

EXPERIMENTAL ANALYSIS OF REFINED WASTE LUBRICATING OILS USING DISTILLATION METHOD TO MINIMIZE ENERGY CONSUMPTION AND ENVIRONMENTAL POLLUTION

A project submitted in partial fulfillment of the requirements for award of the degree of

**MASTER OF ENGINEERING IN ENERGY TECHNOLOGY/
M.ENG. IN (ET)**

By

MOHAMMED RAFIQUUL ISLAM

STUDENT ID: 13MET004P



**Institute of Energy Technology
Chittagong University of Engineering and Technology
June 2025**

APPROVAL

The project titled “EXPERIMENTAL ANALYSIS OF REFINED WASTE LUBRICATING OILS USING DISTILLATION METHOD TO MINIMIZE ENERGY CONSUMPTION AND ENVIRONMENTAL POLLUTION” submitted by Mohammed Rafiqul Islam, ID No: 13MET004P has been acknowledged as meeting the requirements for a Master of Engineering in Energy Technology (M.Engg.) degree in part.

BOARD OF EXAMINERS

Prof.Dr. Sajal Chandra Banik Professor, Department of Mechanical Engineering Chittagong University of Engineering & Technology	Chairman (Supervisor)
Prof. Dr. Jamal Uddin Ahamed Professor, Department of Mechanical Engineering Director, Institute of Energy Technology Chittagong University of Engineering & Technology	Member (Ex-Officio)
Md. Adnan Faisal Siddique Research Assistant Professor, Institute of Energy Technology Chittagong University of Engineering & Technology	Member
Prof. Dr. Mohammad Asaduzzaman Chowdhury Professor, Department of Mechanical Engineering Dhaka University of Engineering & Technology	Member (External)

DECLARATION

The Project Report was fully explored and composed by the author, who also swears that it has never been submitted for acceptance into another degree or professional recognition. To the best of his comprehension, no one wrote or published the content included, with the exception of the relevant sources listed.

Mohammed Rafiqul Islam

ID No.: 13MET004P

Institute of Energy Technology

Chittagong University of Engineering and Technology

COPYRIGHT DECLARATION

I certify that I am the only author of the thesis, which is named “EXPERIMENTAL ANALYSIS OF REFINED WASTE LUBRICATING OILS USING DISTILLATION METHOD TO MINIMIZE ENERGY CONSUMPTION AND ENVIRONMENTAL POLLUTION”. In addition, I sent in a soft copy of my final hardcopy thesis, complete with any necessary final edits that the board of examination has approved.

After a year from the date of submission, I hereby give Chittagong University of Engineering and Technology the right to use my copyright when they share the digital version of the document to their "Digital Repository or Institutional Repository." Additionally, this research project will be subject to Chittagong University of Engineering and Technology's current or soon-to-be-approved Open Education Resources (OER) rules and regulations.

I also sincerely grant Chittagong University of Engineering and Technology the right to duplicate this thesis in whole or in part for academic research purposes via reprography or other means, as needed by persons.

Mohammed Rafiqul Islam

ID No.: 13MET004P

Institute of Energy Technology

Chittagong University of Engineering and Technology

DEDICATION

The author is thankful to Almighty Allah, who has blessed her with supportive parents; wife & all family members gave her the abilities to reach this goal. Special thanks to all beloved whose continuous encourage & help me to complete this project successfully.

ACKNOWLEDGEMENT

The author is truly thankful and wishes to convey her heartfelt appreciation to Prof. Dr. Sajal Chandra Banik, Department of Mechanical Engineering at Chittagong University of Engineering and Technology for his guidance, invaluable advice and unwavering support throughout this project. His encouragement and insights have played a crucial role in the successful completion of this thesis.

I also wish to express my gratitude to primary supervisor, Prof. Dr. Md. Tazul Islam, Department of Mechanical Engineering and former Director of IET at Chittagong University of Engineering and Technology, as well as to Md. Adnan Faisal Siddique, Research Assistant Professor, for their significant suggestions, administrative help and contributions in various aspects related to this thesis.

I extend my sincere thanks to all esteemed teachers and staff of the Institute of Energy Technology at Chittagong University of Engineering and Technology for their cooperation and inspiration in this endeavor.

ABSTRACT

The objective of this research project initiative is to stop environmental contamination and reduce energy usage by recycling different kinds of lubricating oils utilized in vehicles and industrial operations in Bangladesh through vacuum distillation. Bangladesh's lubricants oil market size was approximately 201.10 million liters in 2024 and is estimated to reach 292.30 million liters by 2029, growing at a CAGR of 7.76% from 2024-2029. Bangladesh is completely dependent on imported lubricating oil. Most of Bangladesh imports its lubricating oil from various countries including India, Singapore, and the United Arab Emirates. According to Bangladesh's import data, in the 12 months from March 2023 to February 2024, 555 foreign exporters supplied 4,794 shipments of lubricating oil to 461 Bangladeshi buyers, a growth rate of 10% compared to the previous twelve months. In February 2024 alone, 334 shipments imported lubricating oil, a growth rate of 48% year-on-year compared to February 2023 and a consecutive growth rate of 4% per month since January 2024. Growing at a CAGR of 5.4% from 2022 to 2027, the global fuel oil market size is expected to reach US\$ 96.4 billion by 2027. It is sad and disappointing that Bangladesh has not yet properly managed abandoned waste lubricating oil. As a result, used waste oil is being accidentally or intentionally released directly into the environment like rivers, which hurts the environment by endangering drinking water and the lives of aquatic animals. It is estimated that the annual market size of lubricating oil consumption in Bangladesh will be approximately 216.71 million liters in 2025 and increase to 314.89 million liters by 2030. The main objective of this research project is to properly manage and transform abandoned waste lubricating oil into a wealth resource by purifying it through vacuum distillation. Reduce dependence on imported lubricating oil and protect the environment by repurposing used lubricating oil to make it reusable. This research project experimentally refines waste mono-grade motor oil SAE Grade 50, Automotive Gear Oil 90, and Industrial Oil ISO VG 68 for reuse through compound extraction and distillation methods. Distillation technology is used in 85% of waste oil purification due to its high recovery rate, low cost, energy saving, and environmental friendliness. Lubricating oil acts as a lubricant, corrosion inhibitor, cooling agent, friction reducer, and cleaning agent and removes contaminants from the engine and machinery. In this research study, we collected used lubricating oil from engine workshops named M/S. Best Suppliers and tested it in a standard laboratory German based lubricating oil & grease manufacturer named Lubricants Asia Ltd. (Formally Fuchs Lubricants Bangladesh Ltd.), Chittagong. Different properties analysis of refined oil from waste oil and fresh lubricating oil, such as cloud and pour point, flash point, specific gravity, ash content, viscosity, moisture ratio and acid value showed the best results, which are almost as good as near about same as fresh oil.

The research project's key drawback is the high initial outlay of funds. The financial analysis yields the following results: net present value = BDT 3,425.05 lakh, payback duration = 5 years 6 months, discounted payback period = 6 years 4 months, and IRR = 23%. It was evident from the aforementioned figures that the project is regarded as ecologically friendly, profitable, and financially feasible.

এই গবেষণা প্রকল্পের লক্ষ্য হল বাংলাদেশের যানবাহন ও কলকারখানায় ব্যবহারিত নানা ধরনের লুব্রিকেটিং অয়েলকে পরিশোধনের মাধ্যমে পুনঃব্যবহার উপযোগী করে পরিবেশের দূষণ ও শক্তির অপচয় রোধ করা। গত ২০২৪ সালে বাংলাদেশে লুব্রিকেটিং অয়েলের বাজারের আকার ছিল প্রায় ২০১.১০ মিলিয়ন লিটার এবং অনুমান করা হচ্ছে যা আগামী ২০২৯ সালের মধ্যে ২৯২.৩০ মিলিয়ন লিটারে পৌঁছাবে, ২০২৪-২০২৯ সময়কালে বার্ষিক ৭.৭৬% চক্রবৃদ্ধি হারে বৃদ্ধি পাবে বলে আশা করা হচ্ছে। বাংলাদেশ সম্পূর্ণরূপে আমদানিকৃত লুব্রিকেটিং তেলের উপর নির্ভরশীল। বাংলাদেশ বেশির ভাগ লুব্রিকেশন অয়েল ভারত, সিঙ্গাপুর এবং সংযুক্ত আরব আমিরাতসহ বিভিন্ন দেশ থেকে আমদানি করে। বাংলাদেশের আমদানি তথ্য অনুসারে, মার্চ ২০২৩ থেকে ফেব্রুয়ারি ২০২৪ পর্যন্ত ১২ মাসের মধ্যে ৫৫৫ জন বিদেশী রপ্তানিকারক ৪৬১ জন বাংলাদেশী ক্রেতার কাছে ৪,৭৯৪টি চালান লুব্রিকেশন অয়েল সরবরাহ করেছিলেন, যা পূর্ববর্তী বারো মাসের তুলনায় প্রবৃদ্ধির হার ১০%। শুধুমাত্র ২০২৪ সালের ফেব্রুয়ারিতে, ৩৩৪টি চালান লুব্রিকেশন অয়েল আমদানি করে, যা ২০২৩ সালের ফেব্রুয়ারির তুলনায় প্রবৃদ্ধির হার বছরে ৪৮% এবং ২০২৪ সালের জানুয়ারি থেকে ধারাবাহিক প্রবৃদ্ধি মাসে ৪%। গত ২০২২ থেকে ২০২৭ সালে সিএজিআর ৫.৪% হারে বৃদ্ধি পাওয়ায়, বিশ্বব্যাপী বজর্য তেলের বাজারের আকার ২০২৭ সালের মধ্যে ৯৬.৪ বিলিয়ন মার্কিন ডলারে পৌঁছাবে আশা করা হচ্ছে। দুঃখজনক ও হতাশার বিষয় হল বাংলাদেশে এখন পর্যন্ত ব্যবহৃত লুব্রিকেটিং তেলের সঠিক ব্যবস্থাপনা হয়নি। ফলে ব্যবহৃত তেল দুর্ঘটনাক্রমে বা ইচ্ছাকৃতভাবে পরিবেশে নির্গত হচ্ছে, পানীয় জল এবং জলজ প্রাণীর জীবন বিপন্ন করে পরিবেশের উপর নেতিবাচক প্রভাব ফেলে। ধারণা করা হচ্ছে ২০২৫ সালে বাংলাদেশে লুব্রিকেটিং তেলের বার্ষিক বাজারের আকার প্রায় ২১৬.৭১ মিলিয়ন লিটার এবং ২০৩০ সালের মধ্যে ৩১৪.৮৯ মিলিয়ন লিটারে উন্নীত হবে। এই গবেষণা প্রকল্পটির উদ্দেশ্য হল, পরিত্যক্ত বজর্য লুব্রিকেটিং অয়েলকে পরিশোধনের মাধ্যমে সঠিক ব্যবস্থাপনার সম্পদে রূপান্তর করা। ব্যবহৃত লুব্রিকেটিং তেল পরিশোধনের মাধ্যমে পুনরায় ব্যবহার উপযোগী করে লুব্রিকেটিং তেল আমদানির উপর নির্ভরতা হ্রাস পাবে এবং পরিবেশ সুরক্ষিত হবে। এই গবেষণা প্রকল্পটি যৌগিক দ্রাবক নিষ্কাশন এবং পাতন পদ্ধতির মাধ্যমে বজর্য মনো গ্রেড মোটর তেল SAE গ্রেড ৫০, অটোমোটিভ গিয়ার তেল SAE গ্রেড ৯০ এবং শিল্প তেল ISOVG ৬৮ এর পরিশোধনের মাধ্যমে পরীক্ষামূলক পুনরায় ব্যবহার উপযোগী করে। উচ্চ পুনরুদ্ধার হার, কম খরচ, জ্বালানি সাশ্রয়ী এবং পরিবেশগতভাবে বন্ধুত্বপূর্ণ হওয়ায় ৮৫% বজর্যতেল পরিশোধনে ডিস্টিলেশন প্রযুক্তি ব্যবহার হয়। লুব্রিকেটিং তেল ইঞ্জিনের অংশগুলিকে লুব্রিকেট করতে, ক্ষয়রোধী, শীতলকারী এজেন্ট, ঘর্ষণ কমাতে, পরিষ্কারক এবং ইঞ্জিন থেকে দূষিত পদার্থ অপসারণ করতে কাজ করে। এই গবেষণায়, ফুকস বাংলাদেশ লিমিটেড, চট্টগ্রাম এবং একটি ইঞ্জিন ওয়ার্কশপ থেকে ব্যবহৃত লুব্রিকেটিং অয়েল সংগ্রহ করেছি এবং একটি স্ট্যান্ডার্ড ল্যাবরেটরি থেকে পরীক্ষা করি। বজর্যতেল থেকে পরিশোধিত তেল এবং ফ্রেশ লুব্রিকেটিং তেলের বিভিন্ন বৈশিষ্ট্য, মেঘ এবং ঢালাবিন্দু, ফ্ল্যাশপয়েন্ট, নির্দিষ্ট মাধ্যাকর্ষণ, ছাইয়ের পরিমাণ, রঙ, ঘনত্ব, কাইনেম্যাটিক সান্দ্রতা, সান্দ্রতাসূচক, অর্দ্রতা অনুপাত এবং অ্যাসিডের মান বিশ্লেষণ করে সেরা ফলাফল দেখা গেছে, যাহা ফ্রেশ তেলের কাছাকাছি।

গবেষণা প্রকল্পটির প্রধান অসুবিধা হল প্রাথমিক বিনিয়োগ ব্যয়বহুল। প্রকল্পটির আর্থিক বিশ্লেষণ হিসাবে, পরিশোধের সময়কাল = ০৫ বছর ০৬ মাস, ছাড় পরিশোধের সময়কাল = ০৬ বছর ০৪ মাস, নেট বর্তমান মূল্য = ৩,৪২৫.০৫লক্ষ টাকা, অভ্যন্তরীণ রিটার্ন বিশ্লেষণের হার = ২৩%। গবেষণা প্রকল্পটি আর্থিকভাবে সংগতিপূর্ণ ও লাভজনক পরিবেশ বান্ধব বলে মনে করা হচ্ছে।

INDEX	
-------	--

Title	Page
Cover Page	i
Approval	ii
Declaration	iii
Copyright Declaration	iv
Dedication	v
Acknowledgment	vi
Abstract	vii
সার-সংক্ষেপ	viii
Index	ix-x
Figures	xi-xii
Tables	xiii
Abbreviations	xiv
Symbols	xv

CHAPTER I: INTRODUCTION	1-42
1.1 Evolution of Lubricants	2-8
1.2 Objectives with Specific Aims of Used Waste Oil Refining	8
1.3 Outcomes Expected From The Research	9
1.4 Basic of Lubricant	9-17
1.5 Obligation of Lubricants	17-18
1.6 Classifications of Lubricating Oils	18-19
1.7 Aspects of Waste Lubrication Oil	21-24
1.8 Necessity Of Used Waste Oil Re-Refining	24-26
1.9 Process Of Scrap Oil Refining	26-28
1.10 Technologies for Refining Waste Oil	28-31
1.11 Refining Waste Oil Using the Distillation Method	31-33
1.12 Gains and Challenges of Refining Used Waste Oil	33-35
1.13 Worldwide Perspective of Lubricating Oil	35-37
1.14 Lubricating Oil in Bangladesh Perspective	37-39
1.15 Impact of Contaminants in Oil	39-40

1.16 Disposal and Geographic Impact	41-42
CHAPTER II: LITERATURE REVIEW	43-59
CHAPTER III: DESIGNING AND EXPERIMENTAL METHODOLOGY	60-69
3.1 Introduction	61-62
3.2 Required Materials for Experimental Setup	62-68
3.3 Experimental Procedure	68-69
CHAPTER IV: EXPERIMENTAL RESULTS AND DISCUSSIONS	70-100
4.1 Introduction	71
4.2 Details of Test Method	71-72
4.3 Apparatus Using Testing Purpose	72-77
4.4 Sampling System	77-78
4.5 Oil's Physical and Chemical Aspects	78-80
4.6 Temperature's Impact on Oil Viscosity	81-84
4.7 Parameters Analysis Between Refined and Fresh Base Oils	84-87
4.8 Economical Assessment	88-94
4.9 Outcomes and Conversation	94-100
CHAPTER V: CONCLUSION AND RECOMMENDATIONS	101-102
5.1 Conclusions	102
5.2 Recommendations	102
APPENDICES	I-XVII
REFERENCES	A-I

