 100.0
Kinematic Viscosity @100°C	ASTM D 445	10.5 – 11.5	9.9 – 11.0
Viscosity Index	ASTM D 2270	89.0 – 92.0	87.0 – 91.0
Flash Point , °C	ASTM D 92	225 – 235	221 – 233
Pour Point , °C	ASTM D 97	-3	-3

SN 150 Base Oil

On the lower end of the Grade I light base oil standards, base oil SN 150 is a light-grade base oil. It is primarily employed in the manufacturing of lubricants and lubricant additives. It's a Group I base oil that's been refined using solvents. Foundation Oil SN 500 is a foundation stock for various industrial lubricants, including greases, hydraulic oils, transformer oils, engine oils, gear oils, gearbox fluids and metalworking fluids.

Table 4.14 Using Base Oil SN 150, Refined and Fresh Hydraulic Oil (ISO VG 46) Technical Comparison

Parameters	Test Methods	Fresh hydraulic oil	Refined hydraulic oil
Color	ASTM D 1500	2.0 – 2.2	1.8 – 2.0
Density @ 30°C	ASTM D 1298	0.870	0.859
Kinematic Viscosity @ 40°C	ASTM D 445	30.0 – 31.54	29.0 – 30.49
Kinematic Viscosity @100°C	ASTM D 445	5.0 – 5.5	4.5 – 5.2
Viscosity Index	ASTM D 2270	90 – 92	88 – 91
Flash Point ,ºC	ASTM D 92	200 – 210	196 – 204
Pour Point ,ºC	ASTM D 97	-3	-3

SN 70 Base Oil

Base Oil SN 70 is utilised in many different industrial settings. Base Oil SN 70 is the starting point for various industrial lubricants, including transformer, hydraulic, engine, gearbox, and metalworking fluids. High boiling point, high viscosity index, thermal stability, and high oxidation resistance are characteristics of SN 70 Base Oil.

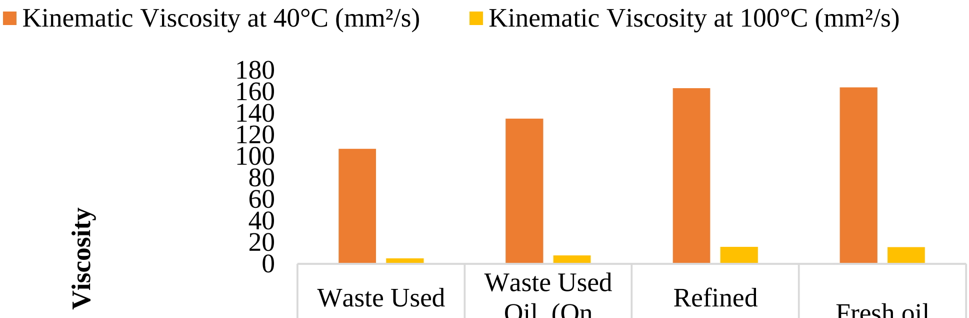
Table 4.15 Using Base Oil SN 70, Refined and Fresh Gear Oil (ISO VG 150) Technical Comparison

Parameters	Test Methods	Fresh Gear oil	Refined Gear oil
Density@ 29.5 ºC	ASTM D 1298	0.858.	0.841.
Appearance	ASTM D 1500	Bright & Clear	Bright & Clear
Kinematic Viscosity@ 40°C	ASTM D 445	11.4	10.33
Flash Point ,ºC	ASTM D 92	140 ℃(COC)	132 ℃ (COC)
Pour Point ,ºC	ASTM D 97	-18 ℃	-19 ℃

4.3 Effect of Refining on Viscosity, Flash point & Density

Viscosity

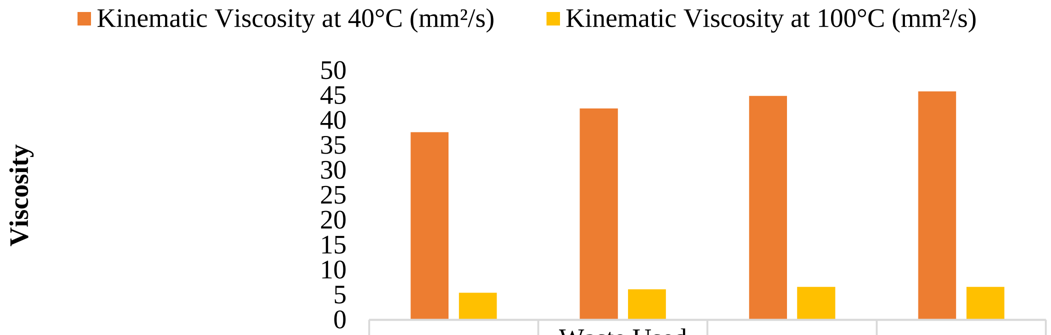
The kinetic viscosity of old motor oil can be influenced by contamination or oxidation, and it can also be lowered by diluting it with lighter fuels like petrol or diesel. As below Figure 4.17, kinematic viscosity at define temperature 40 °C & 100 °C, near about same values found for both refined & Fresh engine oil as shown in Appendix A.3.



	Waste Used Oil	Waste Used Oil (On Treatment)	Refined New Oil	Fresh oil
🟧 Kinematic Viscosity at 40°C (mm²/s)	107	135	163.4	164.1
🟨 Kinematic Viscosity at 100°C (mm²/s)	5.2	7.9	15.9	15.7

Oil Condition

Figure 4.17 Effect of Refining on Viscosity for Engine Oil (SAE 40)

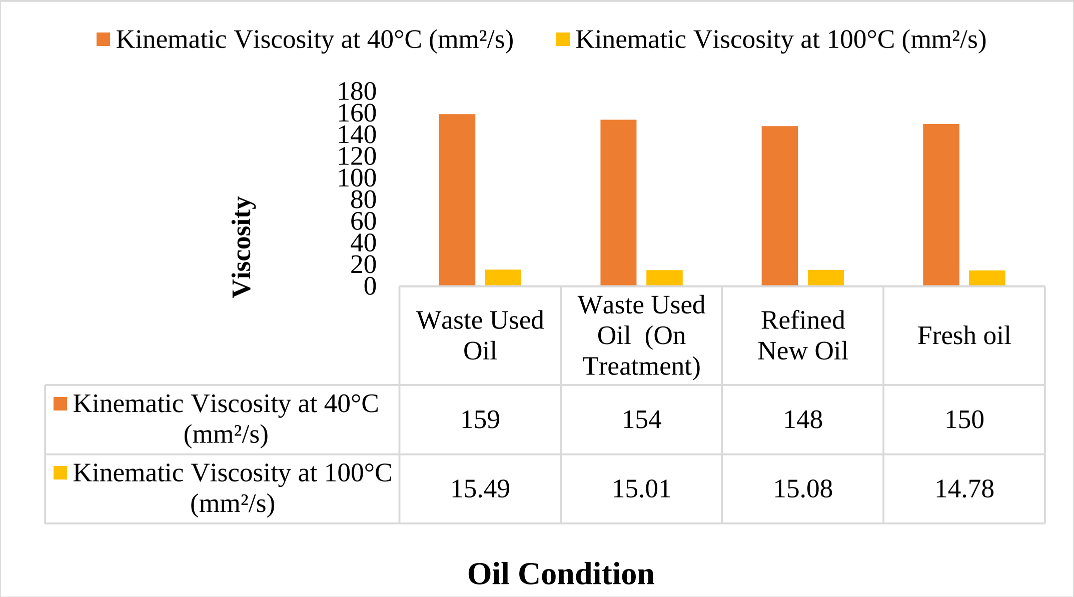


	Waste Used Oil	Waste Used Oil (On Treatment)	Refined New Oil	Fresh oil
🟧 Kinematic Viscosity at 40°C (mm²/s)	37.6	42.4	44.9	45.8
🟨 Kinematic Viscosity at 100°C (mm²/s)	5.42	6.12	6.59	6.6

Oil Condition

Figure 4.18 Effect of Refining on Viscosity for Hydraulic Oil (ISO VG 46)

As above Figure 4.18 at Industrial hydraulic oil (ISO VG 46), kinematic viscosity found very nearly similar at temperature 40 ℃ & 100 ℃ for refined & fresh oil.



	Waste Used Oil	Waste Used Oil (On Treatment)	Refined New Oil	Fresh oil
🟧 Kinematic Viscosity at 40°C (mm²/s)	159	154	148	150
🟨 Kinematic Viscosity at 100°C (mm²/s)	15.49	15.01	15.08	14.78

Figure 4.19 Effect of Refining on Viscosity for Industrial Gear Oil (ISO VG 150)

As above Figure 4.19, kinematic viscosity found closely comparable at temperature 40 ℃ & 100 ℃ for refined & fresh gear oil as shown in Appendix A.2.

Flash Point

The ASTM D97 open cup flash point apparatus was used to analyse the samples' flash points. A thermometer-equipped Bunsen burner held a beaker filled with 10 millilitres of sample. While the lubricating oil in the cup was heating, a flame source was brought in periodically to measure the temperature at which a flash appeared on the sample's surface as shown in Appendix A.3.

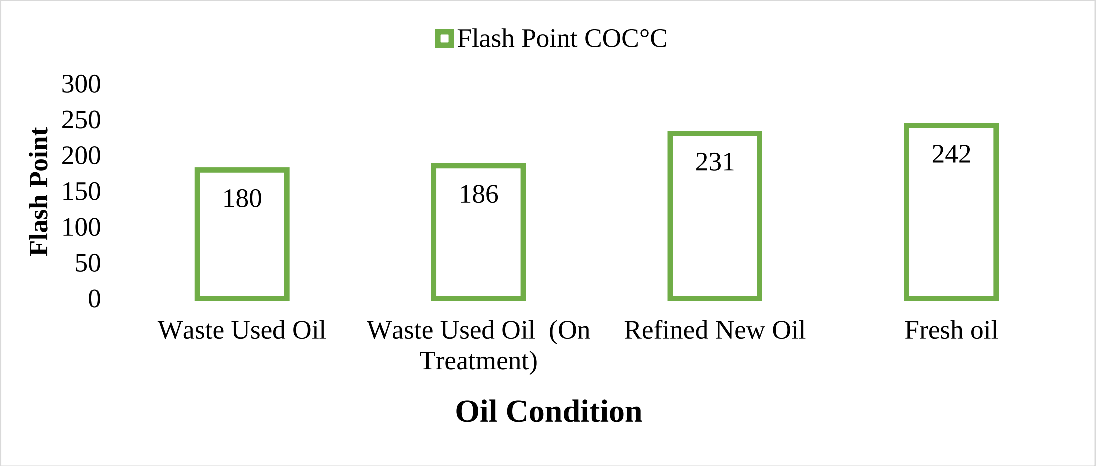


Figure 4.20 Effect of Refining on Flash Point for Engine oil (SAE 40).

AS ref. Figure 4.20 at engine oil (SAE 40), flash point gradually increase for used & on treatment waste oil [A.4]. On the other hand, flash point nearly close for refined & fresh oil.

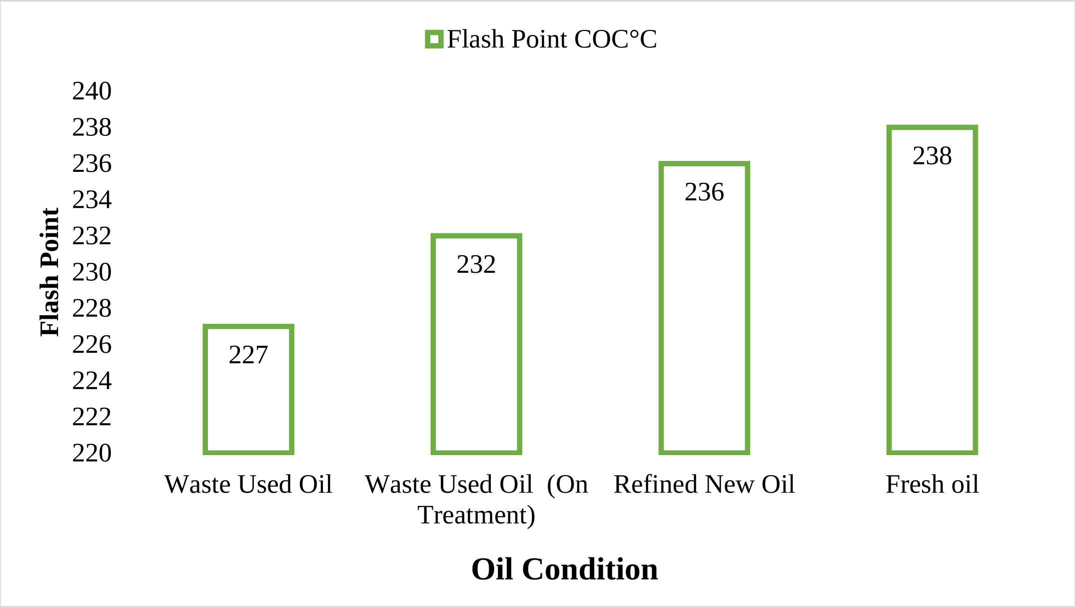


Figure 4.21 Effect of Refining on Flash Point for Industrial Hydraulic Oil (ISO VG 46)

As ref. Figure 4.21 at industrial hydraulic oil (ISO VG 46), flash point gradually increase for used oil, on treatment used oil, refined & also fresh oil. Here, we found flash point close by new refined & fresh oil as shown in Appendix A.5.