FIGURES

Figure No:	Caption	Page
Figure 1.1	Lubricants	3
Figure 1.2	Machinery Lubrication	5
Figure 1.3	Molecular Distribution of Mineral Oil	11
Figure 1.4	Cycle of refined lubricating oil	21
Figure 1.5	Reprocessing of used lubricating oils	29
Figure 1.6	Refining of used lubricating oils	30
Figure 1.7	Distillation method to refining of used lubricating oils	33
Figure 1.8	Market Volume of Lubricants Worldwide in 2024	36
Figure 1.9	Annual Lubricating oil consumption breakdown, 2024 (in Tons)	38
Figure 3.1	Schematic diagram of Refining waste lubricating oils	61
Figure 3.2	Waste Lubricating Oils	63
Figure 3.3	Storage as a pail of Fuchs (German) & Mobil (USA) brand lubricants	63
Figure 3.4	Electric Burner	63
Figure 3.5	Methyl Ethyl Ketone (MKE) sample & bonding structure	64
Figure 3.6	1R-0719 Caterpillar Oil Filter	65
Figure 3.7	Liquid collector Glass Test Tubes	68
Figure 3.8	Flow chart of experimental procedure	69
Figure 4.1	Kinematic Viscosity Bath	73
Figure 4.2	Dual-Bath Kinematic Viscometer	73
Figure 4.3	Metrohm888 Titrando with Touch Control	74
Figure 4.4	Metrohm 798 MPT Titrino	74

Figure 4.5	Metrohm899 Coulometer with generator electrode without diaphragm	75
Figure 4.6	Koehler Cleveland Open Cup Flash Point Tester	75
Figure 4.7	ICP-OES Spectrometers	76
Figure 4.8	Infrared Spectroscopy (FT-IR)	76
Figure 4.9	Dual Twin Foaming Characteristics Test Apparatus	77
Figure 4.10	Temperature vs Viscosity chart of Waste Used Oil.	81
Figure 4.11	Temperature vs Viscosity chart of Waste Used Oil (on Treatment).	82
Figure 4.12	Temperature vs Viscosity chart of Refined New Oil.	83
Figure 4.13	Temperature vs Viscosity chart of Fresh Oil.	84
Figure 4.14	Parameter analysis of Refined and Fresh Base Oils SN 500	85
Figure 4.15	Parameter analysis of Refined and Fresh Base Oils SN 150	86
Figure 4.16	Parameter analysis of Refined and Fresh Base Oils SN 70	87
Figure 4.17	Variation of net present worth with interest rate	93
Figure 4.18	Viscosity Analysis of Used, Refined & Fresh oil.	95
Figure 4.19	Viscosity Index Analysis of Used, Refined & Fresh oil.	96
Figure 4.20	Flash Point of Used, Refined & Fresh oil.	97
Figure 4.21	Pour Point of Used, Refined & Fresh oil	97
Figure 4.22	Density of Used, Refined & Fresh oil	98
Figure 4.23	Samples of used oil	99
Figure 4.24	Samples of on treatment used oil	99
Figure 4.25	Samples of refined oil	100
Figure 4.26	Samples of fresh oil	100

TABLES

Table No:	Caption	Page
Table 1.1	Market Volume of Lubricants Worldwide in 2024	36-37
Table 2.2	Showing the Hierarchy of Used Oil Management	40
Table 3.1	Specification of TAP 3547T	66
Table 3.2	Properties of TAP 3547T	66
Table 3.3	Technical Specification of TAP 8640	66
Table 3.4	Technical Specification of TAP 3433	67
Table 4.1	Details of Test Method	71-72
Table 4.2	Temperature vs Viscosity Table of Waste Used Oil	81
Table 4.3	Temperature vs Viscosity Table of Used Oil (on Treatment).	82
Table 4.4	Temperature vs Viscosity Table of Refined New Oil.	83
Table 4.5	Temperature vs Viscosity Table of Fresh Oil.	84
Table 4.6	Parameter analysis of Refined and Fresh Base Oils SN 500.	85
Table 4.7	Parameter analysis of Refined and Fresh Base Oils SN 150	86
Table 4.8	Parameter analysis of Refined and Fresh Base Oils SN 70	87
Table 4.9	Details of Investment Calculation	88-89
Table 4.10	Project in Details estimation	89
Table 4.11	Details of Utilities & Others for 1m ³ of used oil processing	90
Table 4.12	Composition of output on the basis of mass	90
Table 4.13	Details of Yearly operating cost	91
Table 4.14	Overview of revenue outcome	92
Table 4.15	Variation of net present worth with interest rate	94

ABBREVIATIONS

1	API	American Petroleum Institute
2	AN	Acid Number
3	AW	Anti-wear
4	AGMA	American Gear Manufactures Association
5	ASTM	American Society for Testing and Materials
6	BN	Base Number
7	BDT	Bangladeshi Taka
8	COC	Cleveland Open Cup
9	cSt	Centistokes
10	DIN	DeutschesInstitutfurNormung
11	EP	Extreme Pressure
12	ISO	International Standard Organization
13	LOBS	lube oil base stock
14	SN	Solvent Neutral
15	SAE	Society of Automotive Engineers
16	SUS	Saybolt Universal Seconds
17	UN	United Nation
18	VI	viscosity index

SYMBOLS

%	Percentage
°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 1

INTRODUCTION

1.1 EVOLUTION OF LUBRICANTS

During the beginning of time, lubricants have been used; calcium soaps have been identified on chariot axles as early as 1400 BC. Oil-soaked timber was used to move building stones during the pyramid era. Animal fats, rapeseed oil, and olive oil were the main sources of lubricants in ancient Rome. As metal machinery became more prevalent throughout the Industrial Revolution, there was an increase in the need for lubrication. The industry switched to petroleum-based goods in the early 20th century after first relying on natural oils. The Vacuum Oil Company was the pioneer in the development of vacuum distillation of petroleum, which marked a significant advancement. The highly nonvolatile ingredients included in many lubricants were refined thanks to this invention. By creating a coating that reduces friction between two contacting surfaces, lubrication helps to reduce wear and friction. The lubricant may be a liquid, solid substance, or a polymer. The main topic of this article is oil, one of the most often used lubricating fluids: Lubrication using oil. Different materials are used to lubricate surfaces, but the most common ones are oil and grease. While oil is used in its natural state, grease is made up of oil and a thickening agent to keep it consistent. The lubricating oil may contain additives based on the requirements of the particular application. Mineral, synthetic, vegetable-based, or mixes of various sorts of oils are all possible. The needs of the application dictate the type of oil to be used. While vegetable or biodegradable oils may be chosen in environmentally sensitive settings, synthetic oils may prove advantageous in harsh conditions. The additives in lubricants' oil improve, alter, or lessen the properties of the base oils. The kind of oil and the oil's intended application determine how many additives are used. Lubricants manage temperature by dissipating heat, preventing wear and tear, preventing corrosion, reducing friction, regulating contamination, transferring power in hydraulic systems, and establishing a fluid seal. Although reducing friction is an important goal of lubrication, there are a number of other benefits to this procedure. By forming a barrier against corrosive water and other dangerous elements, lubricating films help to stop corrosion. Additionally, they play a major role in preventing contamination in systems. A range of oils intended to lessen heat, friction, and wear in interconnected mechanical components make up lubricating oil, often known as lubricant or lube. This oil is especially well-known for being used in automobiles as a transmission fluid and motor oil. A lubricant is defined as a material that forms a slick layer to reduce friction between moving surfaces, such as car engines.

A compound that creates a slippery coating to lessen friction between moving parts, such as engines in vehicles, is called a lubricant. When in use, the oil is drawn up by revolving bearing components, moves through the bearing, and then returns to the oil reservoir. The oil level should be around a fourth of the way below the lowest rolling ball's level if your bearing stays still. Enough oil must be able to get to the bearing at high speeds in order to help dissipate the heat produced by friction. Figure 1.1 shows visibility of Lubricants [1]. It is necessary for successful operation of engines and machinery and contains a range of oils with varying viscosities and performance-enhancing additives. Typically, lubricants consist of 90% base oil—typically mineral petroleum fractions—and less than 10% additives. To improve the lubricants' performance, a variety of additives are used. The primary additive families include antioxidants, metal deactivators, anti-wear, corrosion and rust inhibitors, friction modifiers, extreme pressure, anti-foaming agents, demulsifying/emulsifying, stickiness improvers, compounds that give tool surfaces adhesive qualities (in metalworking), and grease complexion agents. Because lubricants not only dissipate heat, keep equipment clean, and prevent corrosion, but also reduce friction and wear by forming a thin liquid coating between moving surfaces, increase machine and must access, limit material wear, and save fuel and energy, they have been used primarily to reduce friction between moving elements of various machinery and equipment.



Figure 1.1 Lubricants [1]

Lubricating fluids from gearboxes, combustion engines, and automobiles are by far the greatest source of spilled oil in developing nations. In addition, small amounts are produced by transformers, hydraulic systems, and other various industrial uses. The volume of spent motor vehicle oil has grown regularly due to the rise in automobile traffic in emerging nations. Most utilized motor oil is produced in tiny amounts in a variety of locations, including garages, tiny workplaces, and private homes. Large industries, truck fleet operators, and railroads are some of the main sources of waste oil. After use, engine, transmission, hydraulic, and cutting oils are referred to as waste lubricating oil. In addition to asphaltic compounds that arise from the engines' bearing surfaces, it also refers to the deterioration of new lubricating components that have been attacked by metals, ash, carbon residue, water, varnish, gums, and other harmful substances. After a few thousand kilometers of driving, these oils need to be replaced and taken out of the car due to stress from significant deterioration in service. An estimated 1.70 to 3.50 million tons of lubricating oils are collected each year in the USA and Europe. Both the economy and the ecology are significantly impacted by this massive amount of waste lubricating oil. The term "used lube oil" refers to synthetic or petroleum-derived oil that is left over after being used for lubrication, cutting, etc. The lubricating oil loses its qualities after a certain amount of use and is no longer suitable for use in machines. Temperature buildup causes the lubricating oil to deteriorate, which lowers its viscosity, specific gravity, and other characteristics. The lubricating fluids also contain dirt and metal components that have been worn down from the surfaces. The lubricant must be replaced with a new one because it loses its lubricating qualities over time due to an excessive decline in the desirable properties. It is startling to learn that base oil just becomes dirty; it never spoils. Two primary factors make lubricating oil unsuitable for continued use: the buildup of impurities and chemical alterations. Fuel ignites to CO₂ and H₂O, which are the primary pollutants. One liter of water is produced for each liter of fuel that is burned. When the engine is hot, this usually exits through the exhaust; but, when it is cold; it may run down and gather in the oil. Rust and sludge formation result from this. The oil turns dark because of them. Incomplete combustion, especially during a warm-up with a rich mixture, is the cause of their genesis [1].

Big amounts of water can be polluted by a small amount of leftover lubricating oil. In addition to being tainted by impurities and leftovers from combustion, waste lubricating oil itself contains a variety of additives. Burning used oil in kilns and high-incinerators pollutes the environment by producing a lot of ash and toxins. Numerous sources produce used waste

lubricating oils, which are then inappropriately disposed of. Because it contains contaminants, waste lubricating oil is a resource that cannot be disposed of carelessly.



Figure 1.2 Machinery Lubrication [2]

Reusing and regenerating waste lubricants is becoming more popular as a solution to environmental issues and economic challenges. Proper lubrication is essential for reducing energy costs in machinery and automobiles. Inadequate lubrication results in bearing damage, engine heating, shortened engine running times, etc., all of which raise maintenance costs. Figure 1.2 shows the application of machinery lubrication [2]. By properly recovering and refining waste oils, new and usable fresh oil is produced, saving energy and protecting the environment from contamination. Refinement aims to eliminate deteriorated additives and impurities and return the oil's characteristics to those specified by the International Standard Organization and the Society of Automobile Engineers. These days, any lead comes from bearing wear and is probably between 2 and 12 parts per million. Previously, typical old engine oil may have had up to 2% lead. It is possible for unburned diesel or gasoline to enter the lubricant, particularly while starting up. Through the air cleaner, this enters the engine. Oxidation products: At high temperatures, some of the oil molecules will oxidize to generate complex and corrosive organic acids. Normal engine wear releases composites of minute particles of silicates, wear metals, iron, copper, and aluminum. With average values of 76.7% saturates, 13.2% mono aromatics, 3.7% di aromatics, and 6.5% poly aromatic-polar material, utilized oil is composed of four main groupings. It needs to be changed periodically because new lubricant deteriorates. After being extracted, the spent oil is disposed of. An important environmental issue is the improper handling of used

lubricating oil. Every car's oil has the potential to be recycled in a safe and effective manner, preventing pollution and conserving energy. Regretfully, the majority of old motor oil is treated incorrectly. Some are dumped straight into waterways or into sewers, which can negatively impact water treatment facilities. Some are poured onto dirt roads or thrown straight onto the ground to eradicate weeds. Millions of gallons are discarded into the trash, where they might contaminate ground and surface water in landfills [2].

Simply said, improper disposal of spent oil is an unused portion of a precious resource. Drilling for more oil is necessary for every gallon of used motor oil that cannot be recovered, which occasionally leads to an increase in oil imports. However, very few of the unique hydrocarbon chains required for motor oil are present in the majority of crude petroleum produced worldwide today. Because of this, the process of refining crude petroleum to make fresh lubricating oil is intricate, costly, and energy intensive nearly three times as much as the process of refining used oil. It is possible to recover and "regenerate" lube base oil to a level that is on par with or superior to its virgin state. There are numerous methods for recycling and recovering a wide range of waste oils, either immediately or following separation and purification. The first choice, according to the structure of waste handling, is to preserve the oil's original attributes so that it can be used directly again. Recovering its heating value and/or applying it to other lower-level applications are more possibilities. It is possible to reprocess some waste oils, especially lubricants, such that they can be used directly again. Following treatment, waste oils can be used as clean burning fuel or as lubrication base stock that is equivalent to refined virgin base oil. Used lubricating substances were first burned to generate energy before being treated and then re-blended into engine lubricants. Waste oil recycling and disposal have become crucial due to stricter environmental regulations and the growing need for environmental protection. The techniques used to refine oil in the early days of the oil business differed greatly from those employed now. Refiners were able to gradually increase the oil's temperature by using the stills. As the temperature increased, they extracted the distillates that were useless, such as gasoline, and only obtained kerosene or lamp oil. Crude oil undergoes a procedure known as partial distillation once it enters the contemporary refinery. In order to refine crude oil further, this technique isolates its many components. When crude oil, which is a blend of several hydrocarbons, is placed in a high-pressure steam boiler, fractional distillation starts. Similar to how boiling water converts into water vapor, this tank causes the oil to boil and turn to vapor. Up to 1112° Fahrenheit is reached by heating the crude oil. The oil passes

through a pipe at the bottom of the distillation column after turning into vapor. The liquid parts are collected in different tanks after passing through pipes. Gases, naphtha, gasoline, kerosene, diesel fuel, lubricating oils, heavy oils, and other substances are among the fractions. Refining is the process of producing high-quality base stock for lubricants or additional petroleum-derived goods by distilling or refining used lubricating oil. In wealthy nations, the use of this technique has skyrocketed. Therefore, many people believe that refining is the best choice for preserving resources, cutting down on waste, and lessening environmental harm. Since lubricants have been crucial for lowering wear, heat, and friction in moving parts, their history is intimately linked to the progress of technology as well as mobility. An outline of the significant turning points in lubricant history is provided here. To lessen friction, early humans employed natural materials like water, vegetable oils, and animal fats. For instance, chariot axles were lubricated with animal fats by the ancient Egyptians. Ancient societies, such as the Greeks and Romans, frequently employed animal fats as greases to lubricate pulleys, wheels, and other mechanical equipment. The demand for improved lubrication increased during the middle Ages as increasingly sophisticated gear, such windmills and watermills, was developed. Plant oils and animal fats continued to be the principal lubricants. Early industrial machinery, like those used in mining and textile manufacture, began using lubricants throughout the Renaissance. [3]

Mineral oils made from petroleum were discovered and used in the 19th century as a result of the Industrial Revolution. Compared to vegetable or animal oils, these oils were more stable and efficient. Crude oil was used to make the first commercial lubricants in the middle of the 19th century. Early cars, railroads, and steam engines all used these lubricants. Grease, a type of semi-solid lubricant created by thickening oils with soaps or other substances, was also developed in the 19th century. The Development of Technology in the 20th Century Synthetic lubricants was created in the beginning of the 20th century. These lubricants are designed chemically to operate better under extreme conditions, including extreme temperatures or heavy loads. Better engine oils and greases were in high demand as the automotive industry grew in the early 20th century. Multi-grade oils were introduced because they work effectively in a variety of temperatures. around order to improve lubricants' performance and longevity, additives like detergents, dispersants, and anti-wear agents were introduced around the middle of the 20th century. The mid-20th century space race prompted the creation of specialty lubricants that could endure high temperatures and the vacuum of space. Innovation and Sustainability in the Twenty-First Century Bio-based

Lubricants Bio-based lubricants derived from renewable resources, such as vegetable oils, have become more and more popular as environmental concerns have grown. These lubricants are less damaging to the environment and biodegradable. Nano-lubricants, which employ nanoparticles to further minimize wear and friction, are the result of advances in nanotechnology. The development of intelligent lubricants that can instantly modify their characteristics in response to load and temperature is still in progress. The application of materials between two moving objects in relation to one another in order to facilitate smooth operation to the extent required is known as lubrication. Rolling bearings are lubricated with oil or grease to reduce noise, wear & tear, and heat produced by their rolling and sliding motions. Solid lubricants are also employed in some unique situations. Rolling bearing lubricant types and quantities are dictated by a number of factors, including operating speed, temperature, and environmental conditions. Lubricants must be updated or oiled on a regular basis since they can no longer perform their intended function effectively due to their service life being exhausted or being contaminated with foreign substances. Real-time lubrication system monitoring and optimization will be made possible by the integration of digital technology, such as Internet of Things sensors. Lubricants have changed over time from being uncomplicated natural materials to intricately designed goods that are vital to modern industry and technology. [4]

1.2 OBJECTIVES WITH SPECIFIC AIMS OF USED WASTE OIL REFINING

The work's goal has been to find the ideal processing parameters for extracting base oil that are useful for creating new lubricants while preventing the co-extraction of metallic elements and degradation products.