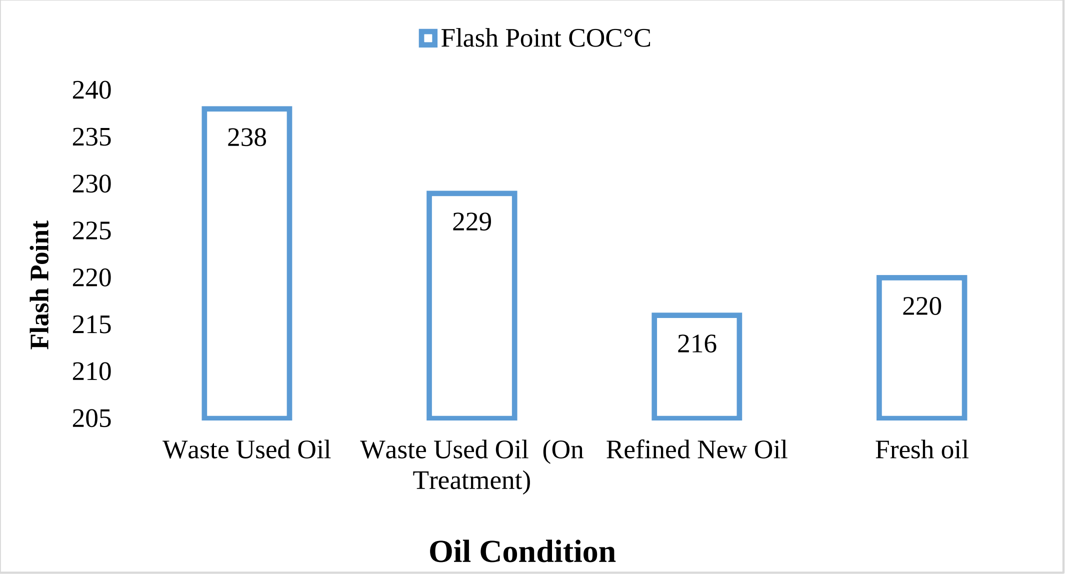


Figure 4.22 Effect of Refining on Flash Point for Industrial Gear Oil (ISO VG 150)

As ref. Figure 4.22 at industrial gear oil (ISO VG 150), flash point variants for used oil, on treatment used oil, refined & also fresh oil. Here also, we found flash point of refined oil adjacent with Fresh oil.

Density

Density of treated oil samples was analyzed by digital hydrometer of Thermo-Hydro.

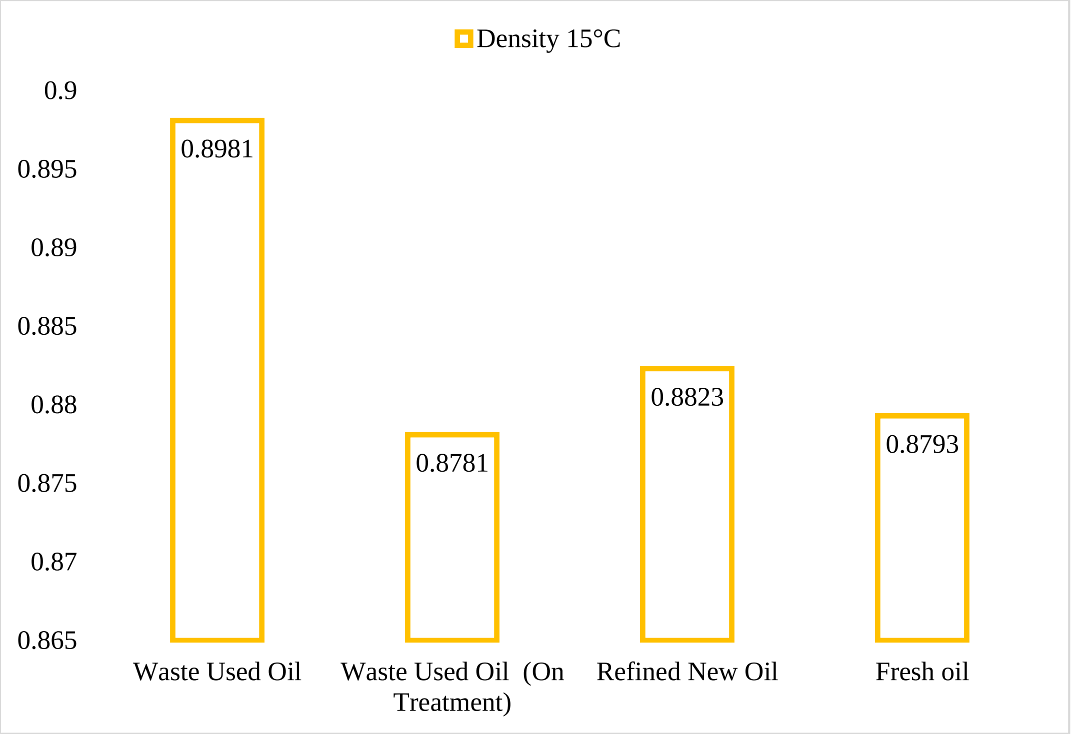


Figure 4.23 Effect of Refining on Density

As ref. above Figure 4.23, at 15 °C density values considerately similar for used oil (on treatment), refined & fresh oil.

4.4 COST ANALYSIS

Investors like to fund ventures that yield a sufficient rate of return. Thus, performing the lubricating oil refining system's financial analysis is essential. According to our data analysis, the daily output of spent lubricant that can be treated is 10 L. Therefore, we have planned a factory with a 7500L/day capacity. It takes roughly 300 days to complete the yearly working days. A minimum of 1200 m^2 of land is needed to establish the necessary size plant.

Table 4.16 (a) Basis for the financial calculation

Sector of Cost	Amount (BDT.)
(i) Total land cost (assuming)	11793840.00
(ii) Cost of building	3000000.00
(iii) Cost of transportation vehicles	3000000.00
(iv) Cost of storage container & collecting	200000.00
(v) Cost of the catalyst expenses (20 tons)	6120000.00
(vi) Cost of machinery (I_1)	140000000.00
(vii) Investment in the auxiliary equipment (I_2) =I_1 *20%	28000000.00
(viii) For the import of the machinery tax rate is (if 5%) tax amount	8400000.00
(ix) VAT collected from (custom is 13% + local development cost is 1.5%)	21880000.00
(x) Assuming the transportation cost of machinery (5%)	8400000.00
(xi) Total engineering cost= (I_1 + I_2) * I_2%	20160000.00
Total Investment Cost	**250953840.00**

Table 4.16 (b) Basis for the financial calculation

Sl.	Item	Calculated basis
1	Project life	20 yrs
2	Construction period	3 yrs
3	Depreciation	Straight line with 4%
4	Salvage value	Zero
5	Income tax rate	10%
6	Inflation	0
7	Capital expenditure	
8	1st year	20% of fixed capital
9	2ndyear	45% of fixed capital
10	3rd year	35 % of (fixed capital +working
11	Capacity utilization	
12	1st and 2nd year	60%
13	3 and subsequent years	100%

Table 4.17 Requirement of utilities for 1m^3 of used oil processing

Sl.	Utilities	Consumption
1	Electricity	90 kwh
2	Heat	18000kcal
3	Water	700 L
4	Catalyst	0.4 kg
5	Hydrogen	0.2%

Table 4.18 Composition of output on the basis of mass

Sl.	Parameter	Quantity (mass %)
1	Base oil	75%
2	Fuel (diesel)	6%
3	Reside	11%
4	Waste water	8%
5	Off gas	0.%

We calculated the annual running costs from our survey and predicted the used oil purchase cost to be BDT 30/L (including collecting and shipping costs and increasing costs of used oil due to the high demand). The current pricing of used oil is BDT 20–BDT 25 per L.

The cost of purchasing used oil for a 300-day running condition is 7500 * 300 * 30 = BDT 67,500,000.

Our annual total oil consumption is 7,500 * 300 = 2, 250,000 L or 2250 m^3.

The cost per unit of electricity for industrial use is 12 BDT.

Then,

Table 4.19 Cost chart

(i)	Cost of electricity = (2250 * 90 *12)	2, 430, 000.00
(ii)	Cost of catalyst removal = (2250 * 0.4 *306)	275,400.00
(iii)	Cost of hydrogen = (2250000 * 0.002 * 100)	450,000.00
	Total heat required= (18000 * 4.2) = 75600 k Joule	
	Assuming the heating value of furnace oil is 38 MJ/Kg	
	Total amount of the fuel required = (75600 kJ/ 38 MJ *2250)	
	= 4476.31 Kg.	
	Specific gravity of the furnace oil is 0.85	
	Then, total amount of fuel=(4476.31 Kg./ 0.85)	
	= 5266 L	
(iv)	Total cost of the fuel = (5266 * 40)	210,640.00
(v)	Labor cost for (25 staffs)	2,448,000.00
(vi)	Extra expenses	1,000,000.00
(vii)	Maintenance cost = (I2 * 4% + I2 * 3%)	6,440,000.00
(viii)	Assuming the straight line depreciation with zero salvage value after 20 years. Then, Depreciation = (I-0)/N per Year	8,400, 000.00
(ix)	Insurance and other fees are 2% of the total investment	4,831,600.00
(x)	Financial cost is 7% of the capital investment	16,847,600.00
Total operating cost		**168,792,040.00**

4.4.1 Annual revenue

Unit cost of base oil produce is Rs.130 per L assuming, during 1st and 2nd year only 60% of oil is sold,

(i)	Then, for 1st and 2nd year, revenue =(7500*300*0.6*130*0.75)	= 131,625,000.00
(ii)	For the remaining years, revenue	= 219, 375,000.00
(iii)	Then the variable cost per unit (1m^3) = BDT. 73331400/2250 (m^3 per year)	= -32591.73.00
(iv)	Net revenue in 1st and 2nd years=(selling cost - total operating cost)	= 50,108,164.00
(v)	Income after the 10 % tax deducted	= 45,097,347.00
(vi)	For the other years =(219,375,000-110,831,400)	= 108,543,600.00
Income after tax deducted		**= 97,689,240.00**

Table 4.20 Table showing overview costs and revenues

Overview:

Particular	**Amount (NBDT. Lakh)**
Investment of the project	
a. Building	30
b. vehicle	30
c. Container	2
d. Catalyst expenses	61.2
e. Machinery	1400
f. Auxiliary equipment	280
g. Import Tax	84
h. Vat &local dev. Tax	244
i. Engineering cost	201.6
j. Transportation of machinery	84
Total	2416.8
Variable Cost	
a. Used oil purchase	675
b. Electricity	24.3
c. Catalyst removal	2.754
d. Hydrogen	4.5
e. Heating fuel	2.1
f. Labour	24.48
Total	733.134
Fixed cost/year	
g. Maintenance cost	64.4
h. Depreciation	84
i. Insurance	48.31
j. Financial cost	168.47
k. Extra	10
Total	375.18
Particulars	Amount (NRs. Lakh)
Revenue from the base oil selling	
a. First year	1316.25
b. Second year	1316.25
And Other Years	2193.75
Revenue from the base oil selling	1316.25

4.4.2 Testing the Financial Feasibility of the Project

Simple payback period

The amount of years needed to recoup a project's investment, exclusive of the time value of money, is known as the payback period.

Table 4.21 Calculation of simple payback period

Period	Cash flow (In Lakhs)	Cumulative cash flow
0	-483.36	-483.36
1	-1087.56	-1570.92
2	-845.8	-2416.72
3	501.081	-1915.639
4	501.081	-1414.558
5	976.89	-437.668
6	976.89	539.222

Then, payback period = (5 years + 437.668/976.89) = 5.448 years or, 5 years and 5 months

Discounted payback period calculation

Interest rate = 10%. Discounted payback period is the number of years required to recover investment made in project considering time value of money.

Table 4.22 Calculation of discounted payback period

Year	Cash Flow	Cumulative cash flow
0	-483.36	-483.36
1	-1087.6	-1619.296
2	-845.8	-2627.02
3	501.081	-2388.647
4	501.081	-2126.4308
5	976.89	-1362.18
6	976.89	-521.508
7	976.89	403.2312

Then the discounted payback period = 6 year + 521.508/924.74 = 6.56 year.

Net Present Worth (NPW)

Interest rate = 10%

NPW (10%) = {-483.36 -1087.56/1.1 -845.88/1.1^2 +501.081/1.1^3 +501.081/1.1^4 +976.89 *(P/A,10%,16) *(P/F,10%,4)}

NPW (10.25%) =NBDT. 3305.24

Since the NPW is greater than zero, project is feasible.

Internal Rate of Return (IRR)

The interest rate on the investment balance of an unrecovered project that ensures that the unrecovered project balance is zero at project termination is known as the internal rate of return. The project's net present value is set to zero to compute the internal rate of return. The project's internal rate of return (IRR) is calculated when its net current value is zero.

NPW (I) = 0

0= {- 483.36 - 1087.56/ i - 845.88/ i^2 + 501.08/ i^3 + 501.08/ i^4 +976.89 x (P/F, i , 4) x (P/A, i ,16)}

Now we calculate the different values of present worth (PW) at different interest (I). Ref. Table 4.23 variation of NPW with I is shown below. Calculation is done from excel program.

Table 4.23 Variation of net present worth with interest rate

S.N.	Interest rate (I %)	NPW (Lakh)
1	2	10613.78
2	4	7973.69
3	6	6014.16
4	8	4542.54
5	10	3425.05
6	12	2567.69
7	14	1,903.61
8	16	1384.74
9	18	976.12
10	20	652.04
11	22	393.41
12	24	185.9
13	26	18.66
14	28	-116.61
15	30	-226.31

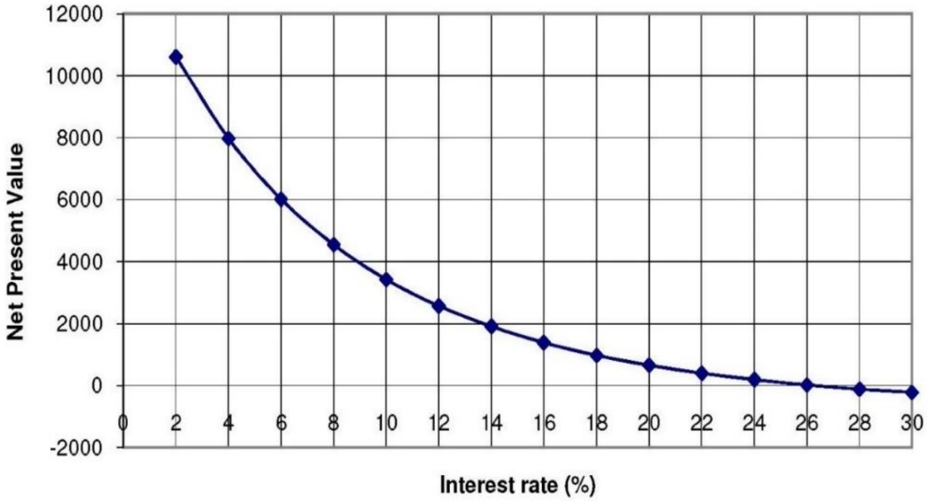


Figure 4.24 Variation of net present worth with interest rate

From above Figure 4.24, calculation of internal rate of return (IRR) is found to be ~ 26%, which is far greater than MARR. Thus the project is feasible.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on experimental studies, all approaches were effective in eliminating impurities from used lubricating base oil and restoring the oil to a quality nearly identical to that of fresh lube oil stocks. Distillation is one of the best methods of recycling but having drawback of expensiveness of solvents used in recycling. Different properties such as appearance, color, pour point, flash point, density, Kinematic viscosity, viscosity index of refined oil and waste oil were analyzed.