1. To explore the amount of lubricating oil consumed the negative effects on the environment and the process of repurposing spent lubricating oil to create refined oil for energy sufficiency and environmental pollution reduction.
2. To design and implement proposed system using very cheap, inexpensive, dependable and effective distillation method compared with various existing converting system.
3. To analyze experimenting results of various properties of refined used oil for different states.
4. To compare the properties of obtained refined oil with the properties of virgin oil.

1.3 OUTCOMES EXPECTED FROM THE RESEARCH

- a) Reduces the use of energy; used oil purification uses one-third less energy than new crude petroleum.
- b) Safeguard natural resources like crude oil and coal.
- c) Aids in avoiding the emission of air, ground water, marine water, and land pollution.
- d) Lowers the expenditure of cleaning up oil spills in the community.
- e) Encourages suited recycling.
- f) Simplifies spending abroad.
- g) Delays the time when the world's oil supply will run out.
- h) Lessen reliance on imported base oil to conserve foreign currency. Cut the cost of sewage treatment.
- i) Remove the incorrect use of waste oil as fuel, which contributes to air pollution and negative emissions [5].

1.4 BASIC OF LUBRICANT

A lubricant is a material, often organic, that is applied to surfaces in contact with one another to lessen friction. This, in turn, lowers the amount of heat produced as the surfaces move. Additionally, it might be used to heat or cool surfaces, transfer forces, or move alien objects. Lubricity is the quality of lessening friction. Its primary purpose is to lessen friction and let a mechanism operate smoothly. Lubricants usually include fewer than 10% additives and 90% basic oil. Reduced wear and friction, enhanced viscosity, resistance to oxidation and corrosion, aging, and contamination, and more are all provided by additives. Sprinkled PTFE tape for plumbing, air cushions and other applications are examples of non-liquid lubricants. Recycling waste lubricant effectively could have an enjoyable effect on the environment and the economy by lowering greenhouse gas emissions and environmental pollution. Lubricating oils facilitate simpler motion of connected parts and protect rubbing surfaces when utilized in service. Liquid lubricants come in a variety of forms, such as mineral, synthetic, and bio-based oils. Grease (oil combined with thickening additives) is a type of semi-solid lubricant. Graphite, molybdenum disulfide, and PTFE (Teflon) are examples of solid lubricants. Air and other inert gases used in certain applications are examples of gaseous lubricants [6].

1.4.1 Goals of Lubrication:

Lubrication serves with these primary targets:

- a) By creating a lubricated layer on the surface of load-transferring components, wear and early fatigue can be avoided by avoiding metal-to-metal contact.
- b) To improve the positive driving qualities, like reduced friction or noise.
- c) By dispersing the generated heat outdoors, it is possible to prevent bearing overheating and lubricant deterioration.
- d) If the flow lubrication method is used, it performs especially well.
- e) To stop corrosion, rust, and the entry of foreign materials.
- f) For gasses, seal by using capillary force, lubricants will fill the space between moving parts, sealing the gap.
- g) Shafts and pistons can be closed using this effect [7].

A good lubricant requires:

- a) Both a high boiling point and a low freezing point.
- b) A higher index of viscosity.
- c) Durability of temperature.
- d) Reliability of hydraulics.
- e) Demulsibility.
- f) Putting off corrosion.
- g) A powerful barrier against oxidation.

1.4.2 Types and Specification of lubricants

1. The oils and Fluid Lubricants:

1(a) Minerals Oils: Created on purification from crude oil. They are widely used in hydraulic systems for industrial machinery, and auto engines. The phrase "mineral oil" denotes lubricating base oils that are made from crude oil. 80–90% of grease is made up of base oil, which is the major part that actually serves the lubricating function. Therefore, choosing the appropriate base oil type and viscosity is crucial. Mineral base oils and compound base oils are the two primary categories of base oils. Mineral oils of different viscosities are commonly utilized. Higher viscosity mineral oils are typically used in places that need to be lubricated at high loads, low speeds, and high temperatures, while lower viscosity mineral oils are used in places that need to be lubricated at low loads, low speeds, and low temperatures. Figure 1.3 shows the Molecular Distribution of Mineral Oil [3]. Compound base oils are typically highly costly and utilized in applications that need to be lubricated at exceptionally high or low temperatures, or every step of a wide temperature

range, with great precision and speed. Ordinarily, compound base oils of the silicon series, ester, or polyalphaolefin (PAO) are utilized; however, fluorine compound oils are becoming more and more popular these days.

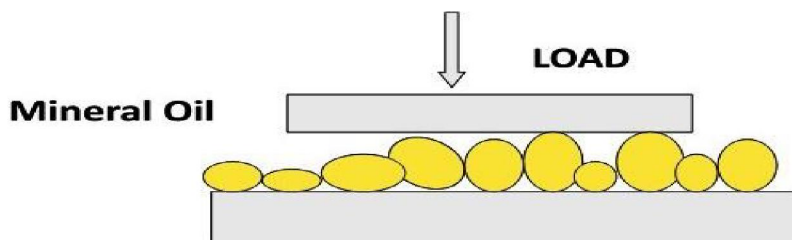


Figure 1.3: Molecular Distribution of Mineral Oil [8]

Base oil types are classified by the American Petroleum Institute (API):

Group I: Saturates < 90% and/or sulfur > 0.03%, with a viscosity index (VI) between 103 and 120 according to the Society of Automotive Engineers (SAE). Produced using hydro finishing, solvent extraction and solvent or catalytic dewaxing techniques. 150 SN (solvent neutral), 500 SN, and 150 BS (bright stock) are examples of common Group I base oils [9].

Group II: Saturates > 90% and sulfur < 0.03%, and SAE viscosity index of 113 to 120. Manufactured by hydrocracking and solvent or catalytic dewaxing processes. Group II base oil has superior anti-oxidation properties since virtually all hydrocarbon molecules are saturated. It has water-white color.

Group III: Saturates >90%, sulfur <0.03%, and SAE viscosity index over 140. Manufactured by special processes such as isohydromerization. Can be manufactured from base oil or slax wax from dewaxing process.

Group IV: Polyalphaolefins (PAO)

Group V: All others not included above, such as Naphthenics, Polyalkylene Glycols (PAG) and POLYesters. [10]

1(b). Synthetic Oils: These oils are through chemical processes designed to operate better under difficult conditions, including excessive temperatures or massive loads. Esters, polyglycols, and polyalphaolefins (PAOs) are common types. "Synthetic oils" or synthetic

hydrocarbons, which are eventually obtained from petroleum, can also be used to make hydrocarbon-derived lubricants [10].

Among these are:

- Polyalpha-olefin (PAO)
- Synthetic esters
- Polyalkylene glycols (PAG)
- Phosphate esters
- Perfluoropolyether (PFPE)
- Alkylated naphthalenes (AN)
- Silicate esters
- Ionic fluids
- Multiply alkylated cyclopentanes (MAC)

1(c). Bio-based Oils: Oils from plants and other natural assets are used to make bio-based oils. They are widely used in contexts where environmental effect is a concern since they are environmentally benign and biodegradable. Vegetable oils and other regenerative assets are used to make bio-lubricants. Triglyceride esters, or fats derived from plants and animals, are typically what they are. Vegetable-derived items are preferred for usage in lubricant base oils. Typical ones are castor oil, palm oil, sunflower seed oil, rapeseed oil, high-oleic canola oil, and tall oil derived from trees. A lot of vegetable oils often get hydrolyzed to produce the acids, which are then meticulously mixed to create unique synthetic esters. Lanolin (wool grease, a natural water repellent) is another naturally made lubricant. Up to the latter half of the 20th century, whale oil was used as a friction modifier addition for automatic transmission fluid, making it a valuable lubricant. Nearly one per cent of the UK's 840,000-ton annual lubricant market was made up of bio-lubricants in 2008. Researchers at Australia's CSIRO have been investigating safflower oil as an engine lubricant since 2020. They have discovered that it performs better and emits less exhaust than petroleum-based lubricants in applications including chainsaws, lawn mowers, and other agricultural machinery. The product has been liked by grain growers who are testing it; one said it requires very little polishing and is biodegradable, bioenergy, and biofuel. Using gene silencing, the scientists have redesigned the plant to generate up to 93% oil, the most oil of any plant currently on the market. When comparing the oil's performance in a large diesel engine to that of conventional oil, investigators at Montana State University's Advanced Fuel Centre in the US have called the findings a "game-changer"[11].

2. Semi-Solid Lubricants (Greases)

- **Calcium-Based Greases:** Known for their water resistance, commonly used in marine applications.
- **Lithium-Based Greases:** Because of their superior stability and performance all along a wide range of temperatures, they are versatile to be utilized in industrial and automotive applications.
- **Polyurea Greases:** Used in electric motor bearings and other high-temperature applications.
- **Silicone Greases:** Known for their wide temperature range and water resistance, often used in electrical and plastic applications.

3. Solid Lubricants

- **Graphite:** Used in high-temperature applications and where liquid lubricants cannot be used, such as in locks and hinges.
- **Molybdenum Disulfide (MoS₂):** Effective in high-pressure and high-temperature environments, often used in aerospace and automotive applications.
- **PTFE (Polytetrafluoroethylene):** Accessed in coatings and composite materials, it is popular for its low friction and chemical resistance. Cooking utensils, for illustration, are often treated with PTFE to form a non-stick surface. It can be used as a growing and lubricant in certain greases because of its chemical inertness and feasible temperature range of up to 350 °C. Because PTFE is soft and flows away from the area of contact, it is useless under high pressures. Then, lubricants made of ceramic or alloy must be used.
- **Inorganic solids:** Hard lubricants include molybdenum disulfide, tungsten disulfide, graphite, and hexagonal boron nitride. Some are lubricated up to exceedingly high temperatures. Some of these materials' weak oxidation resistance might restrict their application; for scenario, molybdenum disulfide falls down at temps above 350 °C in air but at 1100 °C in reducing circumstances.
- **Metal/ Alloy:** Metal alloys, composites, and pure metals can be employed as the only component of surfaces that slide and bearings or as grease additives. Surfaces have been coated with cadmium and gold, which gives them superior slide and corrosion resistance. Sliding bearings are made of lead, tin, zinc, and other bronze alloys; sliding surfaces can also be lubed with their powder [12].

4. **Gaseous Lubricants:** Useful in air bearings and other settings where a low level of impurities and friction is mandatory. Often employed in extremely hot, fast speeds applications, like gas turbines.

5. **Specialty Lubricants**

- **Food-Grade Lubricants:** The intent of food-grade lubricants is to mitigate invasion in equipment used in preparing food and packaging. They meet to strict safety standards and are non-toxic.
- **High-Temperature Lubricants:** Formulated to withstand extreme heat, often used in metalworking and aerospace applications.
- **Low-Temperature Lubricants:** Designed to remain fluid and effective in cold environments, used in refrigeration and Arctic applications.
- **Biodegradable Lubricants:** Made from environmentally friendly materials, used in applications where environmental impact is a concern, such as in marine and agricultural settings.

6. **Additive-Enhanced Lubricants:** By eliminating the formation of deposits and sludge, additive enhanced lubricants help keep engines clean. Often found in engine oils, this organic compound creates a protective coating on metal surfaces to lessen wear. Included in multi-grade lube oils that assist with retaining lubricant viscosity over a range of temperatures. In automotive applications, bringing down friction between moving parts optimizes fuel efficiency.

7. **Dry Lubricants:** such as molybdenum disulfide or graphite, that is deployed as alternatives when liquid lubricants are not practical. Usually contain solid lubricants featured in a volatile carrier that emits a dry lubricant protecting as it evaporates.

8. **Penetrating Lubricating Oils:** Designed to seep into tight spaces and loosen rusted or stuck parts, commonly used in maintenance and repair.

9. **Hydraulic Fluids:** Commonly used in hydraulic systems for their stability and performance. Used in high-risk environments like steel mills and mining operations, where fire resistance is critical.

10. **Gear Oils:** Gearboxes and differentials use EP (Extreme Pressure), it was created to endure high loads and pressures. Synthetic gear oils tend to be used in heavy-duty and high-performance applications because they offer outstanding reliability in adverse conditions. Every lubricant type has special features and is picked depending to the application's needs, include ambient temperature, load, speed, and environmental variables. For machinery and equipment to operate economically and ecologically, lubricants should be chosen and serviced properly [13].

1.4.3 Various Additives used in Lube Oil

Base oil, especially is used for lubrication, and additives compose oils. Two causes lead to the 15–25% of additives found in final oils:

- a) To boost specific qualities of the base oil
- b) Or to confer on the basic oil a fresh appearance.

The chemicals known as additives are added to lubricant oils to improve their performance and continue their shelf life. These additives have been tailored to solve specific issues and raise the lubricant's overall success.

1.4.4 Main types of additives used in lubricating oils:

1. Detergents Additive: The additive's detergency property helps in absorbing acids which accumulate up in the oil and keeping deposits from forming. hence, they raise the oil's performance and serve as a framework for the reserve alkalinity, especially with engine oils, which stops char from roaring and oxidized chemicals from leaving deposits or gums on metal surfaces. The most recent additions are polymers of nitrogen compounds, which do not form ashes. The potential of these detergent additives to flush out silt deposits (calamine, for example) can obstruct the lubricating scheme, thus their usage in fuel systems should be done with caution. Prevent deposits, effluent, and varnish from shaping on engine parts to keep them clean.

2. Dispersants Additive: In engine operation, dispersants help clean the burnt residues, gums, sludge and ashes, and deposits that detergents have removed by releasing solid particles. They also prevent solid particles from collecting together and prevent sludge from building in the motor's cold sections (carter). As a rule, dispersants are totally ash-free and

organic. As a result, conventional oil analyses cannot readily detect them. More pollutants may remain submerged and more acidic chemicals can be neutralized thanks to these additions. But eventually, these additives will outgrow their capacity and need an oil change as they carry out their functions of neutralize acids and suspending impurities. prevent impurities from collecting by dispersing and suspending them inside the oil.

3. Anti-fatigue or Anti Wear (AW) Ingredients: These parts support the oil's ability to combat ant exhaustion. These additives are widely utilized in boundary lubrication to protect machine parts from harm and stop metal loss from friction. They adhere to metal surfaces that are subject to friction and are known as NEUTRAL additives. When these additives come into contact with metal surfaces under barrier and mixed lubrication conditions, they undergo a chemical reaction. Heat produced by metal-to-metal contact activates the molecules, forming a wear-reducing coating. Additionally, they help shield metal from acidic corrosive chemicals and bases from the effects of oxidation. To lessen decline, create a protective coating on metal surfaces.

4. Extreme Pressure (EP) Additives: Create a shield to keep metals from entering into contact with one another under high pressure.

5. Viscosity Index Improvers: Conserve the oil's viscosity at several temperatures to ensure smooth operation.

6. Friction Modifiers: Increase mileage by lowering friction between moving parts.

7. Antioxidants ingredients: The lubricant's oxidation process can be delayed by the antioxidant components. By offering a stronger resistance to higher temperatures, they also aid in extending the time between oil changes. By stopping the production of acids and sludge, you can stop oxidation and prolong the life of the oil.

8. Corrosion Inhibitors or Anti-corrosion ingredients: Ferrous metals are protected from the combined effects of oxygen, water, and some oxides produced during burning by anti-corrosion products. To stop lead and copper from leaking via pipelines, they can be added to the water. Making an emulsion, often a form of passivation that prevents the corrosive

material from entering the metals is a common technique to prevent corrosion. Prevent moisture and acidic byproducts from corroding metal surfaces.

9. Rust Inhibitors: Stop ferrous metals from rusting.

10. Pour Point Depressants: These provide flowability in cold weather by lowering the temperature at which the oil solidifies.

11. Anti-Foaming Agents: The buildup of foam can cause air entrainment and lessen the oil's effective.

12. Demulsifiers: Help water and oil separate, avoiding the creation of emulsions.

13. Emulsifiers: Used in certain applications, such as metalworking fluids, they aid in the mixing of water and oil.

14. Metal Deactivators: Lessen the metals' ability to catalyze oxidation processes.

15. Color Stabilizers: Preserve the oil's hue throughout time, frequently for identification or aesthetic reasons.

16. pH Stabilizers: Prevent corrosion by keeping the oil's pH stable to prevent acidic or alkaline factors.

17. Antifreeze Additives: They keep the fluid sufficiently flowing even at lower temperatures (between 15°C and -45°C). The boiling point of liquids can also be raised using common antifreeze. Effective heat transmission and correct functioning of heat radiators depend on a wide temperature range where the mixture remains liquid, which can be achieved with careful antifreeze selection [14].

1.5 OBLIGATION OF LUBRICANTS

Modern technology has fairly intricate lubrication.

- a) The industrial lubricant must do myriad other tasks in addition to its typical duties of cutting wear, heat, and friction.

- b) Dims resistance and friction between moving parts.
- c) Lubricant, suggesting that it creates a fluid layer between moving parts that are packed full.
- d) Serve as a coolant to alleviate frictional heat, which is produced both within and outside the machine and may be very high.
- e) Acquire and remove toxic substances from both internal and external sources.
- f) In numerous applications, serve as a hydraulic medium.
- g) If the fluid coating is quite thin, prevent wear on heavily loaded parts
- h) Stops corrosion and creates a barrier against toxins and moisture. Prevent corrosion and rust in precise parts composed of different metals.
- i) Conduct defense against the buildup of lubricant system deposits, such as varnish and sludge.
- j) Prevent foaming and aeration, which may lead to faults.
- k) Prevent or stimulate the generation of emulsions in wet systems.
- l) Possess the capacity to isolate water from breathing air or other outside sources.
- m) Guards against decay over time and stops wear and tear.
- n) Helps cool machine parts by dissipating heat.
- o) Prevents contamination, lowers debris, and cleans and seals [15].

1.6 CLASSIFICATIONS OF LUBRICATING OILS

1. Lubricating oil for automotive

- a. Automobile Engine
 - i. Petrol/ octane engine oils
 - ii. Diesel engine oils
- b. Transmission fluid
- c. Gearbox oil
- d. Brake oil
- e. Motor Engine Coolants

2. Oils for farming tractor engines

- a. Transmission Oil for Tractor
- b. Super Tractor Oil Universal

3. Other motor oil

- a. 2-Stroke Motor oils
- b. 4-Stroke Motor oils

4. Industrial Machineries Lubricating Oil

- a. Hydraulic oils
 - i) General Purpose Hydraulic oils
 - ii) High Viscosity Index Hydraulic oils
 - iii) Fire Resistant Hydraulic oils
- b. Air compressor oils
 - i) Reciprocating (Piston) Compressors oils
 - ii) Rotary Screw Compressors oils
 - iii) Rotary Vane Compressors oils
- c. Lubricants for Food Grade
- d. Engine and Compressor oils of Gas engine
- e. Gear fluids
- f. Circulating oils
- g. Refrigerator oils
- h. Steam Turbine Oils
- i. Spindle Oil/ Swing/ Textile/Knitting machine oil
- j. Heat Transfer oil
- k. General purpose machine oil
- l. Flushing oil
- m. Turbine Oil

5. Aviation Engine Oil

- a. Turbine oils for gas engine
- b. Piston type engine oils

6. Marine Engine Oil

- a. Cylinder lube for Crosshead
- b. Crankcase oils
- c. Engine oils for Trunk piston
- d. Lube oils for Stern tube [16].

1.6.1 Oil Lubrication Methods

(1) Oil Sump Lubrication: Approaches for Oil Lubrication the most preferred lubrication skills, notably for low- to medium-speed steps, is oil sump lubrication. In concept, the oil surface should be located in the middle of the lowest rolling element; notwithstanding, it is advantageous to be able to use an oil gauge to verify the exact location of the oil surface.

(2) Drip Feed Lubrication: This system, to regulate the oil supply by varying the oil drip volume, is popular for small bearings that run at a relatively high speed.

(3) Throwaway Lubrication: This approach applies oil to bearings by inserting a gear or circulation ring. It is commonly used for gears or gearboxes in transportation.

(4) Circulation Lubrication: It is mostly used when cooling bearing units that revolve quickly or in situations of heat is required. Oil is cooled and then fed again after being taken through a recovery pipe and fed through a feed pipe. To avoid back pressure on the oil in a bearing, the recovery pipe's diameter should be wider than the feed pipes.

(5) Jet lubrication: It is common for high speed rotary bearings and involves injecting oil into a bearing's inside through one or more nozzles at a constant pressure. Because the air wall created by the surrounding air turning with the bearing can reduce the jet stream, the jet stream speed ought to be greater than one-fifth of the inner ring outer surface's circumferential speed. The more nozzles there are, the smoother and more cooling effect there is, as long as the overall lubricant volume keeps stable.

(6) Spray Lubrication: It uses air to expel the lubricant when it is sprayed into a bearing. It has the following qualities.

- (i) Its churning resistance falls as a result of the little amount of oiling needed, which makes it appropriate for speedy revolutions bearings.
- (ii) It reduces the amount of lubricant that is released, which helps to decrease equipment spoilage.
- (iii) Bearing life is increased due to the constant feeding of fresh lube. As a result, it uses a lot for a variety of machining tasks [17].

1.7 ASPECTS OF WASTE LUBRICATION OIL

Trash lubricating oil is defined through examining its environmental, chemical and physical traits for its composition, degree of damage, and suitability for rehabilitation or landfill. This procedure is crucial in finding the best solutions while reviewing the environmental impact.

1.7.1 USED WASTE LUBRICATING OIL

Reclaimed oil is any petroleum-based or chemical-based oil that has been put to lubricating purposes and is no longer fit for its original uses. The term "used oil" refers any petroleum-based or artificial fluid that has been used for its intended purpose but has since become corrupted by physical or chemical toxins. It usually has lubricating oils, hydraulic oils, motor oils, transmission oils, and other materials after they have been utilized in engines, machinery, or factories. Used oil must be handled properly to prevent environmental harm; it may not be considered to be risky waste. Under waste management regulations, spent oil may have different legal definitions in different nations. Cycle of refined lubricating oil shown in fig.1.4 [17]. Over time, lubricating oils deteriorate as a result of oxidation, heat stress, and contamination from water, particles, and combustion byproducts. Poor disposal of used oil poses serious dangers to the environment. Refining, which turns spent lubricating oil back into usable form, has become popular as a viable alternative for disposal and crude oil elegance. The main technologies, environmental effects, and difficulties related to re-refining rules are examined in this review of the literature.

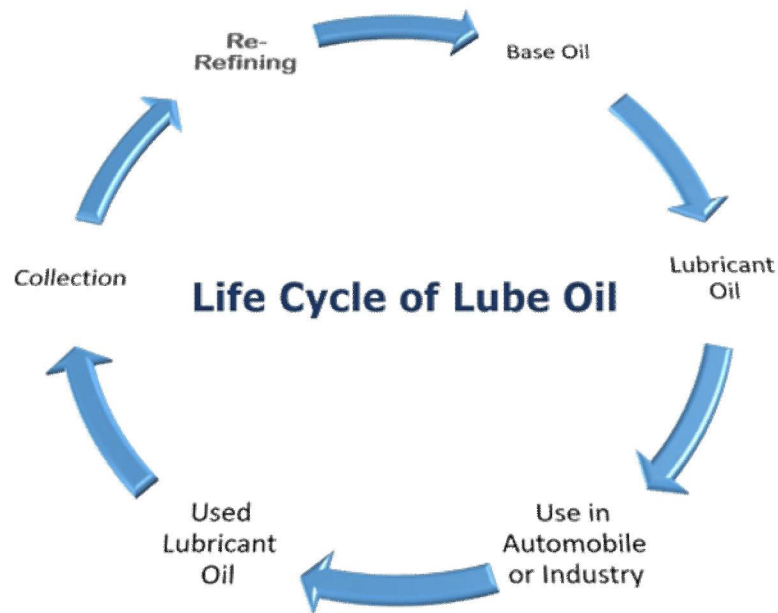


Figure 1.4: Cycle of refined lubricating oil [18]

The key aspects of waste lubricating oil characterization:

1. Physiological Description

- a) Particulate issue's color, clarity, and presence are noted through visual inspection.
- b) Assessment of the oil's flow resistance, which can show dirt or loss.
- c) Checks the mass per unit volume, which is beneficial to find the sort of oil and its level of taint.
- d) The temperature at which volatile particles are present is shown by the spontaneous combustion of oil fumes.
- e) The oil's adaptability for cold conditions is indicated by the lowest temperature at which it flows.

2. Chemical Characterization: Using tools of detection like Inductively Coupled Plasma (ICP) spectroscopy, metals (such as lead, zinc, copper, and iron) and other elements (such as sulfur and phosphorus) may found and counted. Look at the kinds and numbers of hydrocarbons found, often with the aid of gas chromatography-mass spectrometry (GC-MS). Identifies the oil's acidity and if acidic product degradation is present. Determines the alkalinity of the oil, revealing how much acid-neutralizing power still has. Determined by Karl Fischer titration since water may spark corrosion and hamper oil performance, residue that stays after oil fires up, implying the presence of non-living contaminants.

3. Pollutant Analysis: Using filtration and microscopy, this method detects solid waste like carbon deposits, metal particles, and dirt. use approaches such as High-Performance Liquid Chromatography (HPLC) for testing these risky substances. Finding chlorinated pollutants, this can be dangerous and signal the presence of some pollutants or additions. Detection of carboxylic acids, ketones, and aldehydes formed as a result of oil oxidation. When used in engines, machines, or industrial processes, used oil collects a variety of pollutants. If these pathogens are not properly managed, they may be detrimental to both the environment and human health. Certain sorts of debris cause automobile lubricating oil to lose its effectiveness while in use. The main pollutants in used oil are listed below:

3(a). Unwanted contaminants: Mechanical particles from the engine and outside air both add extraneous undesirable substances. Dust, grime, and moisture are airborne contaminants. Since air can cause oil to froth, it could be regarded as a pollutant in and of itself [19].

These are the engine's impurities:

- a) Metallic particles put on by engine wear.
- b) Particles of carbon caused by incomplete fuel combustion.
- c) Metallic oxides are discovered when metals rust.
- d) Water from the cooling system's leak.
- e) Water is a byproduct of fuel combustion and other things that can get into engine crankcases.
- f) Chemical byproducts and additives, which are used to keep engine purity but degrade with time. Sludge, varnish, anti-wear agents (Zinc Dialkyldithiophosphate), and acids are result from response to heat and oxygen.
- g) Fuel and solvent contamination, dilution of gasoline and diesel by incomplete combustion or fuel loss. Industrial cleaners that use chlorinated solvents.
- h) Dirt & Particulates, Soot From diesel engines. Dust, metal shavings, rust from engine wear or external contamination.

4. Environmental and Safety Characterization: Assessment of the oil's harmful effects on living organisms, often using bioassays. Evaluation of how easily the oil can be broken down by microorganisms, important for environmental impact assessments. Determination of the oil's flammability characteristics, crucial for handling and storage safety. Analysis of toxic metals like lead, cadmium, and mercury, which can have significant environmental and health impacts.

5. Productivity Characterization: Appraisal of the oil's ability to lessen wear and friction, through regular tribological testing. Scrutiny of the oil's ability to withstand thermal degradation at elevated temperatures. Assessment of the oil's ability to withstand oxidation, which can result in the creation of sludge and varnish.

6. Enforcement Compliance: Checking that the waste oil meets regulatory standards for recycling, reuse, or disposal, such as those imposed by the European Union (EU) or the Environmental Protection Agency (EPA). Evaluating the waste oil's chemical makeup and grade of contamination to determine if it qualifies as hazardous.

7. Principles and Instruments Used for Analysis

- **Spectroscopy:** Strategies for elemental and molecular analysis from Fourier-Transform Infrared Spectroscopy (FTIR), Atomic Absorption Spectroscopy (AAS), and ICP.

- **Chromatography:** GC-MS and HPLC for in-depth study of contaminants and hydrocarbons.
- **Thermal Analysis:** Approaches that assess thermal properties such as Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA).
- **Tribological Testing:** Tools to measure wear characteristics and lubrication, such as four-ball and pin-on-disk testers.

8. Applications of Characterization: Determining the feasibility and methods for recycling waste oil into base oils or fuels. Evaluating the potential environmental hazards and necessary precautions for disposal or treatment. Ensuring that recycled or refined oils meet the required specifications for reuse.

9. Products of Oil impairment: Many types of products arise as a result of oil deterioration. In the major products are:

Sludge: A mixture of carbon particles, water, dust, dirt, and oil that occurs when fuels burn poorly. Sludge may stay in small particles in the oil or deposit onto distinct engine parts.

Lacquer: When sludge in the oil gets heated to high temperatures, a hard or sticky substance known as lacquer forms on engine parts.

Oil-soluble products: Products of oil oxidation that are unable to be sorted out and end up on engine parts qualify as oil-soluble products. Engine driving conditions have an immense effect on the amount and layout of engine deposits. Carbonaceous deposits at low crankshaft temperatures are mostly caused by fuel's incomplete combustion scraps rather than lubricating oil. However, the lubricating oil may be the cause of the rise in lacquer and sludge creation at elevated temps [20].

1.8 NECESSITY OF USED WASTE OIL RE-REFINING

Waste oil refining, also known as re-refining, is a critical process for environmental, economic, and resource conservation reasons. The key reasons why waste oil refining is important:

Environmental & Health Risks: Soil/ water pollution, Heavy metals and PAHs can persist in the environment. Toxicity to humans, Exposure can cause skin irritation, respiratory

issues, or long-term cancer risks. Firehazard, used oil is flammable, especially if mixed with fuels.

Environmental Protection: Old oil that is not disposed of may greatly harm the environment by contaminating the air, water, and soil. By processing or recycling the oil in a secure way, re-refining helps reduce such risks. Potential dangers like toxic metals and deadly substances tend to accumulate in waste oil. By deleting these impurities, refining lowers the amount of hazardous waste that must be disposed of. Waste oil recycling decreases the probability of deliberately leaks during disposal and shipment.

Resource Conservation: Refining waste oil into base oils reduces the need for virgin crude oil, conserving a finite natural resource. The energy required to re-refine waste oil is considerably less than that needed to produce new oil from crude, leading to overall energy savings. Re-refining supports a circular economy by turning waste into valuable resources, promoting sustainable resource management practices.

Economic Benefits: Refined oil is often less expensive than virgin oil, providing cost savings for industries and consumers. The waste oil refining industry creates jobs in collection, transportation, processing, and distribution. The re-refining process produces valuable by-products like asphalt and fuel oils, which can be sold and used in various industries.

Regulatory Compliance: Many countries have stringent regulations regarding the disposal and recycling of waste oil. Refining helps companies comply with these regulations, avoiding fines and legal issues. Companies that engage in waste oil re-refining can enhance their corporate social responsibility (CSR) profiles by demonstrating a commitment to environmental sustainability.