From experimental result & discussion the following calculation can be drawn.

1. Viscosity was found almost same at difference temperature for three Samples of Refined & Fresh engine oil (SAE 40), hydraulic oil (ISO VG 46) and gear oil (ISO VG 150).
2. Others properties such as Appearance, Color, Density, Kinematic viscosity, Viscosity index, Flash point & Pour point are near about same as for Refined & Fresh engine oil (SAE 40), hydraulic oil (ISO VG 46) and gear oil (ISO VG 150).

3. The financial analysis of the selected process was done using different techniques. From the calculation, we get payback period = 5.448 years, discounted payback period = 6.56 years, and Net present worth = NBDT. 3425.05 lakh, IRR = 26%. From the above values, it was clear that the project was financially feasible.

5.2 RECOMMENDATIONS

1. Public awareness programs should be launched to make people aware about the harmful effect of mismanagement of used lubricating oil and to encourage them to use refined lubricating oil.
2. Collection system should be set up to collect the used lubricating oil all over country also.
3. Study of possibility of used lubricating oil re-refining should be performed for whole country.

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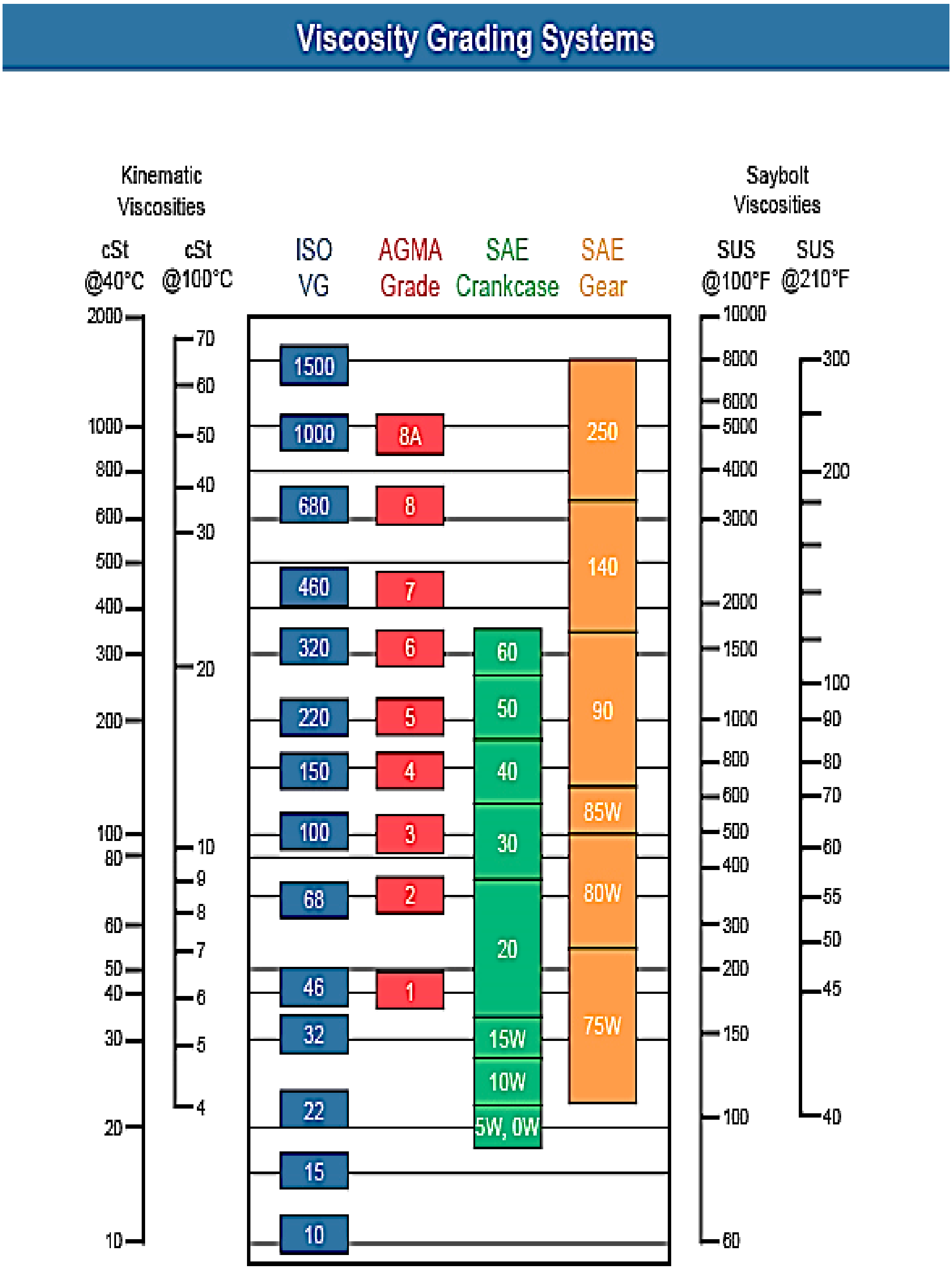
APPENDIX

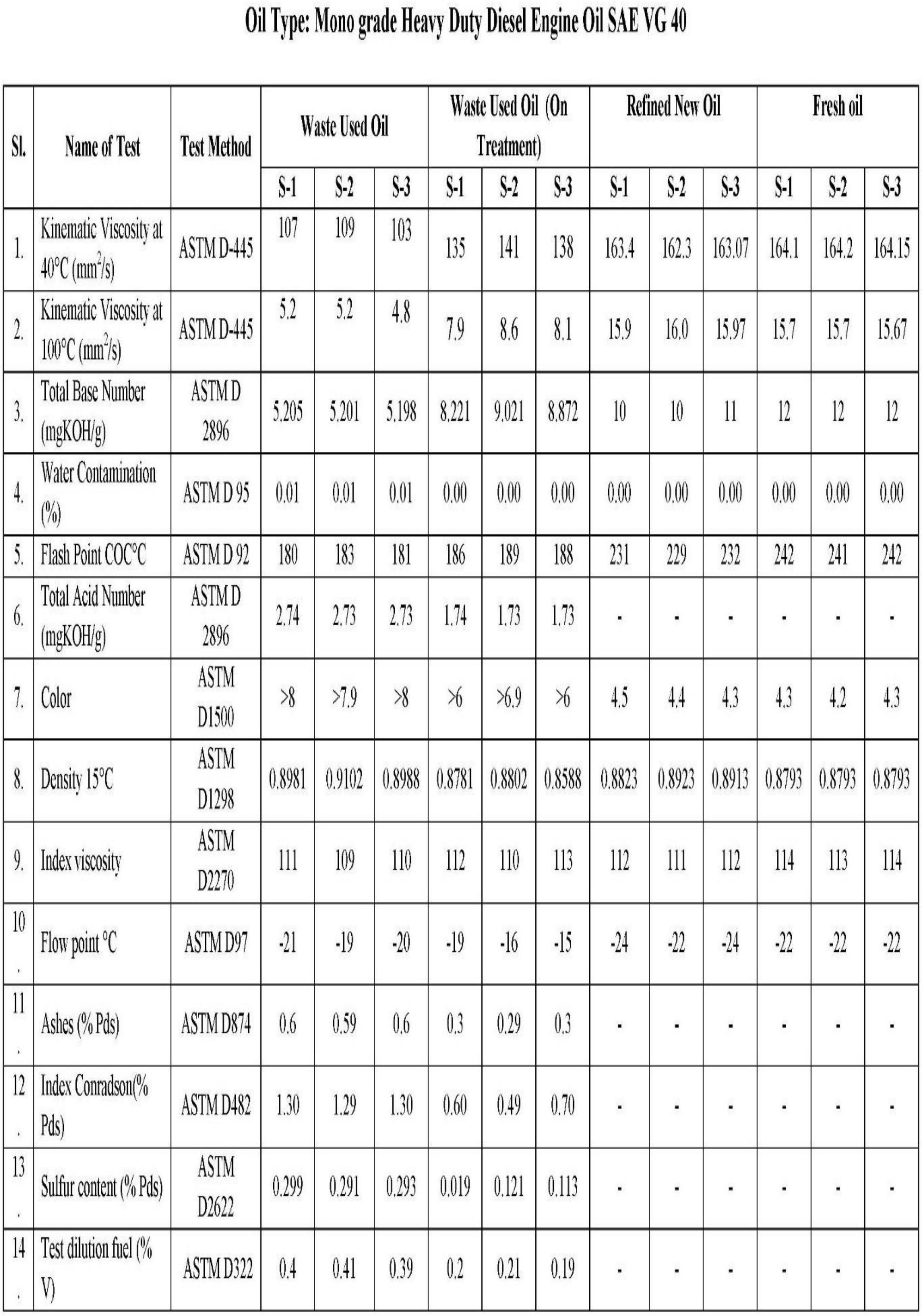
A.1: Viscosity Grading Systems



A.2 : NAS Values

code	5-15 µm	15-25 µm	25-50 µm	50-100 µm	over 100 µm
00	125	22	4	1	0
0	250	44	8	2	0
1	500	89	16	3	1
2	1000	178	32	6	1
3	2000	356	63	11	2
4	4000	712	126	22	4
5	8000	1425	253	45	8
6	16000	2850	506	90	16
7	32000	5700	1012	190	32
8	64000	11400	2025	360	64
9	128000	22800	4050	720	128
10	256000	45600	8100	1440	256
11	512000	91200	16200	2880	512
12	1024000	182400	32400	5760	1024

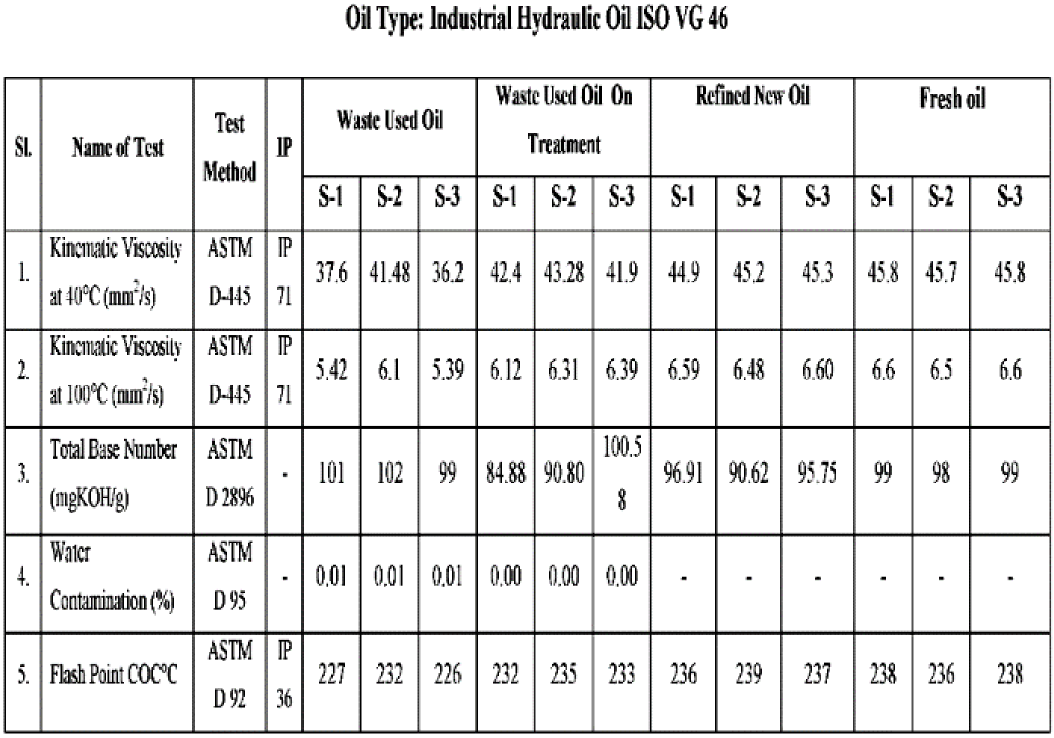
A.3: Sample Test of Mono Grade Heavy Duty Diesel Engine Oil SAE VG 40.