Quality and Performance: Refined base oils can meet or exceed the quality of virgin base oils, making them suitable for use in high-performance applications. Refining provides a consistent supply of base oils, reducing dependency on fluctuating crude oil markets.

Public Health: Properly managing and refining waste oil reduces the risk of exposure to harmful substances; protecting public health. The re-refining process safely disposes of or

neutralizes harmful contaminants, preventing them from entering the environment and affecting human health.

Technological Advancements: The refining industry drives technological advancements in oil processing, leading to more efficient and environmentally friendly methods. Research and development in re-refining can lead to the creation of new products and applications for re-refined oils and by-products.

Management & Recycling: Used oil is often converted into fuel or refined, which extracts debris to create "like-new" oil. Effective disposal avoids harm to ecosystems and complies with laws (e.g., EPA, EU Waste Framework Directive).

Impact on a global scale: Recycling spent oil helps fight climate change by rapidly reducing the carbon footprint linked to oil production and disposal. International environmental standards and practices are set up and enforced through the promotion of waste oil re-refining. Refining waste oil is an essential procedure with numerous beneficial social, economic and environmental effects. Refining aids to biodiversity preservation, natural resource protection, and sustainable development by turning waste oil into valuable resources. It is a vital role in modern ecological protection and waste management plans [21].

1.9 PROCESS OF SCRAP OIL REFINING

1. Pre-Treatment (Preparation): Scrap oil is sterilized by removing water and major contaminants prior to refining.

- **Filtration:** Gets rid of solids including sludge, metal shavings, and grime.
- **Sedimentation:** Heavy sediments may fall to the bottom thanks to erosion.
- **Dehydration:** It uses vacuum distillation or heating to remove water.

2. Distillation: Using variations in boiling points, distillation separates oil from impurities.

- **Atmospheric Distillation:** By heating the oil, lighter components evaporate and later condensed back into liquid form using atmospheric distillation.
- **Vacuum Distillation:** For heavier oils, vacuum distillation is utilized; it lowers boiling points and stops thermal depreciation by operating at lower pressure.

3. Chemical Treatment: To eliminate particular contaminants, chemical procedures are employed.

- **Acid Treatment:** Metals, sludge, and other impurities are reacted with sulfuric acid or other acids, which are eventually dissolved.
- **Clay Treatment:** Impurities like oxidized chemicals and leftover acids absorb using activated clay, also known as Fuller's earth.
- **Solvent Extraction:** Unwanted particles are dissolved and dissolved using solvents such as the fiber or propane.

4. Hydrotreating: This improved refining method

- Sulfur, nitrogen, and oxygen compounds are eliminated by adding hydrogen at high temperatures and pressures.
- Promotes the oil's quality and stability, enable it to be reused.

5. Refining: This process brings waste oil back to a state that is close to virgin oil:

- **Thin-Film Evaporation:** A specific distillation method called thin-film evaporation is used to separate base oil from pollutants and additives.
- **Hydrogenation:** Enhances stability and color by saturating unrefined hydrocarbons and further refining the oil.

6. Additive Blending: To restore the oil's ability to perform after refining, additives are mixed in. To fulfill industry standards, anti-wear agents, detergents, dispersants, and viscosity modifiers are added [22].

7. Final Filtration and Quality Control: To get rid of any residual pathogens, the refined oil is filtered. Tests for quality control make sure the oil satisfies allotted criteria.

The following steps are commonly included in the re-refining process:

- a) **Collection and Transportation:** Waste oil is gathered from different locations and delivered to facilities for further refined.
- b) **Pre-treatment:** Filtration and dehydration are used to remove water, sediments, and other contaminants.
- c) **Distillation:** The process of separating oil into several parts according to their respective boiling points.

- d) **Hydrotreating:** Using hydrogenation, residual impurities are eliminated and oil quality is raised.
- e) **Finishing:** Last-minute blending and purification to satisfy particular criteria for quality.

1.10 TECHNOLOGIES FOR REFINING WASTE OIL

Three core techniques are reprocessing, refining, and incineration can be used to recycle spent lubricating oils.

(i). **Method of Reprocessing:** In to achieve reprocess waste lubricating oil, impurity must be cleaned and its qualities must be restored. Waste oil can be recycled and refined using a variety of methodologies, such as thermal, chemical, and physical treatments. Reprocessing aims for final engine oil with a low water and basic sediment content that won't clog burners, contaminate boiler tubes, or result in a build-up in customer tanks. In fig. 1.5 shows flowchart of reprocessing of used lubricating oils [23].

1. Physical Treatment Methods: These processes remove solid impurities and water without altering the oil's chemical structure.

- **Settling and Filtration:** The oil is left to stand, allowing heavy particles to settle at the bottom. It is then passed through filters to remove dirt and debris.
- **Centrifugation:** High-speed centrifuges separate oil from water and solid contaminants. Effective for removing sludge and metal particles.
- **Vacuum Distillation:** The oil is heated under low pressure to separate water, fuel-like components, and base oil fractions. Produces cleaner oil with minimal degradation.

2. Chemical Treatment Methods: These processes involve adding chemicals to remove impurities and restore lubricating properties.

- **Acid-Clay Treatment:** Sulfuric acid is used to remove sludge and oxidation byproducts. Clay is added to absorb color and remaining contaminants.
- **Solvent Extraction:** Solvents like propane or ketones dissolve and separate impurities. Enhances the quality of recovered base oil.
- **Hydrogenation:** Hydro processing is a way of purifying waste oil with hydrogen at high

pressure and temperature. Provides superior re-refined oil with no unwanted substances such as sulfur and nitrogen.

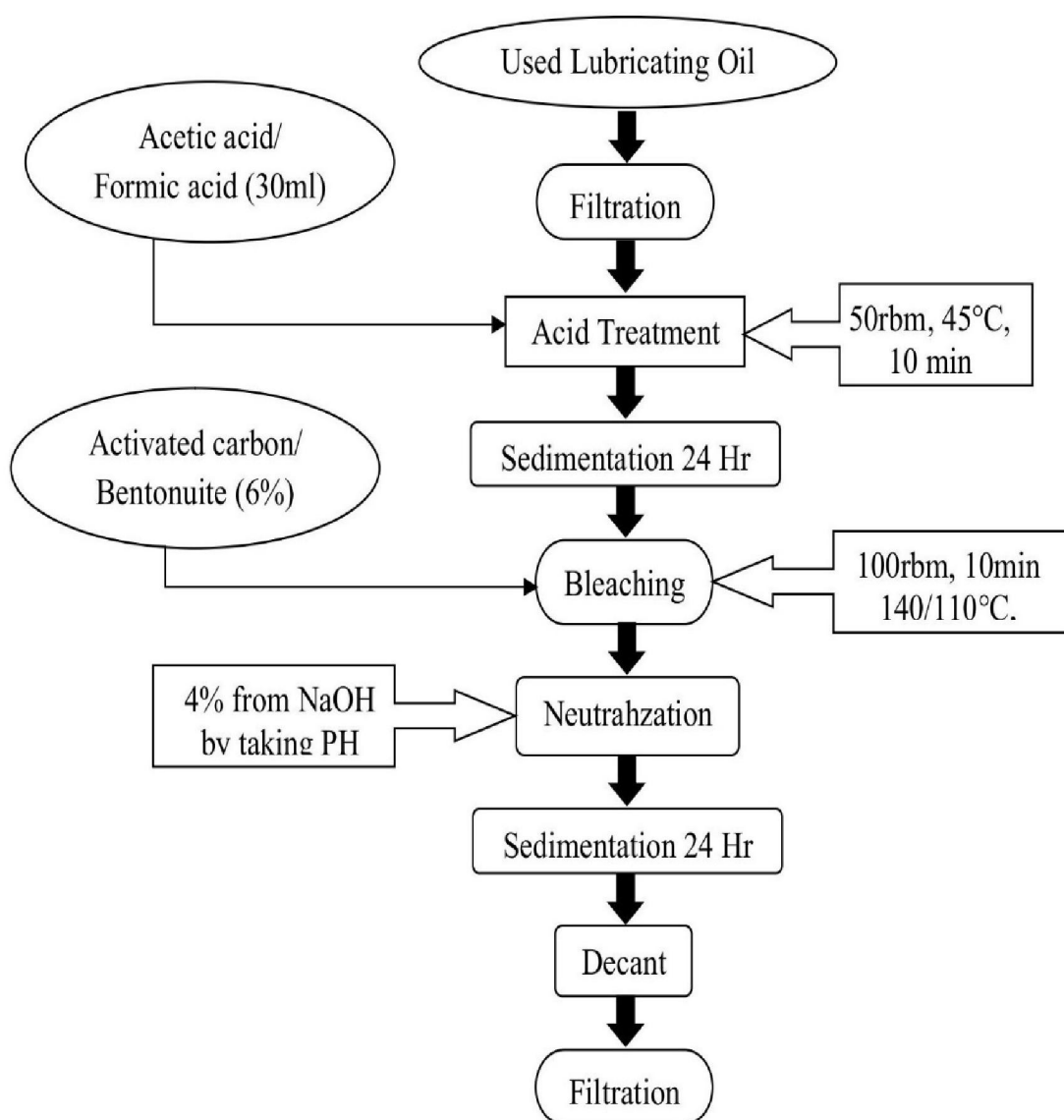


Figure1.5 Flowchart of reprocessing of used lubricating oils [23]

3. Pyrolysis: No oxygen, the oil is heated to temperatures between 400 and 600°C. Converts bigger molecules into portions of basic oil or reusable fuel, emits gas, diesel, and gasoline as outputs for energy recovery.

(ii). Refining: Lots of re-refining methods have been put up for the recycling of waste oil over time. In rich nations, adoption of this process has risen dramatically, with few nations

using it to meet up to 50% of their lubricating oil needs. Different western nations came up with a variety of ways of reusing used lubricating oil.

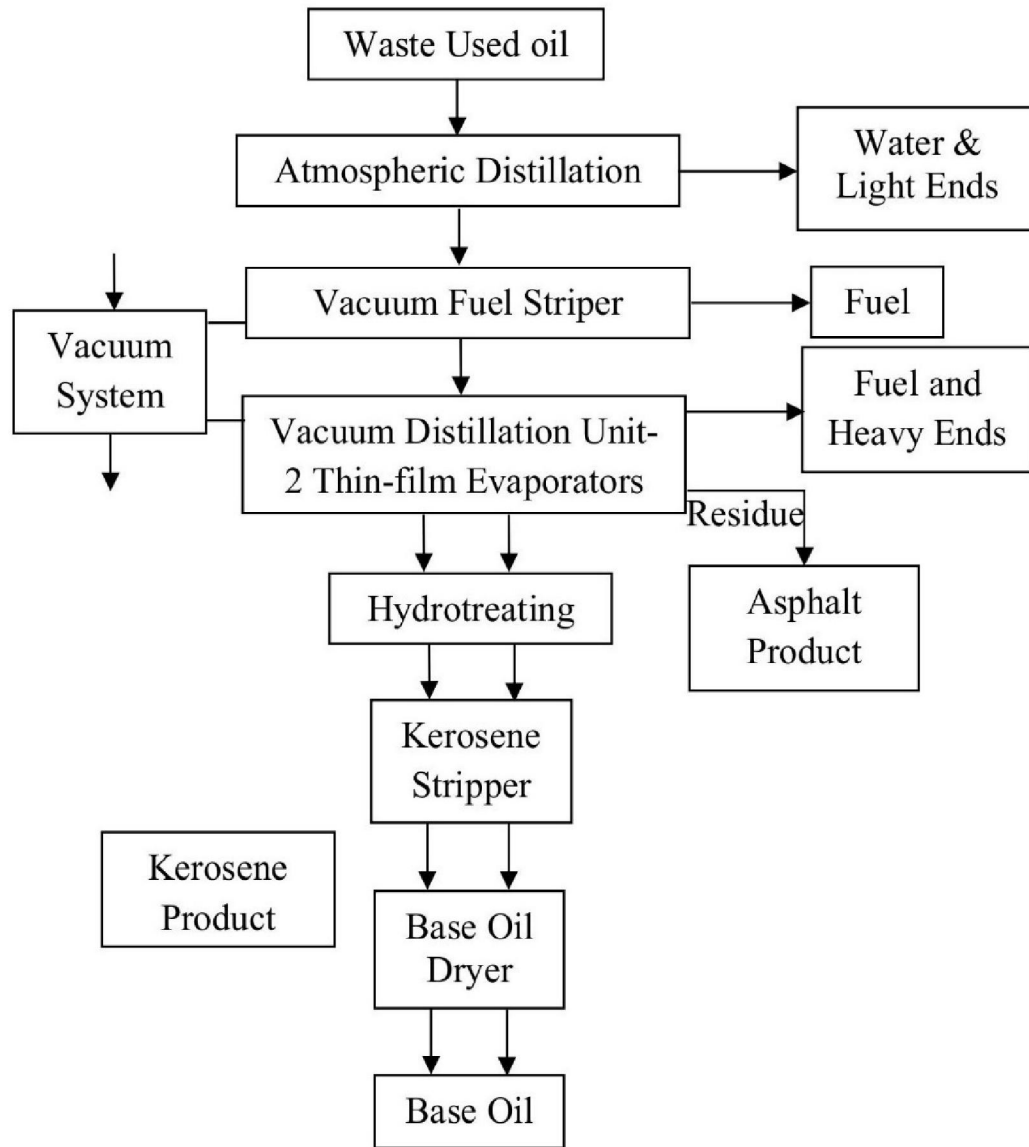


Figure1.6 Block diagram of refining of used lubricating oils [24].

Usually, the procedure includes pre-treatment by heat or filtration, followed by either separating the solvent with clay and chemical treatment with hydro-heating or vacuum distillation with hydrogen completing or clay. Figure 1.6 shows block diagram of refining of used lubricating oils. For tiny enterprises with capacities that vary from 10,000 to 30,000 tons, vacuum distillation coupled with clay contacting provides a less polluting and

economical solution to the re-refining process. Before being disposed of in landfills, the residual by-product is fully compacted and baled in thick plastic sheets. A credible recycling company's involvement may greatly boost the trust ratio [24].

(iii). Incineration: When recyclable oil is highly dirty, especially with polychlorinated biphenyls (PCB) and polychlorinated terphenyls (PCT), this tactic is better. It suggests that cement producers use controlled high-temperature burning when there is no hazardous waste incinerators provided. Rotating cement kilns have flame ends that can reach temperatures of 2000–2400°C. This extreme heat is required to neutralize acid chemicals and degrade organics. Since the concentrations of heavy metals are still very low when compared to the natural supplies used in the cement production process, the presence of heavy metals is considerably decreased. However, keep in mind that in order to guarantee accordance to air quality regulations, regular surveillance of gas emissions at the cement manufacturers would be necessary [25].

1.11 REFINING WASTE OIL USING THE DISTILLATION METHOD

The procedure of distillation uses selective condensation and boiling to isolate parts or molecules from a liquid mixture. A liquid is heated to the boiling point inside an object during the distillation process. The process of distillation involves the turning of water vapor into explosive liquids and their next separation through selective boiling. Distillation is a liquid purification method that can separate combo components with notably differing boiling points. Distillation can produce a nearly total separation or a slight separation that raises the concentration of particular blend components. By pushing one of the components in the solution of liquid into a gaseous form, the distillation process takes advantage of the difference in their boiling points. It is crucial to remember that distillation is an act of physical separation rather than a chemical reaction. Laboratory scale distillation, industrial distillation, herb distillation for perfumery, and drugs and food processing are the four main groups of distillation uses.

a) Simple distillation: In it, the vapor is sent straight into a condenser. As a result, the distillate is not pure; rather, its composition matches that of the vapors at the specified level of pressure and temperature.

b) Fractional distillation: A variety of vaporization-condensation cycles inside a packed fractionating column need to occur to separate the components using fractional distillation.

c) Steam distillation: It is used for separating heat-sensitive chemicals.

d) Vacuum distillation: In light of the standard testing action we used for the distillation process, the principle of vacuum distillation is that it drowns out the surrounding air from the gadget in order to distil or heat the explosive liquid at a temperature lower than the desired one. This prevents vapor from forming as a result of the heating process that is followed in a stripping process.

e) Air-sensitive vacuum distillation: Certain chemicals that sustain air-sensitive vacuum distillation also have high boiling points. As demonstrated above, an ordinary vacuum distillation system can be employed, in which an inert gas is used to replace the vacuum once the distillation process is finished.

f) Short path distillation: This type of distillation normally goes out at low pressure and includes the distillate traveling a brief distance, often just a few centimeters.

g) Zone distillation: It is a long-container distillation method in which the refined matter partly melts in a moving liquid zone and its vapor in the solid phase collapses at condensate pulling in a cold area.