Oil Type: Mono grade Heavy Duty Diesel Engine Oil SAE VG 40

Sl.	Name of Test	Test Method	Waste Used Oil			Waste Used Oil (On Treatment)			Refined New Oil			Fresh oil		
			S-1	S-2	S-3	S-1	S-2	S-3	S-1	S-2	S-3	S-1	S-2	S-3
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTM D-445	107	109	103	135	141	138	163.4	162.3	163.07	164.1	164.2	164.15
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTM D-445	5.2	5.2	4.8	7.9	8.6	8.1	15.9	16.0	15.97	15.7	15.7	15.67
3.	Total Base Number (mgKOH/g)	ASTM D 2896	5.205	5.201	5.198	8.221	9.021	8.872	10	10	11	12	12	12
4.	Water Contamination (%)	ASTM D 95	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.	Flash Point COC°C	ASTM D 92	180	183	181	186	189	188	231	229	232	242	241	242
6.	Total Acid Number (mgKOH/g)	ASTM D 2896	2.74	2.73	2.73	1.74	1.73	1.73	-	-	-	-	-	-
7.	Color	ASTM D1500	>8	>7.9	>8	>6	>6.9	>6	4.5	4.4	4.3	4.3	4.2	4.3
8.	Density 15°C	ASTM D1298	0.8981	0.9102	0.8988	0.8781	0.8802	0.8588	0.8823	0.8923	0.8913	0.8793	0.8793	0.8793
9.	Index viscosity	ASTM D2270	111	109	110	112	110	113	112	111	112	114	113	114
10.	Flow point °C	ASTM D97	-21	-19	-20	-19	-16	-15	-24	-22	-24	-22	-22	-22
11.	Ashes (% Pds)	ASTM D874	0.6	0.59	0.6	0.3	0.29	0.3	-	-	-	-	-	-
12.	Index Conradson(% Pds)	ASTM D482	1.30	1.29	1.30	0.60	0.49	0.70	-	-	-	-	-	-
13.	Sulfur content (% Pds)	ASTM D2622	0.299	0.291	0.293	0.019	0.121	0.113	-	-	-	-	-	-
14.	Test dilution fuel (% V)	ASTM D322	0.4	0.41	0.39	0.2	0.21	0.19	-	-	-	-	-	-

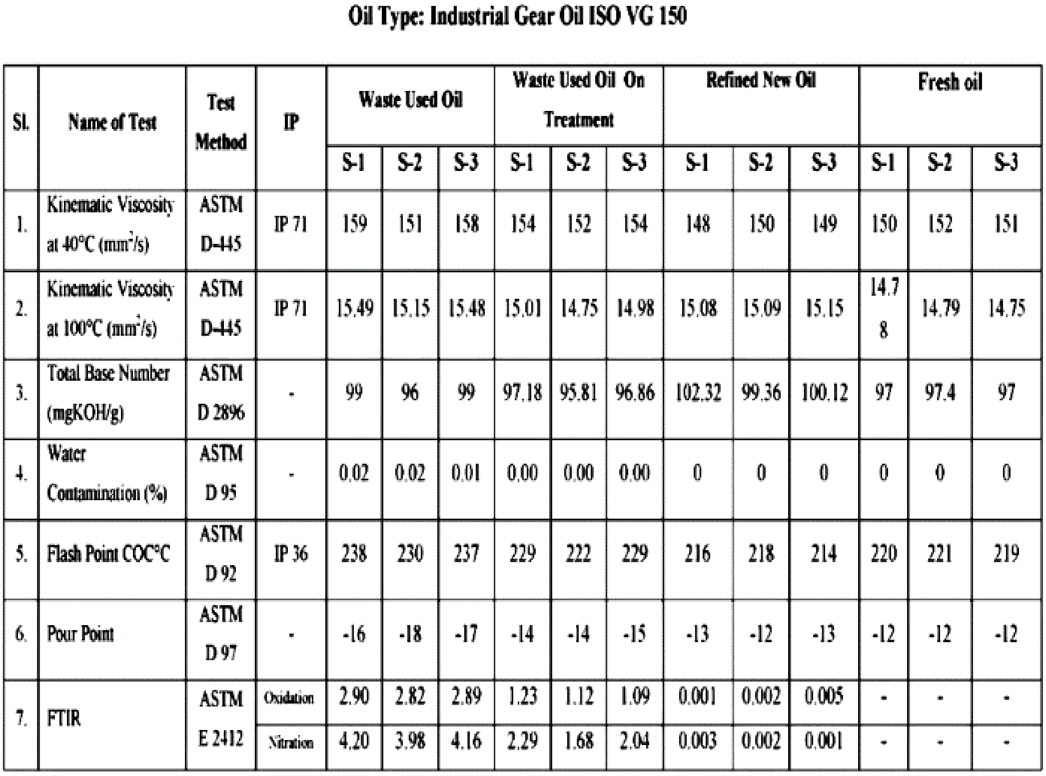
A.4 : Sample Test of Industrial Hydraulic Oil ISO VG 46.



Oil Type: Industrial Hydraulic Oil ISO VG 46

Sl.	Name of Test	Test Method	IP	Waste Used Oil			Waste Used Oil On Treatment			Refined New Oil			Fresh oil		
				S-1	S-2	S-3	S-1	S-2	S-3	S-1	S-2	S-3	S-1	S-2	S-3
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTM D-445	IP 71	37.6	41.48	36.2	42.4	43.28	41.9	44.9	45.2	45.3	45.8	45.7	45.8
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTM D-445	IP 71	5.42	6.1	5.39	6.12	6.31	6.39	6.59	6.48	6.60	6.6	6.5	6.6
3.	Total Base Number (mgKOH/g)	ASTM D 2896	-	101	102	99	84.88	90.80	100.58	96.91	90.62	95.75	99	98	99
4.	Water Contamination (%)	ASTM D 95	-	0.01	0.01	0.01	0.00	0.00	0.00	-	-	-	-	-	-
5.	Flash Point COC°C	ASTM D 92	IP 36	227	232	226	232	235	233	236	239	237	238	236	238

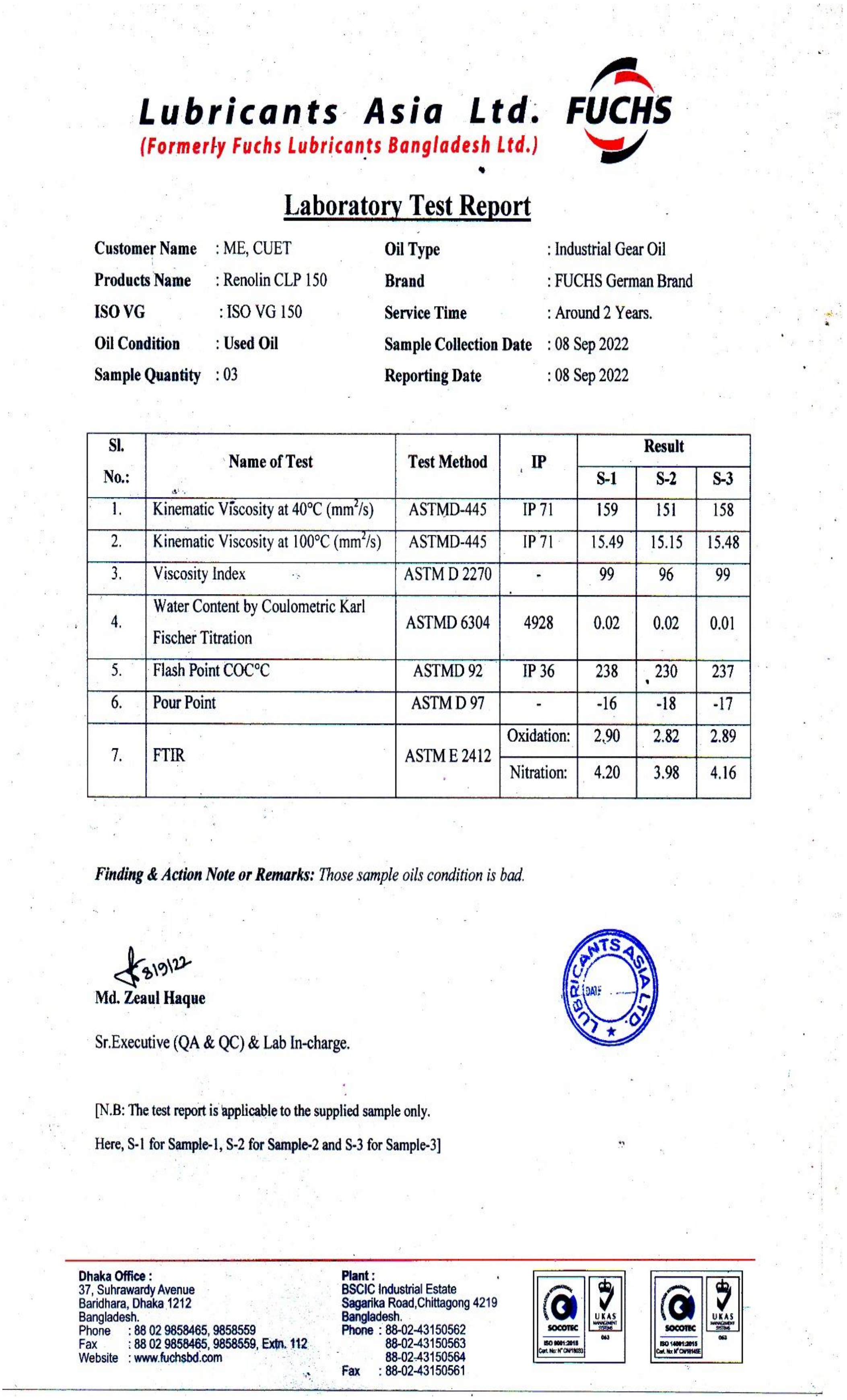
A.5 : Sample Test of Industrial Gear Oil ISO VG 150.



Oil Type: Industrial Gear Oil ISO VG 150

Sl.	Name of Test	Test Method	IP	Waste Used Oil			Waste Used Oil On Treatment			Refined New Oil			Fresh oil		
				S-1	S-2	S-3	S-1	S-2	S-3	S-1	S-2	S-3	S-1	S-2	S-3
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTM D-445	IP 71	159	151	158	154	152	154	148	150	149	150	152	151
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTM D-445	IP 71	15.49	15.15	15.48	15.01	14.75	14.98	15.08	15.09	15.15	14.78	14.79	14.75
3.	Total Base Number (mgKOH/g)	ASTM D 2896	-	99	96	99	97.18	95.81	96.86	102.32	99.36	100.12	97	97.4	97
4.	Water Contamination (%)	ASTM D 95	-	0.02	0.02	0.01	0.00	0.00	0.00	0	0	0	0	0	0
5.	Flash Point COC°C	ASTM D 92	IP 36	238	230	237	229	222	229	216	218	214	220	221	219
6.	Pour Point	ASTM D 97	-	-16	-18	-17	-14	-14	-15	-13	-12	-13	-12	-12	-12
7.	FTIR	ASTM E 2412	Oxidation	2.90	2.82	2.89	1.23	1.12	1.09	0.001	0.002	0.005	-	-	-
			Nitration	4.20	3.98	4.16	2.29	1.68	2.04	0.003	0.002	0.001	-	-	-

A.6: Laboratory Test report of Used Lubricating Oil ISO VG 150.



Lubricants Asia Ltd. **FUCHS**
(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET	**Oil Type**	: Industrial Gear Oil
Products Name	: Renolin CLP 150	**Brand**	: FUCHS German Brand
ISO VG	: ISO VG 150	**Service Time**	: Around 2 Years.
Oil Condition	: **Used Oil**	**Sample Collection Date**	: 08 Sep 2022
Sample Quantity	: 03	**Reporting Date**	: 08 Sep 2022

Sl. No.:	**Name of Test**	**Test Method**	**IP**	**Result**		
				S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTMD-445	IP 71	159	151	158
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTMD-445	IP 71	15.49	15.15	15.48
3.	Viscosity Index	ASTM D 2270	-	99	96	99
4.	Water Content by Coulometric Karl Fischer Titration	ASTMD 6304	4928	0.02	0.02	0.01
5.	Flash Point COC°C	ASTMD 92	IP 36	238	230	237
6.	Pour Point	ASTM D 97	-	-16	-18	-17
7.	FTIR	ASTM E 2412	Oxidation:	2.90	2.82	2.89
			Nitration:	4.20	3.98	4.16

Finding & Action Note or Remarks: *Those sample oils condition is bad.*

8/9/22

Md. Zeaul Haque

Sr.Executive (QA & QC) & Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.

Here, S-1 for Sample-1, S-2 for Sample-2 and S-3 for Sample-3]

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Website : www.fuchsbd.com

Plant :
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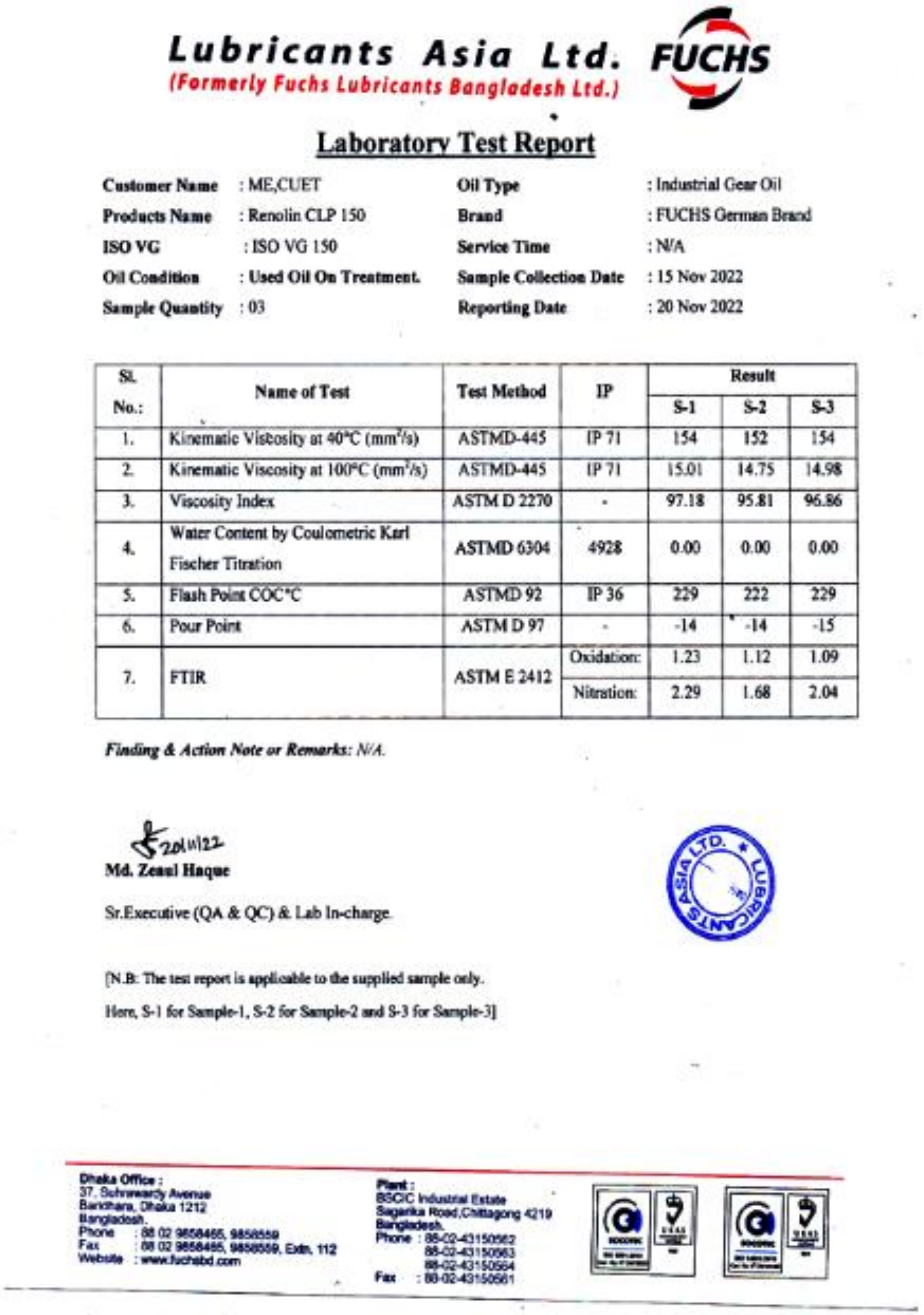
Sagarika Road,Chittagong 4219
Bangladesh.
Phone : 88-02-43150562
88-02-43150563
88-02-43150564
Fax : 88-02-43150561

A.7: Laboratory Test report of Used Oil (On Treatment) ISO VG 150.