Distillation Method: First, air distilling served to eliminate all of the moisture from the material. Distillation is a type of process that uses heat to separate each part of a liquid mix. In short, such type of separation is caused by changes in the vapor pressure of distinct elements at the same temperature. The vacuum distillation flask was filled with 200 milliliters of waste oil. By placing 30 grams of clay in a plugged funnel and letting the lube oil flow through the clay bed, this fluid oil stream was cleansed. Vacuum filtration is what this is. Filter is a unit process that entails a solid from a solution using a screen or porous media that keeps the solid in place while allowing the liquid to pass through. However, vacuum filtration was used. Working plan of re-refining of used lubricating oils shows according to figure 1.7 [26]. Vacuum filtering refers to as filtration that uses normal pressure on downstream of the filter media and less than atmospheric pressure on the upstream side.

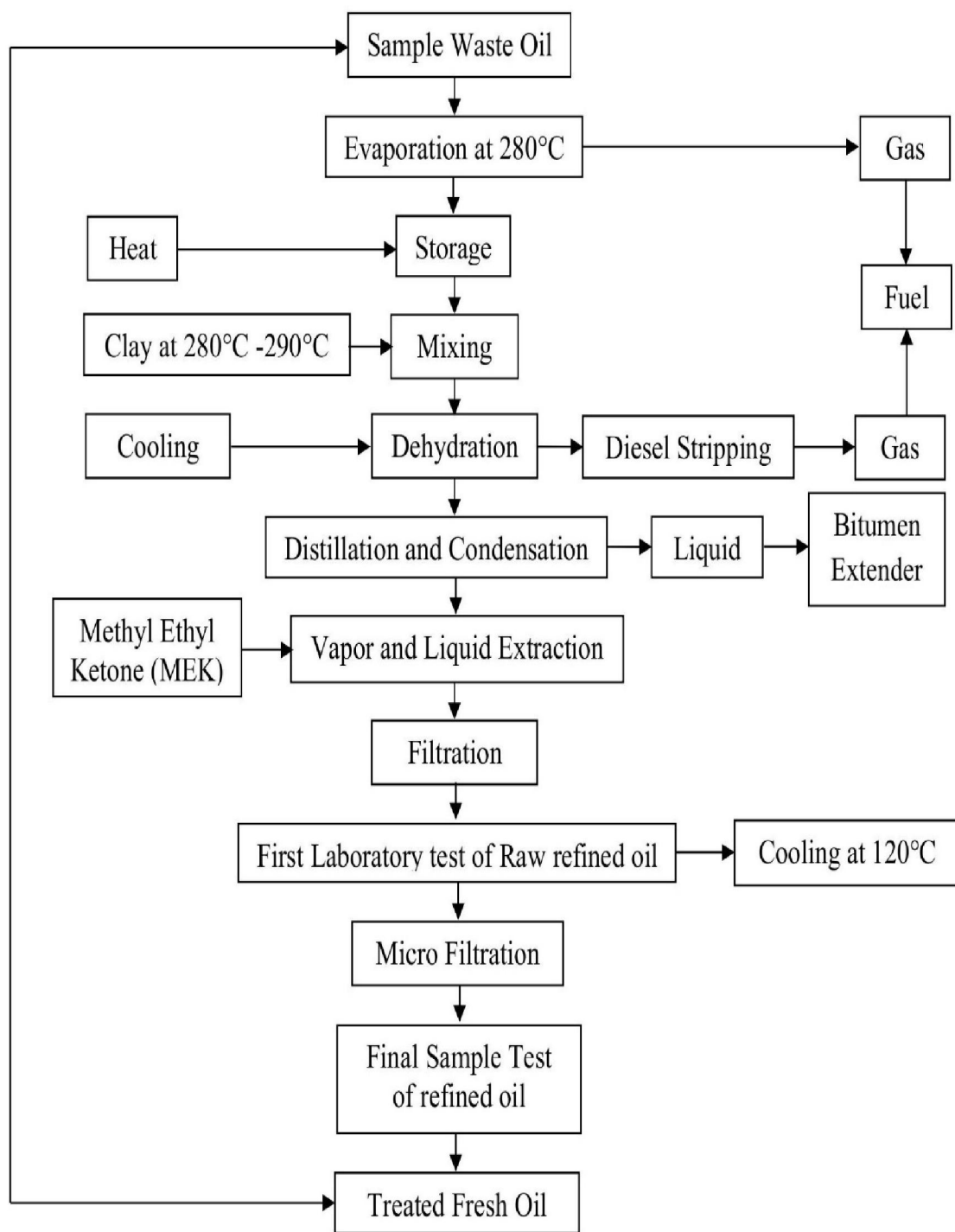


Figure1.7 Block diagram of distillation method to refining of used lubricating oils [26]

1.12 GAINS AND CHALLENGES OF REFINING USED WASTE OIL

Metal ions, dioxins/furans, polycyclic aromatic hydrocarbons, and chlorinated hydrocarbons are a few possibly harmful compounds found in used oil. They qualify as mutagens and carcinogens. Refining spent waste oil is the centerpiece of resource conservation and

sustainable garbage handling because it has major technical, financial, and green benefits. For any used oil manufacturer who commits to its environmental skills and image, luxurious re-refining to reclaim base oil for use again is an environmentally conscious method of treating used fluid. But there are cons to the procedure as well, such as costly fees, intricate technology demands, and barriers to entry.

1.12.1 Benefits of Used Waste Oil Refining: Regarding raw lube oil, 60% less energy is used in the creation of refined lubricant. It has the capacity to create enough power to power every home through the recycling of surplus oil. It can be used for a wide choice of petrochemical-based products, namely plastics. Long term green solution. Lowers the amount of lube oils imported. A great substitute to second-grade fuels [27].

- **Environmental Benefits:** Prevents improper disposal of waste oil, which can contaminate soil, water and air. Reduces the risk of oil spills and leaks. Decreases the demand for virgin crude oil, conserving finite natural resources. Refining requires less energy compared to producing virgin oil, reducing greenhouse gas emissions. Properly re-refined oil reduces the amount of hazardous waste sent to landfills or incinerators.
- **Economic Benefits:** Refined oil is often cheaper than virgin oil, providing cost savings for industries and consumers. The re-refining industry generates employment opportunities in collection, processing and distribution. Reduces reliance on imported crude oil, enhancing energy security for many countries. Refined oil and by products (e.g., fuel oil) can be sold, creating additional revenue streams.
- **Technical Benefits:** The base oil made using conventional refining technology is on par with or superior to virgin oil. Lubricants, hydraulic fluids and industrial fuels are just a few of the uses for refined oil. Refining improves the value of oil by allowing multiple times of use.
- **Regulatory Compliance:** Helps industries comply with environmental regulations regarding waste oil disposal and recycling. Aligns with corporate and governmental sustainability initiatives.

1.12.2 Constraints on Used Waste Oil Refining:

Due to limited lab space, not all of the used lubricating oil's properties were investigated. Just three particular oils are meant for use in the lubricating oil gathering system. Calls for a robust collection system. A flourishing market is needed for refined lubricant oil. Necessitates a large budget. A dependable recycled business helps for the re-refining option for it to assure the product's economic feasibility. It is high-priced for correct disposal of end waste leftovers.

- **High Initial Investment:** Developing a re-refining facility requires a large outlay of funds for advanced technology. Costs for labor, energy, and care can be major even for startups.
- **Technical Challenges:** It can be difficult to fully eliminate every trace element, like heavy metals, additives and sludge, and it might take several stages of process. The input debris determines the quality of the re-refined oil.
- **Environmental Concerns:** Customers who believe that virgin oil is preferable might reject refined oil. Pricing and demand may be affected by the refining industry's rivalry with the living virgin oil market.
- **Market Challenges:** Refined oil may face resistance from consumers who perceive it as inferior to virgin oil. The re-refining industry competes with the well established virgin oil market, which can affect pricing and demand.
- **Regulatory Hurdles:** Keeping with strict safety and ecological norms may result in greater operating costs. It can be laborious and time-consuming to obtain the required authorization for the collection and re-refining of waste oil [28].

1.13 WORLDWIDE PERSPECTIVE OF LUBRICATING OIL

From 2021 to 2028, the international lubricants market is going to surge at a compound annual growth rate (CAGR) of 3.7%, from its 2024 size of USD 130.81 billion. Figure 1.8 table-1.1 shows market volume of lubricants globally in 2024 [29].

The rising market for bio-based lubricants are causing a shift in the raw material patterns in the industry. The demand for automotive oils and greases is expected to increase due to the booming trade in autos and their spare parts [29]. The market will benefit from the expected boost in the consumer cars segment driven by the significant economic rebound in North America and Europe. Global commerce has been integrated by big companies as Sinopec, British Petroleum, ExxonMobil Corporation, Chevron, Royal Dutch Shell, and Total SA.

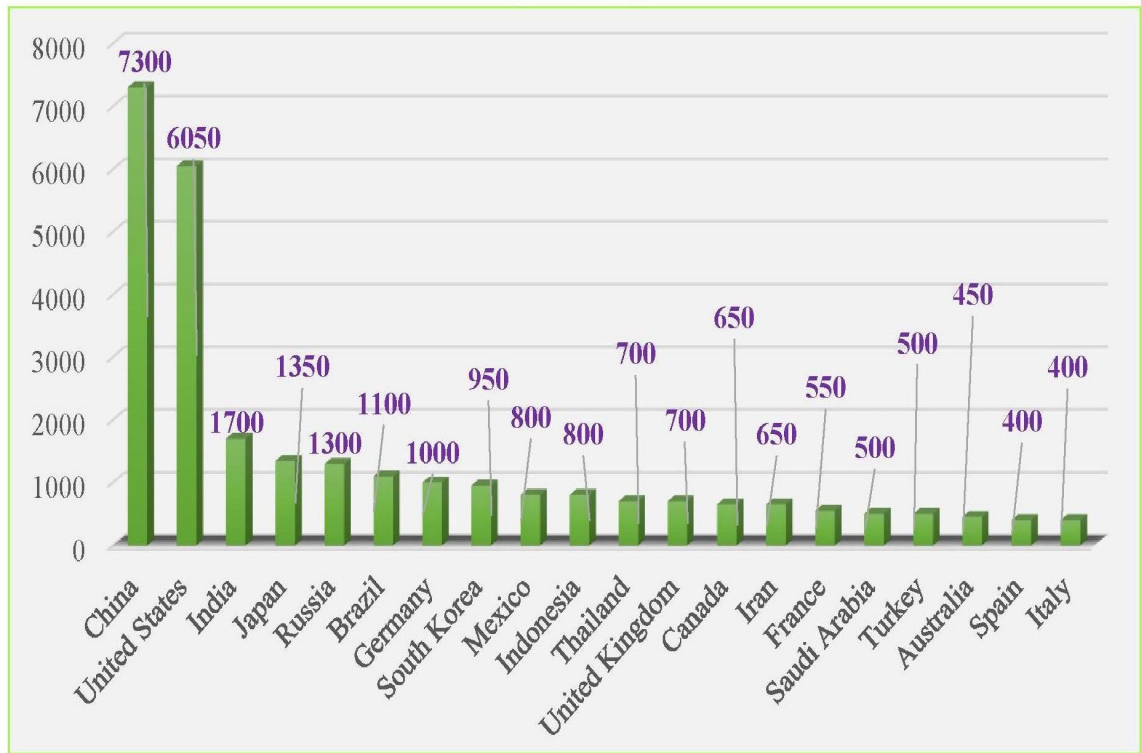


Figure 1.8: Market Volume of Lubricants Worldwide in 2024 [29]

Table-1.1: Market Volume of Lubricants Worldwide in 2024, top-leading countries.

No.	Country Name	Volume (in 1,000 Tons)
1	China	7300
2	United States	6050
3	India	1700
4	Japan	1350
5	Russia	1300
6	Brazil	1100
7	Germany	1000

8	South Korea	950
9	Mexico	800
10	Indonesia	800
11	Thailand	700
12	United Kingdom	700
13	Canada	650
14	Iran	650
15	France	550
16	Saudi Arabia	500
17	Turkey	500
18	Australia	450
19	Spain	400
20	Italy	400

1.14 LUBRICATING OIL IN BANGLADESH PERSPECTIVE

As the variety of transport and power plants in operating has risen over the past eight years, the market for diverse fossil fuels has grown at a mean rate of almost 6%. However, due to a lack of in-country production end users are yet to gain from the advantages that often offer an aggressive marketplace, such as lower costs and a range of products. With a total demand of 1.60 lakh tons, the petroleum products market had a value at Tk. 3,616 crore in 2019. Due to market insiders, the products are going to be in popularity as society grows as they play a role for the care and functioning of all apparatus. According to figures 1.9 [30] from the Bangladesh Power Development Board, the country's power plants rose to 133 in the last nine years, meaning that electricity production has almost tripled.

Based on trusted sources, they own just over half of the market share, with the other half split among different brands. Although the market for engine oils grows, customers are still struggling since local vendors are unable to meet the criteria set forth by original equipment manufacturers (OEM) for the oils used in their devices. At the moment, Bangladesh offers almost 150 varieties of lubricating oil.

The top five brands in Bangladesh's lubricating oil market are as follows:

- Mobil (MJL Bangladesh Ltd.)
- Caltex/ Chevron (Navana Petroleum)

- Total (Trade Services International)
- BP (Jamuna Oil Company Limited)
- Lubricant Asia Ltd - Fuchs

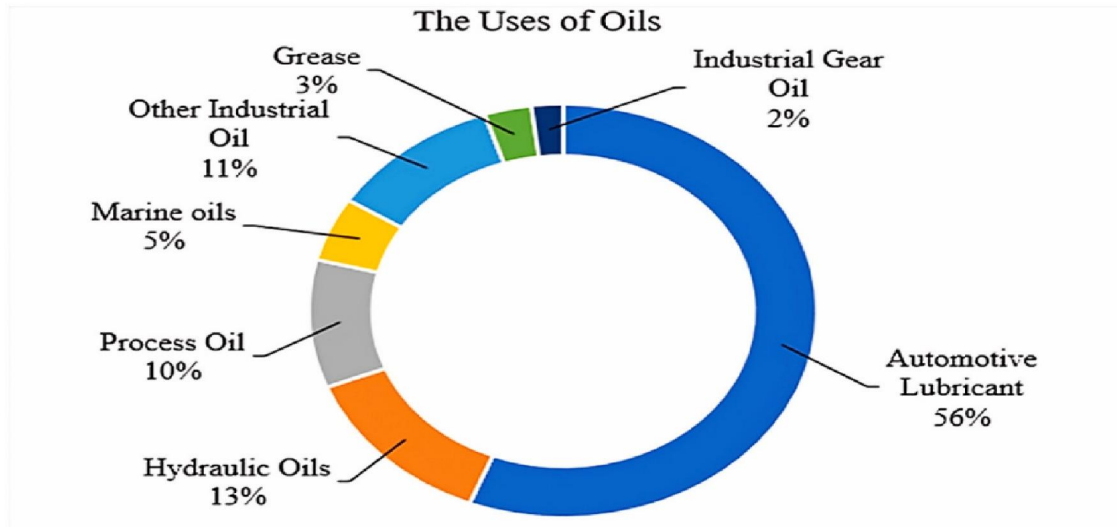


Figure 1.9: Annual Lubricating oil local consumption breakdown, 2024 (in Tons) [30]

Lubricating oil Blending Plants in Bangladesh:

1. MJL Bangladesh Limited (Mobil & Omera brands)
2. Jamuna Oil Company Limited (Jamuna Brand)
3. Meghna Oil company Limited (Meghna Brand)
4. Padma Oil company limited (Padma Brand)
5. Lubricant Asia Ltd (FUCHS Brand)
6. Lub-rref Bangladesh Limited (BNO)
7. Global Oil Co. Ltd. (AP Oil)
8. Shah Aminullah Lubricants Ltd. (Boss Lubricants)
9. SOACL (Lube Zone Oil, Moto Lube etc.)
10. Pacific Oil Ltd. (SINO brand)
11. Alhaj Abdul Kuddus Pvt. Ltd. (J1 Oil)
12. Fossil Lubricants Pvt Ltd. (Fossil Oil)
13. City Lubricating oil Industries Ltd. (Amirath Oil)
14. Sigma Oil Industries Ltd., Narayanganj (Sigma, Soil)
15. Bashumoti Distribution Ltd., Hemayetpur (BOPIL & SPEEDY Oils)
16. Min Oil Co. Ltd., Savar- Mol-X (Use Recycle Oil)
17. Lube House Industries Ltd., Norsingdhi (National Oil)

18. Karnafully Oil & Chemical Ltd. (Use Recycle Oil)
19. Oriental Oil Company Ltd., Jessore (HP, Veedol and Gulf)
20. United Lubricating oil Limited, Mongla (Petronas product)
21. Star Lube Pvt Ltd. (Star Brand)

1.15 IMPACT OF CONTAMINANTS IN OIL

Any toxins that may arise during operation have an impact on the lubricating oils attributes.