Lubricants Asia Ltd.
(Formerly Fuchs Lubricants Bangladesh Ltd.)

FUCHS

Laboratory Test Report

Customer Name : ME,CUET
Products Name : Renolin CLP 150
ISO VG : ISO VG 150
Oil Condition : **Used Oil On Treatment.**
Sample Quantity : 03
Oil Type : Industrial Gear Oil
Brand : FUCHS German Brand
Service Time : N/A
Sample Collection Date : 15 Nov 2022
Reporting Date : 20 Nov 2022

Sl. No.:	**Name of Test**	**Test Method**	**IP**	**Result**		
				S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm²/s)	ASTMD-445	IP 71	154	152	154
2.	Kinematic Viscosity at 100°C (mm²/s)	ASTMD-445	IP 71	15.01	14.75	14.98
3.	Viscosity Index	ASTM D 2270	-	97.18	95.81	96.86
4.	Water Content by Coulometric Karl Fischer Titration	ASTMD 6304	4928	0.00	0.00	0.00
5.	Flash Point COC°C	ASTMD 92	IP 36	229	222	229
6.	Pour Point	ASTM D 97	-	-14	-14	-15
7.	FTIR	ASTM E 2412	Oxidation:	1.23	1.12	1.09
			Nitration:	2.29	1.68	2.04

Finding & Action Note or Remarks: *N/A.*

20/11/22
Md. Zeaul Haque

Sr.Executive (QA & QC) & Lab In-charge

[N.B: The test report is applicable to the supplied sample only.
Here, S-1 for Sample-1, S-2 for Sample-2 and S-3 for Sample-3]

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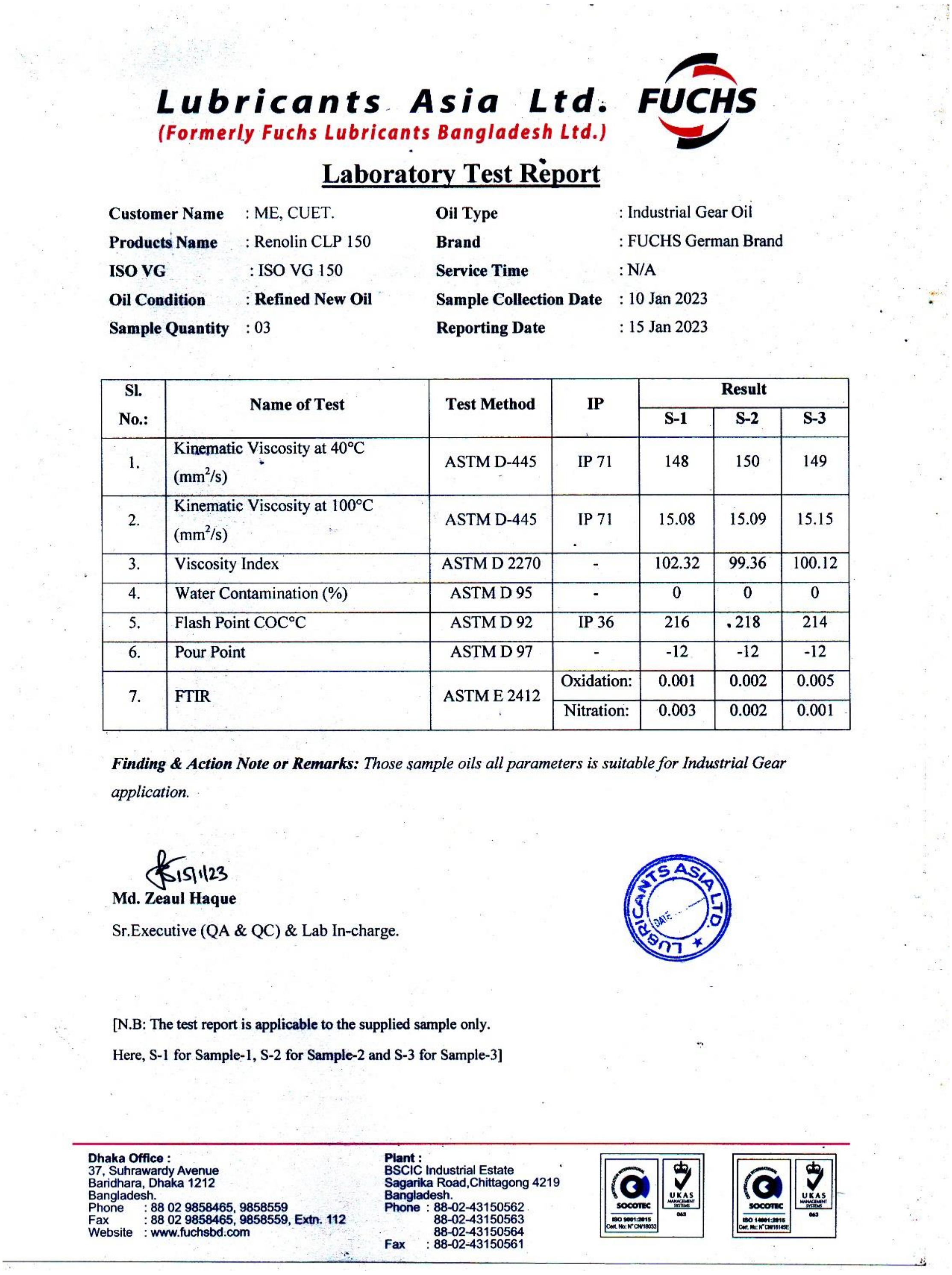
88-02-43150563
88-02-43150564
Fax : 88-02-43150561

A.8 : Laboratory Test report of Refined new Oil ISO VG 150.



Lubricants Asia Ltd. **FUCHS**

(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET.	**Oil Type**	: Industrial Gear Oil
Products Name	: Renolin CLP 150	**Brand**	: FUCHS German Brand
ISO VG	: ISO VG 150	**Service Time**	: N/A
Oil Condition	: **Refined New Oil**	**Sample Collection Date**	: 10 Jan 2023
Sample Quantity	: 03	**Reporting Date**	: 15 Jan 2023

Sl. No.:	**Name of Test**	**Test Method**	**IP**	**Result**		
				S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTM D-445	IP 71	148	150	149
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTM D-445	IP 71	15.08	15.09	15.15
3.	Viscosity Index	ASTM D 2270	-	102.32	99.36	100.12
4.	Water Contamination (%)	ASTM D 95	-	0	0	0
5.	Flash Point COC°C	ASTM D 92	IP 36	216	218	214
6.	Pour Point	ASTM D 97	-	-12	-12	-12
7.	FTIR	ASTM E 2412	Oxidation:	0.001	0.002	0.005
			Nitration:	0.003	0.002	0.001

Finding & Action Note or Remarks: *Those sample oils all parameters is suitable for Industrial Gear application.*

15/1/23
Md. Zeaul Haque
Sr.Executive (QA & QC) & Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.
Here, S-1 for Sample-1, S-2 for Sample-2 and S-3 for Sample-3]

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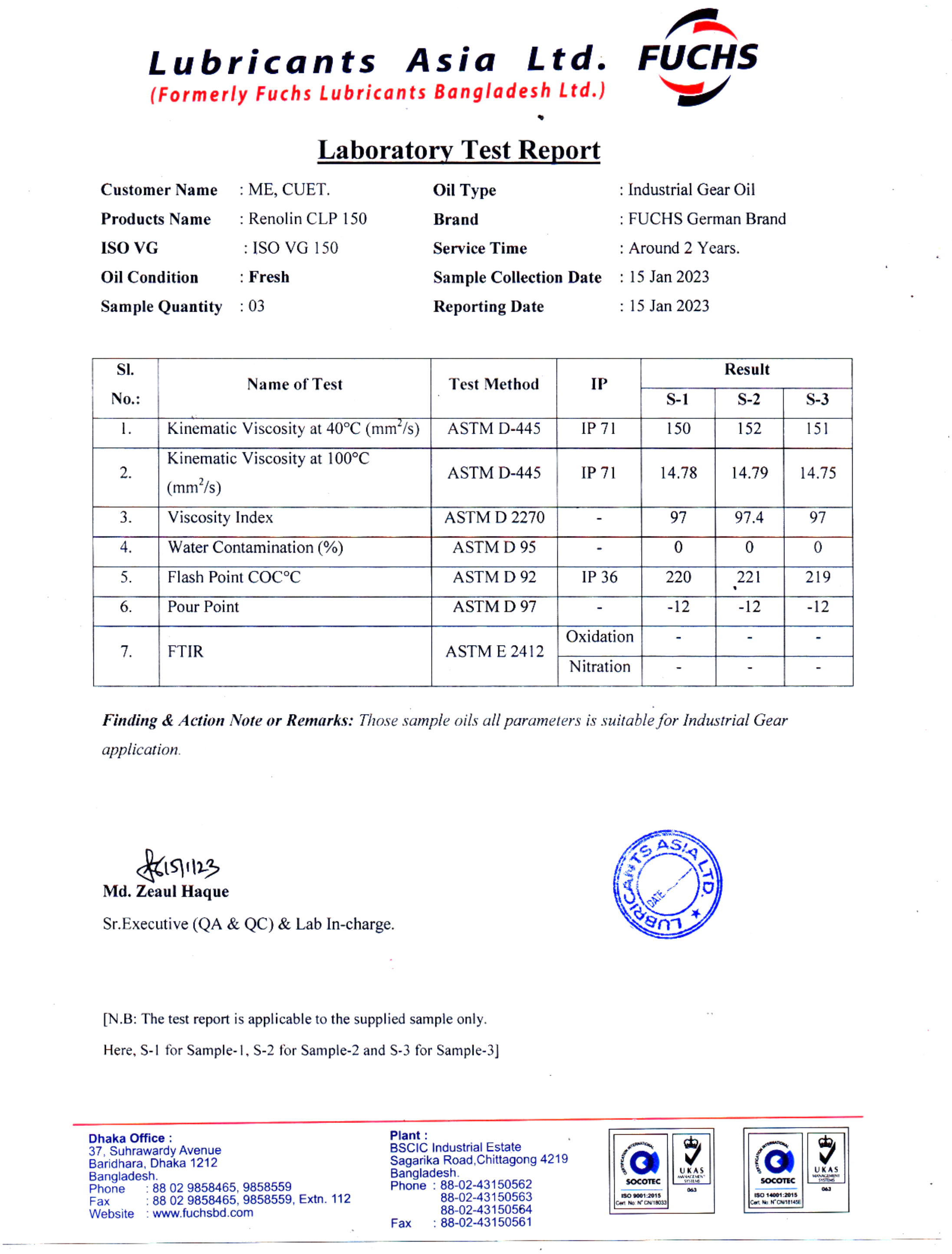
SOCOTEC ISO 9001:2015 Cert. No: N° CN/18033 UKAS MANAGEMENT SYSTEMS 063

SOCOTEC ISO 14001:2015 Cert. No: N° CN/18145E UKAS MANAGEMENT SYSTEMS 063

A.9 : Laboratory Test report of Fresh Oil ISO VG 150.



Lubricants Asia Ltd. **FUCHS**
(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET.	**Oil Type**	: Industrial Gear Oil
Products Name	: Renolin CLP 150	**Brand**	: FUCHS German Brand
ISO VG	: ISO VG 150	**Service Time**	: Around 2 Years.
Oil Condition	: **Fresh**	**Sample Collection Date**	: 15 Jan 2023
Sample Quantity	: 03	**Reporting Date**	: 15 Jan 2023

Sl. No.:	**Name of Test**	**Test Method**	**IP**	**Result**		
				S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTM D-445	IP 71	150	152	151
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTM D-445	IP 71	14.78	14.79	14.75
3.	Viscosity Index	ASTM D 2270	-	97	97.4	97
4.	Water Contamination (%)	ASTM D 95	-	0	0	0
5.	Flash Point COC°C	ASTM D 92	IP 36	220	221	219
6.	Pour Point	ASTM D 97	-	-12	-12	-12
7.	FTIR	ASTM E 2412	Oxidation	-	-	-
			Nitration	-	-	-

Finding & Action Note or Remarks: *Those sample oils all parameters is suitable for Industrial Gear application.*

15/1/23
Md. Zeaul Haque
Sr.Executive (QA & QC) & Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.

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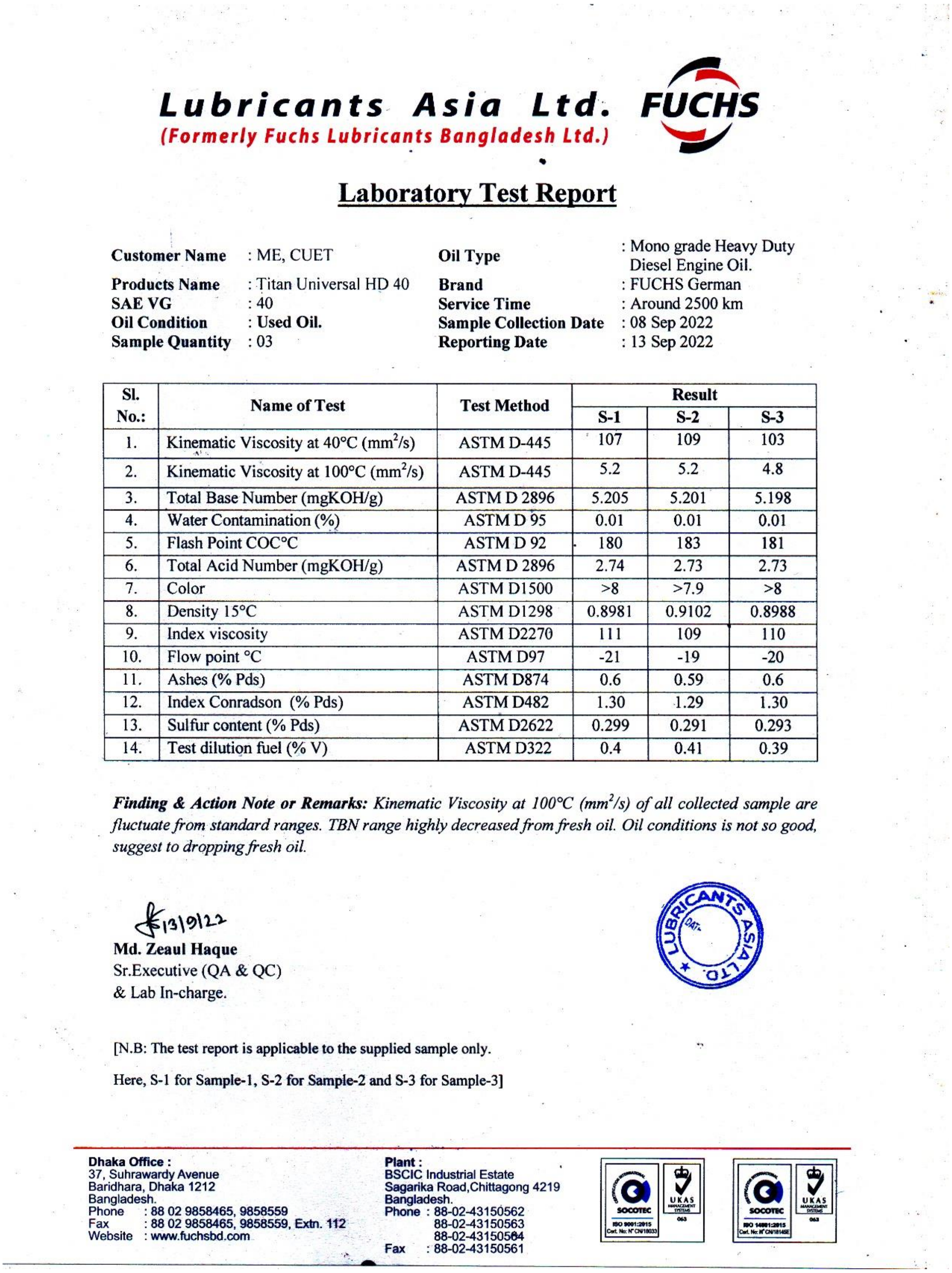
88-02-43150563
88-02-43150564
Fax : 88-02-43150561

A.10 : Laboratory Test report of Used Oil SAE VG 40.



Lubricants Asia Ltd. **FUCHS**

(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET	**Oil Type**	: Mono grade Heavy Duty Diesel Engine Oil.
Products Name	: Titan Universal HD 40	**Brand**	: FUCHS German
SAE VG	: 40	**Service Time**	: Around 2500 km
Oil Condition	: **Used Oil.**	**Sample Collection Date**	: 08 Sep 2022
Sample Quantity	: 03	**Reporting Date**	: 13 Sep 2022

Sl. No.:	**Name of Test**	**Test Method**	**Result**		
			S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTM D-445	107	109	103
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTM D-445	5.2	5.2	4.8
3.	Total Base Number (mgKOH/g)	ASTM D 2896	5.205	5.201	5.198
4.	Water Contamination (%)	ASTM D 95	0.01	0.01	0.01
5.	Flash Point COC°C	ASTM D 92	180	183	181
6.	Total Acid Number (mgKOH/g)	ASTM D 2896	2.74	2.73	2.73
7.	Color	ASTM D1500	>8	>7.9	>8
8.	Density 15°C	ASTM D1298	0.8981	0.9102	0.8988
9.	Index viscosity	ASTM D2270	111	109	110
10.	Flow point °C	ASTM D97	-21	-19	-20
11.	Ashes (% Pds)	ASTM D874	0.6	0.59	0.6
12.	Index Conradson (% Pds)	ASTM D482	1.30	1.29	1.30
13.	Sulfur content (% Pds)	ASTM D2622	0.299	0.291	0.293
14.	Test dilution fuel (% V)	ASTM D322	0.4	0.41	0.39

Finding & Action Note or Remarks: *Kinematic Viscosity at 100°C (mm^2/s) of all collected sample are fluctuate from standard ranges. TBN range highly decreased from fresh oil. Oil conditions is not so good, suggest to dropping fresh oil.*

13|9|22

Md. Zeaul Haque
Sr.Executive (QA & QC)
& Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.

Here, S-1 for Sample-1, S-2 for Sample-2 and S-3 for Sample-3]

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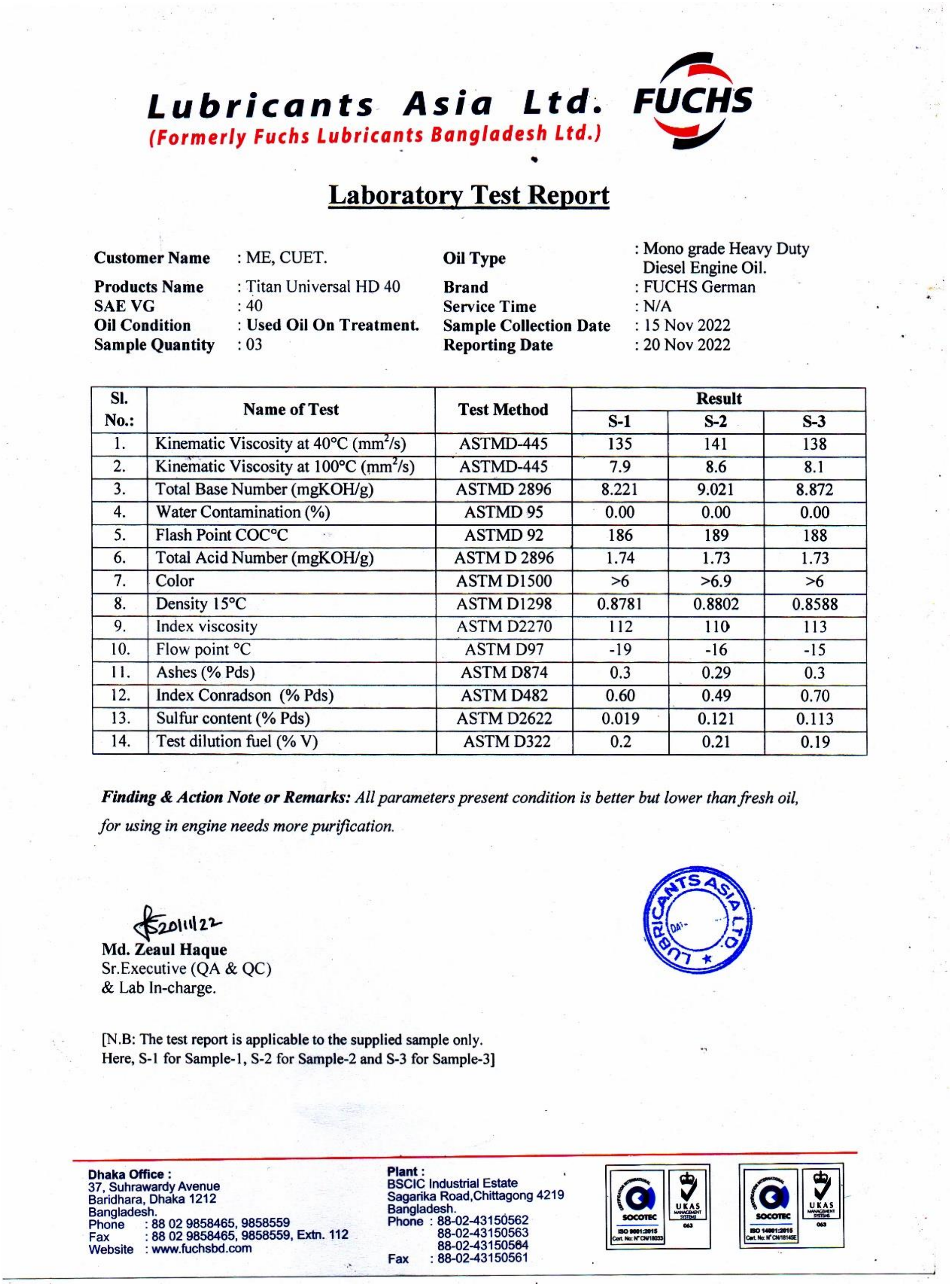
SOCOTEC ISO 9001:2015 Cert. No: N° CN/18033 UKAS MANAGEMENT SYSTEMS 063

SOCOTEC ISO 14001:2015 Cert. No: N° CN/18145E UKAS MANAGEMENT SYSTEMS 063

A.11 : Laboratory Test report of Used Oil (On Treatment) SAE VG 40.



Lubricants Asia Ltd. **FUCHS**

(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET.	**Oil Type**	: Mono grade Heavy Duty Diesel Engine Oil.
Products Name	: Titan Universal HD 40	**Brand**	: FUCHS German
SAE VG	: 40	**Service Time**	: N/A
Oil Condition	: **Used Oil On Treatment.**	**Sample Collection Date**	: 15 Nov 2022
Sample Quantity	: 03	**Reporting Date**	: 20 Nov 2022

Sl. No.:	Name of Test	Test Method	Result		
			S-1	S-2	S-3
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTMD-445	135	141	138
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTMD-445	7.9	8.6	8.1
3.	Total Base Number (mgKOH/g)	ASTMD 2896	8.221	9.021	8.872
4.	Water Contamination (%)	ASTMD 95	0.00	0.00	0.00
5.	Flash Point COC°C	ASTMD 92	186	189	188
6.	Total Acid Number (mgKOH/g)	ASTM D 2896	1.74	1.73	1.73
7.	Color	ASTM D1500	>6	>6.9	>6
8.	Density 15°C	ASTM D1298	0.8781	0.8802	0.8588
9.	Index viscosity	ASTM D2270	112	110	113
10.	Flow point °C	ASTM D97	-19	-16	-15
11.	Ashes (% Pds)	ASTM D874	0.3	0.29	0.3
12.	Index Conradson (% Pds)	ASTM D482	0.60	0.49	0.70
13.	Sulfur content (% Pds)	ASTM D2622	0.019	0.121	0.113
14.	Test dilution fuel (% V)	ASTM D322	0.2	0.21	0.19

Finding & Action Note or Remarks: *All parameters present condition is better but lower than fresh oil, for using in engine needs more purification.*

20/11/22

Md. Zeaul Haque
Sr.Executive (QA & QC)
& Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.
Here, S-1 for Sample-1, S-2 for Sample-2 and S-3 for Sample-3]

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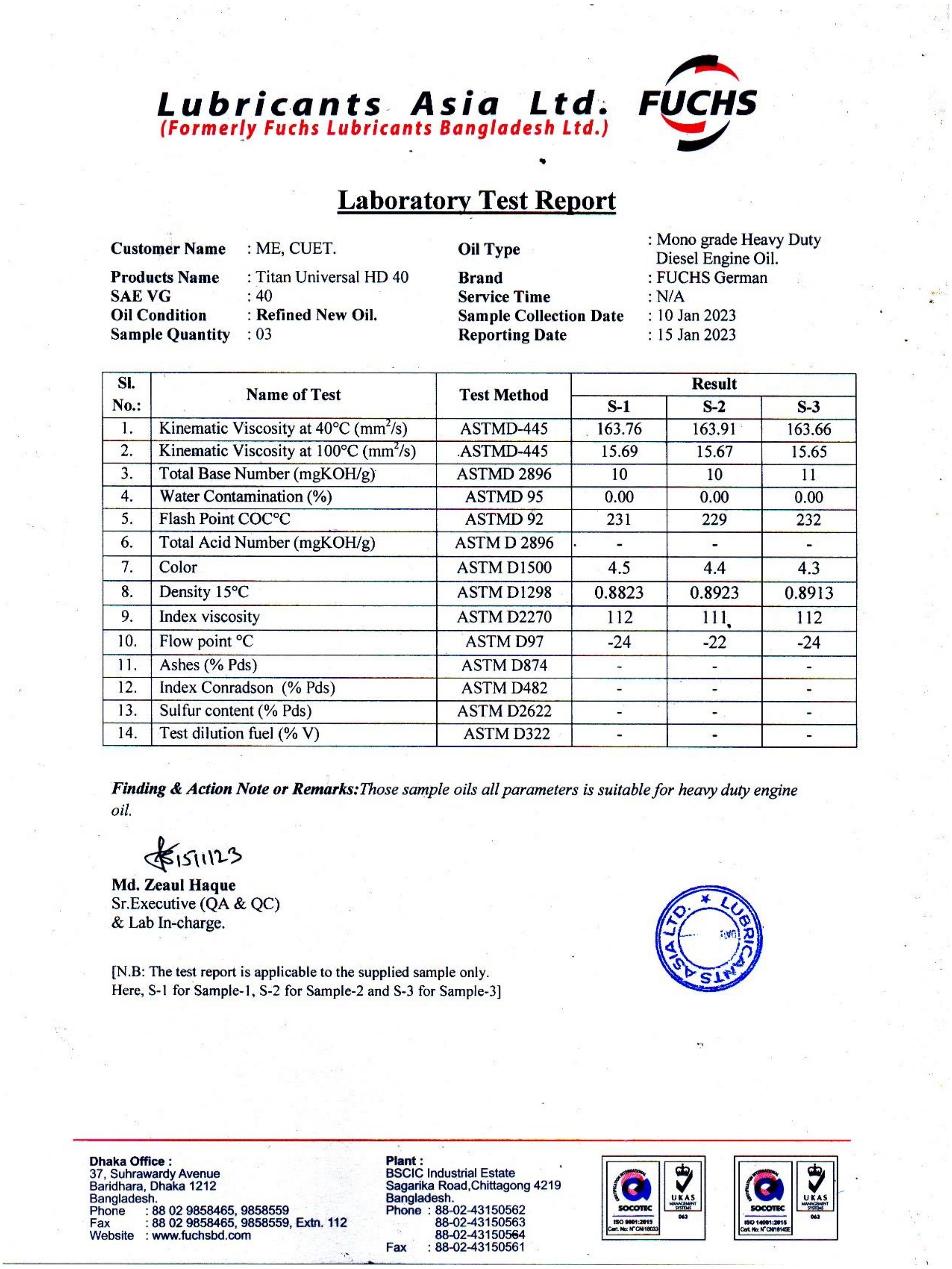
SOCOTEC ISO 14001:2015 Cert. No: N° CN/18145E UKAS MANAGEMENT SYSTEMS 063

A.12 : Laboratory Test report of Refined New Oil Used Oil SAE VG 40.