These are the effects of the polluting:

- (i). Water harms iron and steel, even in small amounts. Furthermore, the water causes emulsions, or water sludge, to form, which can block pump valves, oil channels, or other oil handling systems. A further issue that leads to foaming gives is water.
- (ii). The lubricant's circulation of solid dirt, dust, grit, and metallic pieces results in worn out bearing surface scoring, and might fail from seizing of metal stress.
- (iii). Slurry deposits block tiny oil clearances and routes. Lacquers and paints cause valves to stick and stop the oil pump from running always. Engine leftover fuel is a case of a liquid pollutant that dilutes lubricating oil and may lower its viscosity above a safe level. With thicker oil, lubricant pests cause the oil to become more viscous and disrupt its flow. Heat transfer capability and the lubricating valve are altered [31].

1.15.1 NEED FOR MANAGING OF USED OIL

One of the main drivers of pollution in the world is used oil, mostly due to its high toxicities, enormous output volume, and inept handling. A thriving oil spill handler will benefit nature and economies. In Bangladesh, used oil serves mainly for two roles: first, as fuel oil, and second, as lubrication oil. It should be illegal to burn spent oil for fuel since it releases hazardous gases in the air. The lubricating qualities of solely treated lubricating oil are only partially restored, and using it could cause engine faults and reduce engine life [32].

Ecological concerns: Any type of oil has the potential to be bad for our planet. Oil sludge has a capacity to sink to the bottom of aquariums, covering the soil and all life that may be present. When there is an oil film on water, less light can reach the water, which lowers the rate of photosynthetic. Oxygen production decreases as photosynthetic fades. Also, the oil

film may prevent oxygen from the air from passing through the layer of water. Oil can quickly seep into the dirt in the ground and cause alike problems for macroscopic insects and soil bacteria. The water table or a body of water like a lake will inevitably contain this oil.

Economic impact: By collecting and reusing spent motor oil, we can conserve energy and lessen our reliance on foreign oil. Two and a half quarts of superb lubricating oil can be made from one gallon of used oil. The same 2-1/2-quart volume, however, requires a refinery of 42 gallons of crude oil (although the 42 gallons of crude are used to make numerous other goods).

Human health effects: By use, inhalation, or skin contact, pollutants in used oil can cause a number of illnesses and disorders in humans and other mammals.

Reducing lose oil production through the use of efficient engines, raising lubricating oil quality, etc., is the first option in the waste oil control hierarchy. The second choice is to refine the spent oil, which entails improving its quality so that it can be utilized as lubricant once more. Refining is ranked second because it saves significant foreign exchange and is an ecologic practice. Since our nation is entirely dependent on imports for virgin lubricating oil refining is very helpful. In table 1.2 shows hierarchy of used oil management [33]. Reprocessing the used oil to make it suitable for use as fuel oil is the third option. In order to remove sludge and suspended particles, used oils intended for fuel must typically undergo settlement procedures. This kind of easy treatment may significantly enhance the material's quality to remove carbon, heavy metals, sludge and suspended debris. The collection of spent oil and rightful disposal receives last priority [33].

Table 1.2: Hierarchy of Used Oil Management

Ranking of garbage disposal (from the ecological point of view)	Choice	Intelligent action
Most Preferable 	Stop the waste before it begins.	Source decrease (e.g., more time between oil drains)
	Reuse and locate the item.	Refine spent oil
	Burn it to recover energy	Burn spent oil to restore heating value
Least Favorable	Debris way to dispose such as incineration or land filling	Gather and recover used oil for suitable recycling.

1.16 DISPOSAL AND GEOGRAPHIC IMPACT

About 40% of all lubricants are thought to be discharged into the environment. Recycling, burning, land filling and water discharge are common disposal ways; however, in most countries, dumping and water discharge are strictly restricted because even a tiny bit of lubricant may poison huge quantities of water. Companies spend hundreds of millions of dollars a year cleaning their waste waters to get them down to acceptable levels, and most rules allow an upper limit of lubricant that may be present in waste streams. Regulations also apply when burning lubricant as fuel, usually to produce power, mostly because of the relatively high number of additives involved. A detailed look of the effects of waste oil dumping and refining is provided below [34]:

(i) Geographic consequence:

- Prevents waste oil from being wrongfully disposed of, which could harm the air, water, and soil. Reduces the chance of leaks and oil spills.
- Reduces the demand for virgin crude oil, conserving finite natural resources.
- Re-refining requires less energy compared to producing virgin oil, reducing greenhouse gas emissions.
- Properly re-refined oil reduces the amount of hazardous waste sent to landfills or incinerators.
- Waste oil can seep into the soil, making it infertile and unsuitable for agriculture.
- Oil spills and leaks can contaminate surface water and groundwater, affecting aquatic life and drinking water supplies.

(ii) Economic Impact:

- Refined oil is often cheaper than virgin oil, providing cost savings for industries and consumers.
- Refined oil and by-products (e.g., fuel oil) can be sold, creating additional revenue streams.
- The refining industry generates employment opportunities in collection, processing, and distribution.
- Reduces reliance on imported crude oil, enhancing energy security for many countries.
- Remediation of contaminated sites can be extremely expensive.
- Treating health issues caused by exposure to contaminated environments can strain healthcare systems.
- Contaminated land and water can reduce agricultural and industrial productivity.

(iii) Social Impact:

- Proper disposal and refining reduce the risk of exposure to harmful pollutants, improving public health.
- Job creation and economic growth in the refining industry can benefit local communities.
- Promotes awareness and adoption of sustainable practices among consumers and industries.
- Communities near contaminated sites may face increased health risks.
- Poorer communities are often disproportionately affected by improper waste disposal practices.
- Contaminated land and water can affect the livelihoods of farmers, fishers, and other dependent communities.

(iv) Technological Impact:

- Advances in refining technologies improve efficiency and output quality.
- Modern refining processes maximize the recovery of usable oil, reducing waste.
- Developing and implementing effective waste oil management technologies can be complex and costly.
- Meeting stringent environmental and safety regulations can be challenging for small-scale operators.

(v) Regulatory Impact:

- Helps industries comply with environmental regulations regarding waste oil disposal and recycling.
- Governments may offer incentives and support for sustainable waste management practices.
- Compliance costs and permitting can be burdensome for small businesses.

The disposal and refining of waste oil have profound environmental, economic, social, technological and regulatory impacts. While refining offers significant benefits, including pollution reduction, resource conservation and cost savings, improper disposal can lead to severe environmental and health consequences [35].

CHAPTER 2

LITERATURE REVIEW

Because used oils include a lot of pollutants and natural dirt, they fall under the category of unsafe waste, which calls for specific handling practices. They also have significant economic worth as a by-product, and their reuse makes it easier to switch from fossil fuel-derived products to green lubricants. For this kind of garbage, numerous recycling systems have been developed. This paper's goal is to outline the many recycling strategies currently in use across the world, as well as to give research on the methods, materials and advantages of recycling spent motor oil. Lubricating oil contains a highly polluting substance that needs to be handled properly. Pollution may result from improper waste lubricant disposal into the ground or water sources, including sewers. Recycling those outdated lubricants will help to reduce the price of oil. Lubricating oil serves to minimize material wear, increase the efficiency of fuel and energy-efficient equipment, and decrease friction between moving parts of various machinery or equipment. Finally, lubricants keep machines clean, reduce heat, and stop corrosion. Waste lubricating oil is used hydraulic, cutting, motor, and transmission oil. Cars and other machinery require oil changes or removals after a few thousand kilometers or hours. Both the economy and the ecology are greatly impacted by the enormous amount of waste lubricating oil. Whether the lubricants are burned as low-grade fuel or spilled into the air, water, or land, they have the potential to cause serious harm to the planet by releasing toxic metals and other pathogens. The best option is to use inexpensive, non-toxic ingredients to restore the tribological properties of lubricants. Scientist Chongqing Fason has developed a waste lubricant oil distillation factory using modern technology. During the refining process, it can remove metallic compounds, sulfur, and base nitrogen from distilled oil. The final distillation product may be changed into new base oil or golden diesel fuel, depending on the needs of the customer. Many lubricant studies have been conducted to restore tribological behavior. Due to challenges from both the public and the private sectors, the used oil re-refining sector has long existed and changed throughout time. In the beginning, used oil was frequently discarded on the ground and in water, and it was also occasionally burned as fuel. However, it was also occasionally purified and reused. To supply its lubricating oil needs, South Africa depends on imported crude oil. In 1940, they began processing used oil. In 1942, the first refined oil specification was created, and by 1946, it had been combined with the specifications for virgin engine oil. Over 150 small businesses were re-refining more than three hundred million gallons of spent oil by the mid-1960s as a result of initiatives to reclaim wasted oil in the United States [36].

With the rise of automobiles, industrial equipment, and power plant machinery, the lubricant market in Bangladesh has grown. The rates of car growing population are displayed here. Between 2011 and 2016, the average number of vehicles registered climbed by 37% and as of 2016, there were 2,879,708 people living in the country (BRTA). According to the government plan, the power sector will grow by 9% in MW due to a major rise of engine-based fast rental power plants from 2013 to 2016 at a GDP growth rate of 7%, as well as the 3-4% growth of general production and process industries. At almost 100 million liters per year, the domestic demand for lubricating oils grows dramatically. About 10 to 15 million liters of used or waste oil are created countrywide each year from apparent consumption after a specific running hour interval. Also, heavy fuel oil (HFO)-based power plants have made operating HFO a major challenge. In addition to producing thick sludge, this HFO fuel can include heavy metals that are harmful to ecosystems. Due to a lack of awareness and regulatory oversight, the majority of used energy sources and byproducts are directly exposed to the environment. Automobiles are an essential part of our existence. What will we do with the spent oil from our vehicles and other equipment that is crucial to striking a balance between our need for easy transportation and our goal to maintain a healthy and safe planet for present and future generations? Strict laws regarding and the disposal of spent engine oil could help reduce pollution and save energy for a safer and healthier future [37].

The jerky motion referred to as "stick-slip" was researched by J. B. Sampson et al. (1943) 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 [38].

The ECE R49 test cycle, 12-liter normally aspirated Euro I reference engine, and ultra-low sculpture gasoline were used in the Jefferd et al. (1983) study. The findings demonstrated a substantial difference in the legally required emissions depending on the lubricant formulation. Compared to SAE 10W-40, high-end part-synthetic heavy-duty diesel engine oil, two fully synthetic brands with superior performance requirements produced higher particulate matter by over 20% [39].

Waste lubricating oil is a resource that cannot be disposed of carelessly since it contains contaminants, according to M. Falconer et al. (1986). 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 [40].

According to C. Gao's (1995), Meniscus development at the sliding interface and dynamical analysis for a pin-on-disk sliding system, 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 [41].

A two-component, two-dimensional friction model for a lubricated line contact was created by A. A. Polycarpou et al. in 1996. It includes instantaneous separation of the sliding bodies, fluid properties standard to the sliding direction, average load, and sliding velocity. Unstable friction studies with constant normal loads and time-varying sliding speeds served as the basis for the model. It captures the instantaneous fluid shear and solid friction components and is applicable to quasi-steady, unstable, continuous, and intermittent sliding [42].

C. R. Yang et al. (1999), a 0.45% carbon steel pair is used to study wear behavior and dynamic friction in a reciprocating friction drive system. The findings demonstrate that the traction force variation is dominated by the fluid friction caused by lubricant shearing during the initial slip period, resulting in a positive slope g . The transition zone is where the wear is most noticeable. However, the wear is independent of the friction zones and only occurs at a larger average load due to the Hertzian contact action. The static friction force is independent of the stick time [43].

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), 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 [44].

R. I. Taylor et al. (2000), demonstrates how the study examines the differences between fuel-efficient oils for passenger cars and heavy-duty diesel engines, as well as how employing fuel-efficient lubricants can reduce friction and increase fuel efficiency. In order to predict the advantages of fuel consumption under different speed and load conditions, it also considers true losses due to air and tire rolling resistance [45].

As reported by Z. He et al. (2002), 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 [46].

The study conducted by Comfort (2003), 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 [47].

X. Zeng and other associates (2004), created an oil-soluble, ash-free, non-phosphorus material using cyanuric chloride and sodium octyl mercaptan in tetrahydrofuran. Its

tribological properties were evaluated using a four-ball wear tester and EP wears test equipment. The findings showed that OTT outperforms OT as an anti-wear and friction-reducing additive, even though OT exhibits more extreme pressure features [48].

According to Boughton et al. (2004), 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. This article uses the life-cycle assessment (LCA) approach to quantify and analyze the environmental benefits and consequences of each management decision in a product end-of-life scenario. 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 [49].

X. Zeng et al. (2006), Three novel phosphorus-free triazine derivatives, ZOO, ZOS, and ZDION, were developed and evaluated for their tribological behavior in rapeseed oil, their ability to resist heat, and their ability to inhibit corrosion. ZDION exhibits subpar anti-wear performance, but ZOS have the best extreme pressure, anti-wear, and friction-reducing qualities. Because of their ability to adsorb and react with the steel surfaces, the synthetic additives improve the tribological behavior of the base stock that contains them during the rubbing process. Iron oxide, sulfate, sulfide, and organic molecules with N and O make up this protective layer [50].

B. K. Sharma and companions (2007), Because of their remarkable lubricity, biodegradability, favorable viscosity-temperature properties, and less evaporation loss, vegetable oils hold great promise as environmentally friendly lubricants. However, their weak thermo-oxidative stability and poor cold-flow behavior restrict their use. By choosing the right mix of chemicals, this study provides a methodical approach to improving their oxidation behavior. The synergy between antioxidants and anti-wear additives was investigated on four antioxidants and three anti-wear additives in vegetable oils using a rotary bomb oxidation test (RBOT) and pressure differential scanning calorimetry (PDSC). According to the findings, the antioxidant dialkyldithiocarbamate inhibited phenol and performed better than diphenylamine [51].

M. Rahman et al. (2008), 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 [52].

According to J. Booth (2008), 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 [53].

S. D. Publishing and T. Agargaon (2009), 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 [54].

Researchers in Nabil M. Abdel-Jabbar et al. (2010), examined the adsorption process for re-refining waste lubricating oil utilizing a variety of adsorbent materials. Among the adsorbent materials utilized were oil adsorbent, egg shale powder, date palm kernel powder, and acid-activated date palm kernel powder. Adsorption over a predetermined volume of adsorbent in ambient circumstances was investigated. Natural adsorbents such as powdered date palm kernels, oil adsorbent, egg shale powder, demulsifiers, and stabilized condensate were used to successfully adsorb waste oil. The date palm kernel powder approach to waste oil processing seems promising [55].

M. Mofidi and associates (2011), outlined how abrasion from sliding against rough surfaces can cause elastomeric seals to fail. The two-body abrasive wear of sealing elastomers under lubricated and dry conditions was investigated in this work. The findings demonstrated that abrasive wear may increase or reduce in the presence of lubricants, contingent on the material, oil, abrasive size, average load, and test duration. When using fine abrasives, lubrication has a greater impact on increasing abrasive wear [56].

J. D. Udonne (2011), Engines and other machinery's moving parts are lubricated with lubricating oils, which are viscous liquids. This study project's primary objective is to compare four methods for recycling used lubricating oils: activated charcoal and clay, distillery and clay, and acid treatment and clay. Test results showed that viscosity rose from 25.5 to 86.2 for distillation and 89.5 for activated/clay treatments, compared to 92.8 cs for fresh lube oil. While other data indicated varied degrees of improvement, the acid therapy yielded the best results [57].

S. Verma et al. (2012), Practical issues like contact mechanics, material response to loading, contact edges, oil absorption, cleaning, and specimen shape are covered in the friction testing of elastomers in lubricated contact. The results show that utilizing mineral oil or synthetic ester produces results that are similar [58].