Lubricants Asia Ltd. **FUCHS**
(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET.	**Oil Type**	: Mono grade Heavy Duty Diesel Engine Oil.
Products Name	: Titan Universal HD 40	**Brand**	: FUCHS German
SAE VG	: 40	**Service Time**	: N/A
Oil Condition	: **Refined New Oil.**	**Sample Collection Date**	: 10 Jan 2023
Sample Quantity	: 03	**Reporting Date**	: 15 Jan 2023

Sl. No.:	Name of Test	Test Method	Result		
			S-1	S-2	S-3
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTMD-445	163.76	163.91	163.66
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTMD-445	15.69	15.67	15.65
3.	Total Base Number (mgKOH/g)	ASTMD 2896	10	10	11
4.	Water Contamination (%)	ASTMD 95	0.00	0.00	0.00
5.	Flash Point COC°C	ASTMD 92	231	229	232
6.	Total Acid Number (mgKOH/g)	ASTM D 2896	-	-	-
7.	Color	ASTM D1500	4.5	4.4	4.3
8.	Density 15°C	ASTM D1298	0.8823	0.8923	0.8913
9.	Index viscosity	ASTM D2270	112	111	112
10.	Flow point °C	ASTM D97	-24	-22	-24
11.	Ashes (% Pds)	ASTM D874	-	-	-
12.	Index Conradson (% Pds)	ASTM D482	-	-	-
13.	Sulfur content (% Pds)	ASTM D2622	-	-	-
14.	Test dilution fuel (% V)	ASTM D322	-	-	-

Finding & Action Note or Remarks:*Those sample oils all parameters is suitable for heavy duty engine oil.*

15/1/23

Md. Zeaul Haque
Sr.Executive (QA & QC)
& Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.
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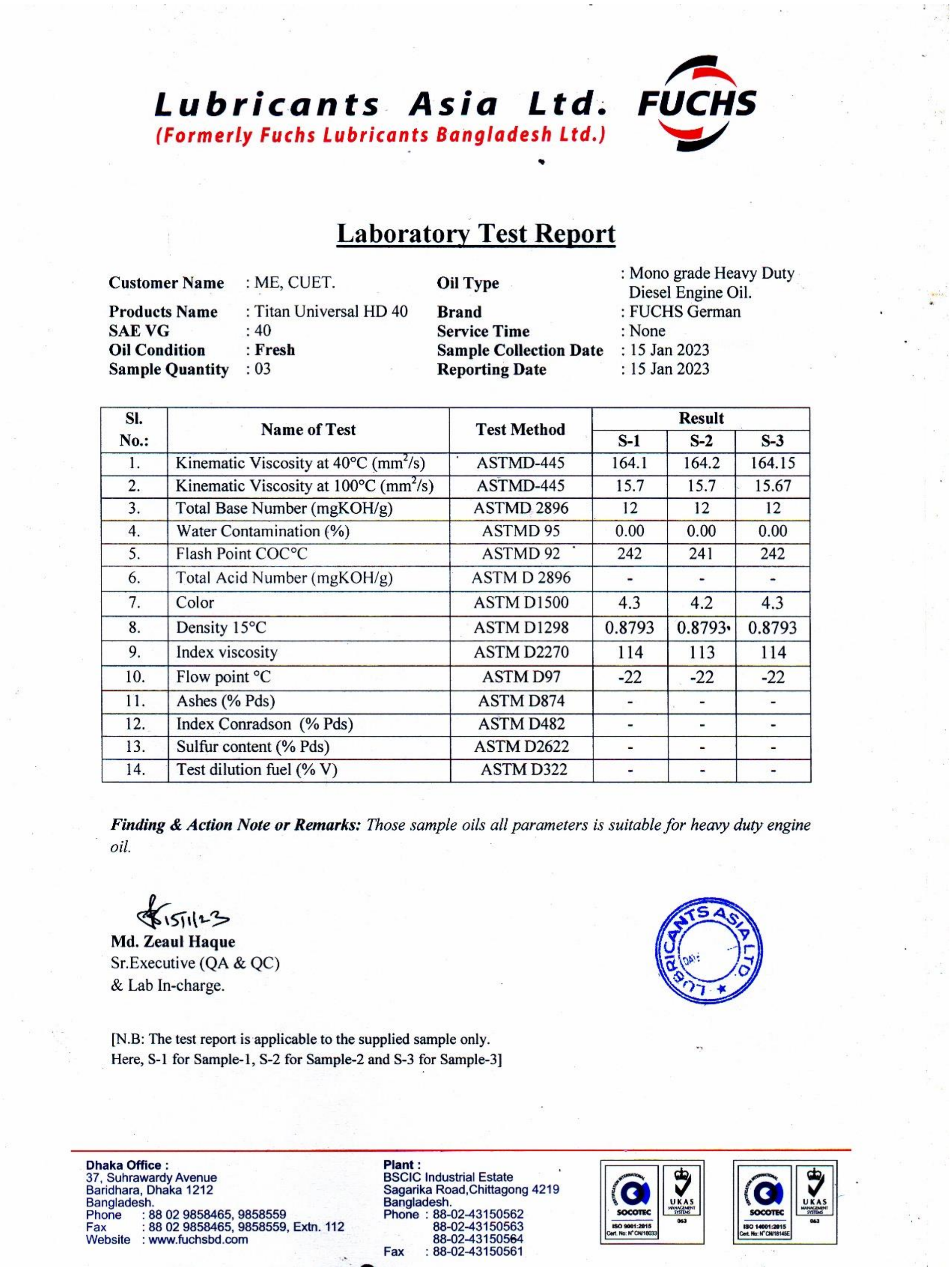
A.13 : Laboratory Test report of Fresh Oil SAE VG 40.



Lubricants Asia Ltd. FUCHS
(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET.	**Oil Type**	: Mono grade Heavy Duty Diesel Engine Oil.
Products Name	: Titan Universal HD 40	**Brand**	: FUCHS German
SAE VG	: 40	**Service Time**	: None
Oil Condition	: **Fresh**	**Sample Collection Date**	: 15 Jan 2023
Sample Quantity	: 03	**Reporting Date**	: 15 Jan 2023

Sl. No.:	**Name of Test**	**Test Method**	**Result**		
			S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTMD-445	164.1	164.2	164.15
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTMD-445	15.7	15.7	15.67
3.	Total Base Number (mgKOH/g)	ASTMD 2896	12	12	12
4.	Water Contamination (%)	ASTMD 95	0.00	0.00	0.00
5.	Flash Point COC°C	ASTMD 92	242	241	242
6.	Total Acid Number (mgKOH/g)	ASTM D 2896	-	-	-
7.	Color	ASTM D1500	4.3	4.2	4.3
8.	Density 15°C	ASTM D1298	0.8793	0.8793	0.8793
9.	Index viscosity	ASTM D2270	114	113	114
10.	Flow point °C	ASTM D97	-22	-22	-22
11.	Ashes (% Pds)	ASTM D874	-	-	-
12.	Index Conradson (% Pds)	ASTM D482	-	-	-
13.	Sulfur content (% Pds)	ASTM D2622	-	-	-
14.	Test dilution fuel (% V)	ASTM D322	-	-	-

Finding & Action Note or Remarks: *Those sample oils all parameters is suitable for heavy duty engine oil.*

15/1/23
Md. Zeaul Haque
Sr.Executive (QA & QC)
& Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.
Here, S-1 for Sample-1, S-2 for Sample-2 and S-3 for Sample-3]

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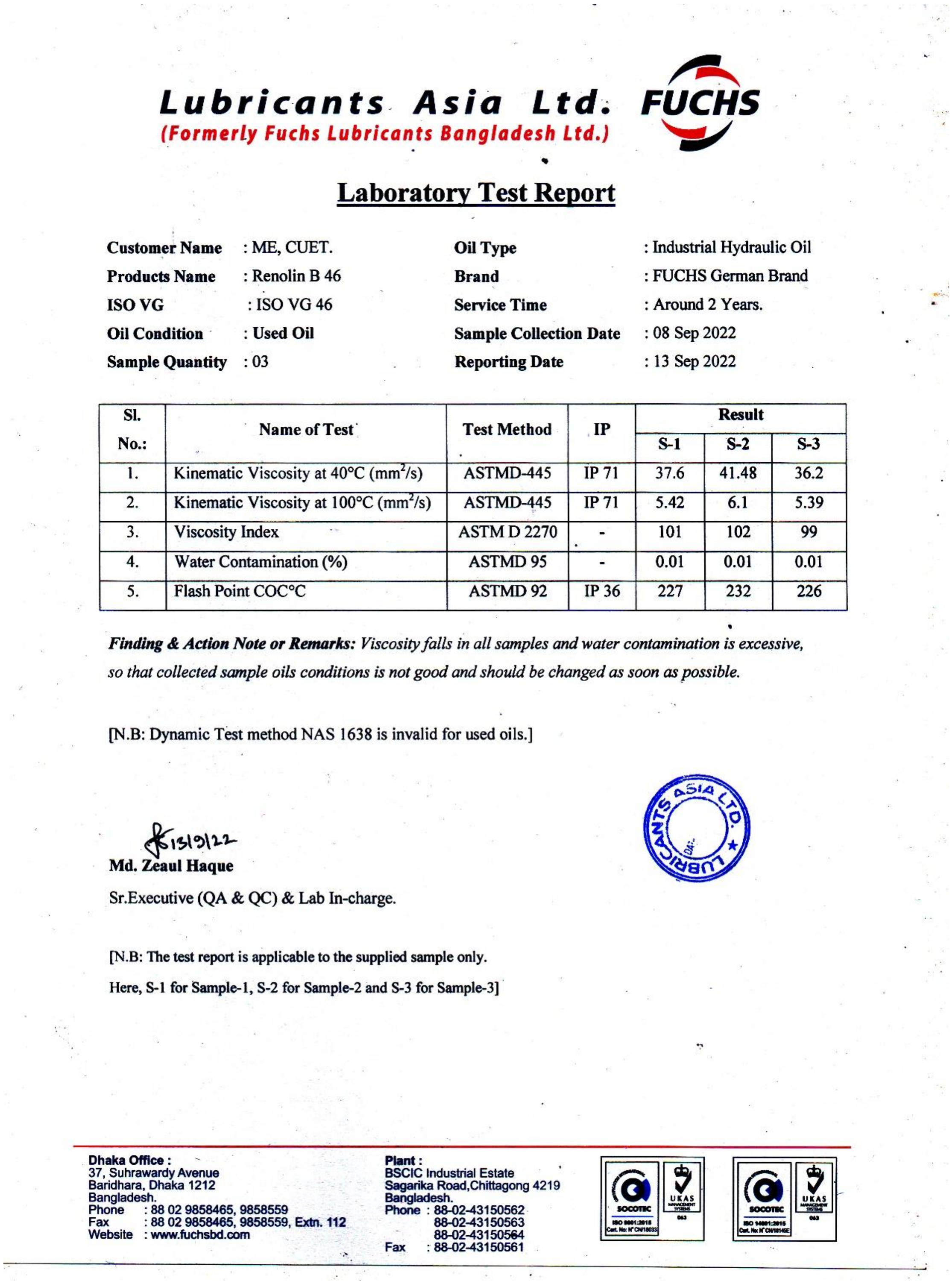
ISO 14001:2015 Cert. No: N° CN/18145E

A.14 : Laboratory Test report of Used Oil ISO VG 46.



Lubricants Asia Ltd. **FUCHS**

(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET.	**Oil Type**	: Industrial Hydraulic Oil
Products Name	: Renolin B 46	**Brand**	: FUCHS German Brand
ISO VG	: ISO VG 46	**Service Time**	: Around 2 Years.
Oil Condition	: **Used Oil**	**Sample Collection Date**	: 08 Sep 2022
Sample Quantity	: 03	**Reporting Date**	: 13 Sep 2022

Sl. No.:	**Name of Test**	**Test Method**	**IP**	**Result**		
				S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTMD-445	IP 71	37.6	41.48	36.2
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTMD-445	IP 71	5.42	6.1	5.39
3.	Viscosity Index	ASTM D 2270	-	101	102	99
4.	Water Contamination (%)	ASTMD 95	-	0.01	0.01	0.01
5.	Flash Point COC°C	ASTMD 92	IP 36	227	232	226

Finding & Action Note or Remarks: *Viscosity falls in all samples and water contamination is excessive, so that collected sample oils conditions is not good and should be changed as soon as possible.*

[N.B: Dynamic Test method NAS 1638 is invalid for used oils.]

13/9/22

Md. Zeaul Haque

Sr.Executive (QA & QC) & Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.

Here, S-1 for Sample-1, S-2 for Sample-2 and S-3 for Sample-3]

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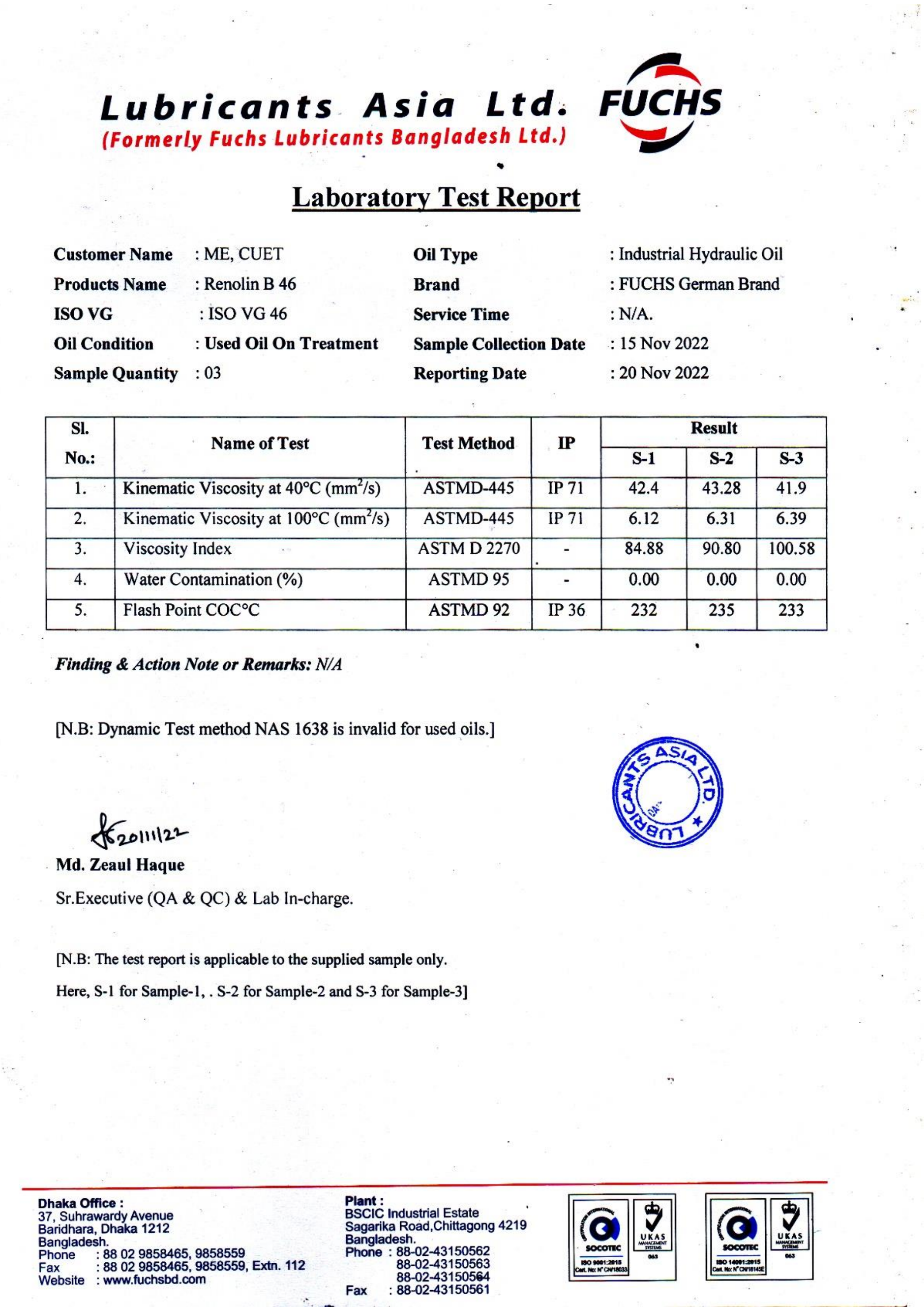
A.15 : Laboratory Test report of Used Oil (on Treatment) ISO VG 46.



Lubricants Asia Ltd. **FUCHS**

(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET	**Oil Type**	: Industrial Hydraulic Oil
Products Name	: Renolin B 46	**Brand**	: FUCHS German Brand
ISO VG	: ISO VG 46	**Service Time**	: N/A.
Oil Condition	: **Used Oil On Treatment**	**Sample Collection Date**	: 15 Nov 2022
Sample Quantity	: 03	**Reporting Date**	: 20 Nov 2022

Sl. No.:	Name of Test	Test Method	IP	Result		
				S-1	S-2	S-3
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTMD-445	IP 71	42.4	43.28	41.9
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTMD-445	IP 71	6.12	6.31	6.39
3.	Viscosity Index	ASTM D 2270	-	84.88	90.80	100.58
4.	Water Contamination (%)	ASTMD 95	-	0.00	0.00	0.00
5.	Flash Point COC°C	ASTMD 92	IP 36	232	235	233

***Finding & Action Note or Remarks:** N/A*

[N.B: Dynamic Test method NAS 1638 is invalid for used oils.]

20|11|22

Md. Zeaul Haque

Sr.Executive (QA & QC) & Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.
Here, S-1 for Sample-1, . S-2 for Sample-2 and S-3 for Sample-3]

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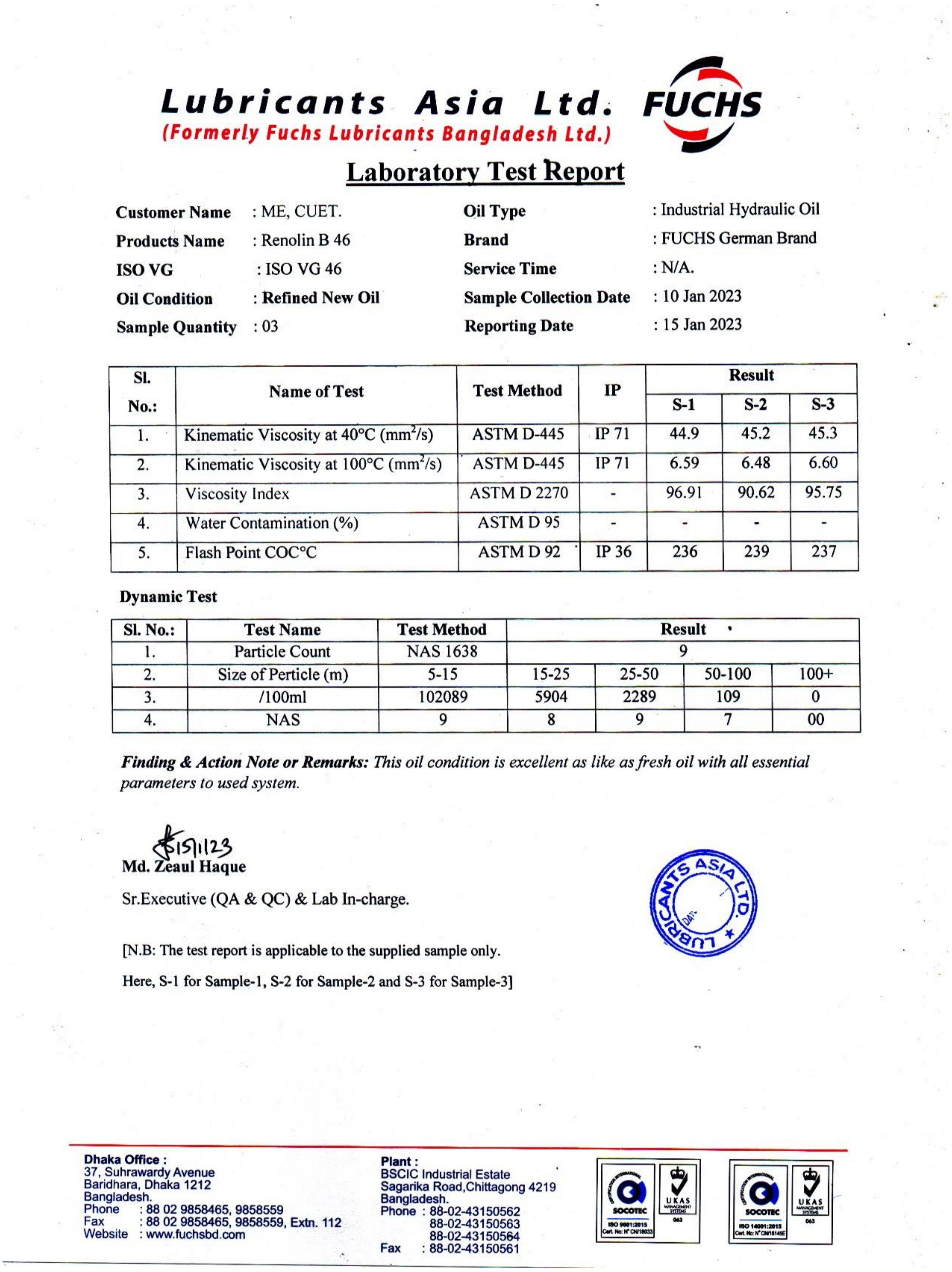
A.16 : Laboratory Test report of Refined Lubricating Oil ISO VG 46.



Lubricants Asia Ltd. FUCHS
(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET.	**Oil Type**	: Industrial Hydraulic Oil
Products Name	: Renolin B 46	**Brand**	: FUCHS German Brand
ISO VG	: ISO VG 46	**Service Time**	: N/A.
Oil Condition	: **Refined New Oil**	**Sample Collection Date**	: 10 Jan 2023
Sample Quantity	: 03	**Reporting Date**	: 15 Jan 2023

Sl. No.:	**Name of Test**	**Test Method**	**IP**	**Result**		
				S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTM D-445	IP 71	44.9	45.2	45.3
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTM D-445	IP 71	6.59	6.48	6.60
3.	Viscosity Index	ASTM D 2270	-	96.91	90.62	95.75
4.	Water Contamination (%)	ASTM D 95	-	-	-	-
5.	Flash Point COC°C	ASTM D 92	IP 36	236	239	237

Dynamic Test

Sl. No.:	**Test Name**	**Test Method**	**Result**			
1.	Particle Count	NAS 1638	9			
2.	Size of Perticle (m)	5-15	15-25	25-50	50-100	100+
3.	/100ml	102089	5904	2289	109	0
4.	NAS	9	8	9	7	00

Finding & Action Note or Remarks: *This oil condition is excellent as like as fresh oil with all essential parameters to used system.*

15/1/23
Md. Zeaul Haque
Sr.Executive (QA & QC) & Lab In-charge.

[N.B: The test report is applicable to the supplied sample only.
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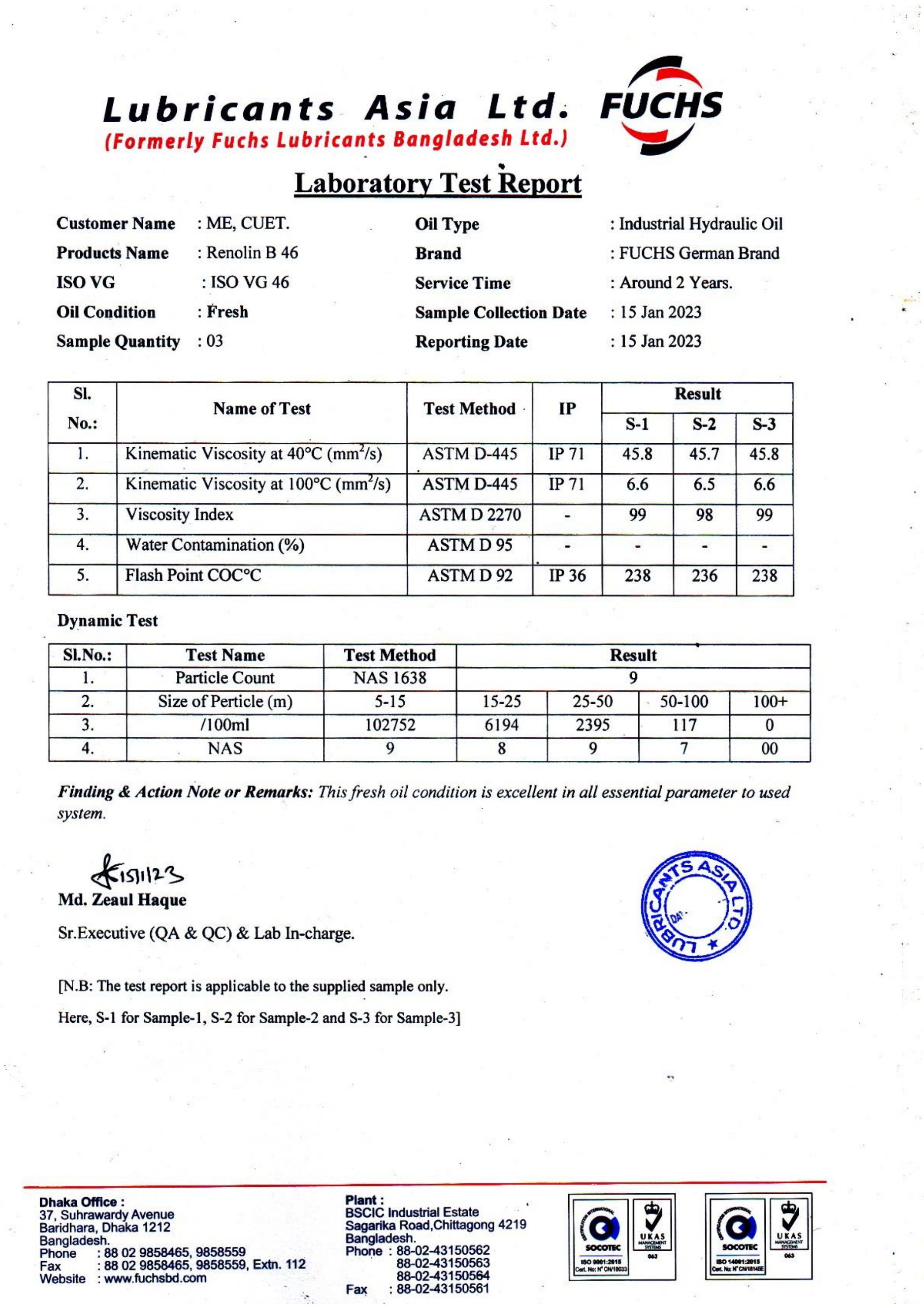
A.17: Laboratory Test report of Fresh Lubricating Oil ISO VG 46.



Lubricants Asia Ltd. **FUCHS**

(Formerly Fuchs Lubricants Bangladesh Ltd.)

Laboratory Test Report

Customer Name	: ME, CUET.	**Oil Type**	: Industrial Hydraulic Oil
Products Name	: Renolin B 46	**Brand**	: FUCHS German Brand
ISO VG	: ISO VG 46	**Service Time**	: Around 2 Years.
Oil Condition	: **Fresh**	**Sample Collection Date**	: 15 Jan 2023
Sample Quantity	: 03	**Reporting Date**	: 15 Jan 2023

Sl. No.:	**Name of Test**	**Test Method**	**IP**	**Result**		
				S-1	**S-2**	**S-3**
1.	Kinematic Viscosity at 40°C (mm^2/s)	ASTM D-445	IP 71	45.8	45.7	45.8
2.	Kinematic Viscosity at 100°C (mm^2/s)	ASTM D-445	IP 71	6.6	6.5	6.6
3.	Viscosity Index	ASTM D 2270	-	99	98	99
4.	Water Contamination (%)	ASTM D 95	-	-	-	-
5.	Flash Point COC°C	ASTM D 92	IP 36	238	236	238

Dynamic Test

Sl.No.:	**Test Name**	**Test Method**	**Result**			
1.	Particle Count	NAS 1638	9			
2.	Size of Perticle (m)	5-15	15-25	25-50	50-100	100+
3.	/100ml	102752	6194	2395	117	0
4.	NAS	9	8	9	7	00

Finding & Action Note or Remarks: *This fresh oil condition is excellent in all essential parameter to used system.*

15/1/23

Md. Zeaul Haque

Sr.Executive (QA & QC) & Lab In-charge.

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