J. Zhu et al. (2012), 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 [59].

According to M. Yu et al. (2012), 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 [60].

Lubricant Condition Monitoring (LCM), according to J. M. Wakiru et al. (2018), 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 [61].

Naveed Anwar et al., (2012), However, the environment is at risk from spent oil waste generated by automobiles and other associated industries. The purpose of the current study was to assess the advantages and disadvantages of the popular acid/clay method for wasted oil recovery. Waste oil samples were contaminated and tainted with soil and water. Despite the lack of standard standards or parameters for comparison, only a few tests were conducted to understand the characteristics of the waste oil product that is already on the market, including those that measure copper strip corrosion, water content, sedimentation, and flash points. However, the findings of the analysis revealed a poor reflection. These results showed that because the product is not environmentally friendly, improved processing methods are required. The impacts of air pollution from burning or using recovered and waste oil on human health, especially occupational health and safety, need further research. The purpose of lubricating oils is to maintain the cleanliness of machinery and improve its performance in harsh operating environments. Base oils (virgin oil) and substances known as

"Additives" are used to make them. The acidic material is then neutralized using hydrated sodium silicate [62].

The study carried out by Tiago Cousseau (2013), 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 behavior, 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 [63].

M. Diphare et al. (2013), Waste lubricating oil contains pollutants, it is a resource that should not be disposed of carelessly. It is becoming more and more common to reuse and regenerate waste lubricants utilizing recovery techniques like burning, reprocessing, and re-refining. This study examines and contrasts regenerative technologies in order to establish the foundation for developing policies and choosing recovery methods [64].

E. Vidović et al. (2014), 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 [65].

In V. Kapustina et al. (2014), 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 [66].

According to N. B. Selukar and S. M. Wagh et al. (2014), 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 [67].

Shri Kannan C. and others (2014), highlighted how burning spent oil in kilns and incinerators releases a lot of ash and poisons into the atmosphere, harming the ecosystem. Refining used oil can provide better-valued products while lowering pollution. The amount of virgin base oil required to create fresh fat is reduced when wasted lubricant is refined. Re-refining restores the oil's properties to satisfy SAE (Society of Automotive Engineers) standards by removing degraded additives and contaminants. Engines and gearboxes are among the many automobile parts that are greased with lubricating grease. The two main functions of lubricating oil are to reduce friction and serve as a heat transfer medium. It also stops corrosion and eliminates worn metal parts. Spent engine oil is collected and refined for future use. The steps in the treatment procedure include solvent extraction and vacuum distillation. The efficiency of the lubricating oil is increased through the application of additives. The characteristics of refined lubricating oil and fresh lubricant are similar. In sequence, the following values were noted: density, specific gravity, viscosity, viscosity index, pour point, cloud point, fire point, aniline point, TAN, 0.910, 167 Cp, 51, 260°C, 323°C, -10°C, 70°C, 14°C, and 10.05 mg/g. Following refinement, these characteristics increased to 884 kg/m³, 0.884, 266 Cp, 81, 276°C, 313°C, -22°C, 105°C, 11°C, and 0.53 mg/g, in that order [68].

F. Danane et al. (2014), used motor oil collected by NAFTAL and stored in the port of Algiers is examined and treated experimentally. In order to develop an appropriate re-refining process for this, it carried out laboratory trials. We were able to differentiate between the various regeneration processes—pretreatment, metal removal aided by chemical agents, and a final treatment that includes bentonite passage and filtration—thanks to the results of these analyses. After the process, the engine oil that is left over is an essential oil that can be utilized once more. We have been able to optimize a number of parameters and

eliminate the majority of pollutants thanks to this approach. For wasted lubricants to be used in the future as a beneficial energy source that lowers energy consumption and environmental pollution, they must be repurposed or refined. The final tests' findings demonstrate that the recommended process was successful in producing finished engine oil with significantly improved qualities that were on par with base oil [69].

According to S. Baskar et al. (2014), in a pin-on-disc wear tester, the wear and friction behavior of journal-bearing material were investigated using three lubricating oils. Wear tests were conducted using sliding speeds ranging from 2 to 10 m/s and a maximum load of 200 N. The results showed that the journal-bearing material changed according to the sliding conditions and lubricating oils, with CMRO having a lower friction coefficient and SAE 20W40 and CMRO exhibiting more noticeable wear. Wear mechanisms were discussed, and worn surfaces were assessed using SEM [70].

In this study, E. Matas et al. (2015), 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 anti-wear (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 [71].

The examination of new engine oils using engine testing is covered by Y. Nakamura et al. (2015), to ascertain whether they affect the fuel economy of engines. The main technologies utilized are additive technologies, which provide the best settings for the viscosity modifier, friction modifier, and HTHS viscosity based on the lubrication state of the valve train, pistons, cylinders, and bearings. After rig testing verified the friction modifier's ability to reduce friction, engine tests were used to assess the effect of the improved fuel economy. It is anticipated that this study would increase the use of 5W-30 engine oil based on mineral oil in heavy-duty diesel engines [72].

As explored in T. Khosla et al. (2016), the designing, manufacturing, and use of low-friction polymer surfaces are inspired by the "weeping" lubrication mechanism of articular cartilage. Two novel methods based on surface texturing and microspheres are studied to reduce friction in wet conditions. When fluid is positioned between two shearing surfaces, the lubrication process is moved to the hydrodynamic/mixed domain, which results in low friction. The tribological properties of these surfaces are examined at different shear velocities and applied stresses. Combining an ideal surface texture with conventional boundary lubricants may provide a new method of achieving unprecedentedly low friction. By using surface texturing of soft polymers and microspheres, this thesis offers an initial proof of the idea for coating total joint replacement implants that could reduce friction in an aqueous solution. Future research attempts to determine the effects of particle size, concentration, and magnetic field strength on the effectiveness of magnetic iron-core HCS [73].

P.M. James et al. (2016), 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. To guarantee that the re-refined oil is suitable for engine operation, this project entails a number of studies, tests, and pollutants [74].

According to A. E. Elsayed et al. (2016), this study looked at how two different solvent mixtures—A (xylene+butanol+methanol) and B (xylene+butanol+isopropanol)—affect activated alumina as an adsorbent material to produce lubricating oil after bleaching. Spent oil was centrifuged for 30 minutes at 1500 rpm and then left to settle for an hour in this investigation. To get rid of impurities, the oil was filtered via a Bencher funnel with a vacuum pump. One of the most important experimental measurements of the re-refining process is the amount of sludge extracted from the used oil. The rate at which sludge is eliminated increases in tandem with the solvent-oil ratio. The optimal solvent-oil ratio at 70°C was found to be 3:1 in every scenario examined in this study. Utilizing two solvent combinations (A and B) to recycle used oil improves the physico-chemical properties of the base. This has to do with eliminating the components of the pollutants [75].

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). 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 [76].

S. E. F. Hegazi et al. (2017), 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 [77].

Another team of researchers looked into the recycling and reuse of spent oil (S. Dhinesh and Kumer et al. 2017). 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. Just one-third of the energy needed to refine crude oil and create virgin base oil is needed to produce refined oil, which is made from spent oil. Because of this, re-refining is often seen as the best option in terms of reducing waste, environmental harm, and resource consumption [78].

Y. M. V. Markine and associates (2017), outlined how comparing the slip-adhesion area, shear stress, and other outcomes produced by the two models allows one to compare the CONTACT model with the finite element (FE) model using real wheel-rail profiles. The impacts of different operating patterns (such as changing friction, traction, etc.) on the surface and subsurface tribological responses of wheel-rail contact are simulated by a series of simulations using the verified FE model. Although the majority of explicit FE simulation findings agree with CONTACT results, stress concentrations from below the surface may rise to the surface as traction and friction increase [79].

J. George and associates (2017), 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 [80].

S. Mia et al., (2017), Tribology is the science and technology of interacting surfaces in relative motion as well as associated disciplines and activities. 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 [81].

This scientific work by W. Balasooriya et al. (2018), intends to look into how the tribological characteristics and surface damage mechanisms of hydrogenated nitrile butadiene rubber

(HNBR) in contact with various liquids are affected by swelling-induced aging. 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 [82].

According to Temitayo E. Oladimej et al. (2018), 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 [83].

J. Artif and associates (2019), this study examined the most recent laws, announcements, rules, guidelines, and specifications about lubricants used in Bangladesh's oil industry. It reported on the system for managing the base oil recovery process from waste lubricantsto 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 [84].

N. A. Raof and associates (2022), 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 [85].

Yan Bin Sun and associates (2022), Five friction couples are evaluated using an SRV tester at room temperature for friction and wear behavior. 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 [86].

According to S. K. Sharma (2023), 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 [87].

CHAPTER III
DESIGNING AND EXPERIMENTAL METHODOLOGY

3.1 INTRODUCTION

Main objectives of this thesis are differentiating physical & chemical characteristics between used waste lubrication oils and as usual standard fresh lubrication oils. Design and implementing proposed system using distillation method compared with existing system. Experimenting analysis and observing results for various states, finally outcome fresh lubrication oils for machinery using. Figure 3.1 shows the schematic diagram of refining waste lubricating oils [88]. This chapter includes designing, Experimental analysis and component details of refining waste lubricating oils.

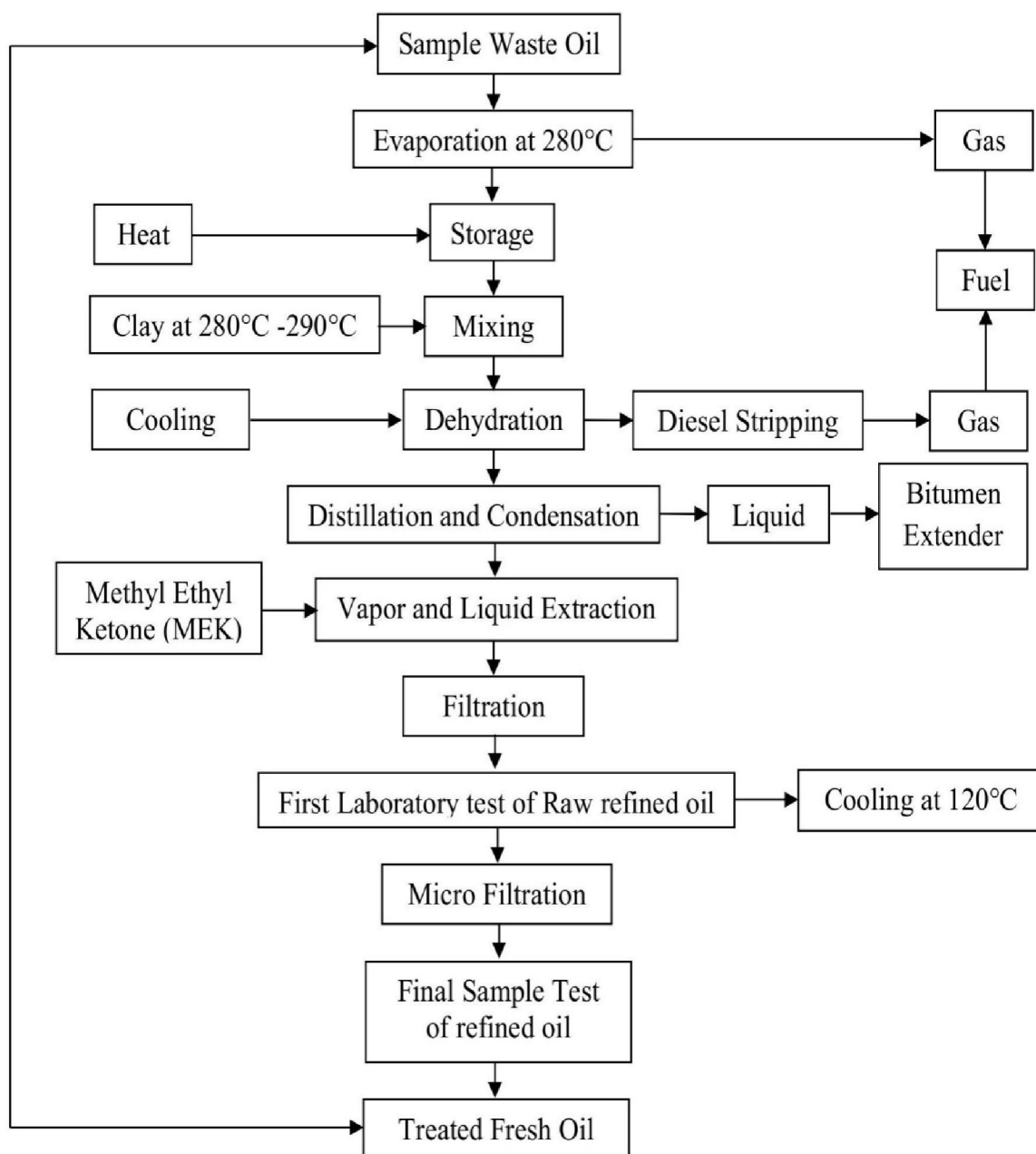


Figure 3.1 Schematic diagrams of refining waste lubricating oils [26]

Here different types of waste lubricating oils were used. Waste lubricating oils were given into system storage. System storage was heated externally by heaters which made with nicrome wire. Waste lubricating oil were heated in system and reduced water by dehydration process. By heating few gases as fuel be produced. Diesel stripping done by heat and few gases as fuel be produced like previous. Lube oil distillation and condensation process done by heating then liquid Bitumen extender. Next stage is MEK mixing with vapor and liquid new raw base oils. By proper filtration this outcome forward to laboratory for known oil condition. To ensure suitable raw base oils from system adding required additives and again forward to laboratory for known oil condition, fresh oils comes from waste lubricating oil which can use in vehicles engine or industrial machineries [89].

3.2 REQUIRED MATERIALS FOR EXPERIMENTAL SETUP

The required materials for an experimental setup typically include the apparatus, chemicals, safety equipment, and tools for data recording and analysis. Specific items vary based on the experiment, but common needs include glassware like beakers and flasks, measuring tools, and potentially lab coats and goggles

Components of Experimental Setup:

1. Used Waste lubricating oil;
2. Storage of lubricating oil;
3. Heater/ Electric Burner;
4. Methyl Ethyl Ketone (2-butanone) reagent;
5. Oil Filter;
6. Chemical Additives;
7. Liquid sample collector tube;
8. Sample Preparation;

3.2.1 Used Waste lubricating oil

Oil residue has some toxic qualities and is regarded as hazardous waste. One million liters of water can become tainted by one liter of waste oil. Lubricant oil waste can come from a variety of human activities, including mining, producing, and workshops. Both Fresh and Waste lubricating oils 06 sample 02 from each item used & fresh were collected from M/S. Eastern Trade Syndicate in Chittagong, Bangladesh. Figure 3.2 shows samples are mono grade Engine oil SAE 50, Industrial oil ISO VG 68 and Automotive Gear oil SAE-90.



Figure 3.2 Sample of Waste lubricating oils.

3.2.2 Storage of lubricating oil

Storage can have straight or slanted sides and usually has a handle or bail. In Fig. 3.3 shows the storage [91]. Its local meaning is identical to plasticsbucket a capacity of 20 L.



Figure 3.3 Storage as a pail of Fuchs (German) & Mobil (USA) brand lubricants [91]

3.2.3 Heater/ Electric Burner

With nine power settings, a high-grade black crystal glass plate, overload and interior high temperature protection a timer function, a waterproof preset, and a child lock feature. Fig.3.4 shows Electric Burner is a powerful induction burner that can be used for all heating methods.



Figure 3.4 Electric Burners [92]

3.2.4 Methyl Ethyl Ketone (2-butanone) reagent

2-butanone (also known as methyl ethyl ketone or MEK) is regarded as an aprotic and photophilic solvent. It has been shown to have anticonvulsive properties in rats with lithium-pilocarpine-induced status epilepticus. 2-butanone is a synthetic molecule, it can also be found naturally in nature. It has a pungent, sweet smell and is a translucent liquid. Another name for it is MEK, or methyl ethyl ketone. 20 °F is the flash point. Heavier than air vapors. doesn't react with water or a lot of everyday goods. Stable during regular transit. irritates the eyes, throat, and nose. Toxic materials may be produced during combustion. densities of 6.7 lb/g. used as a solvent, to create other compounds, and to turn petroleum into wax. In Fig. 3.5 shows the chemical molecule methyl ethyl ketone (MKE) has the formula $\text{CH}_3\text{C}(\text{O})\text{CH}_2\text{CH}_3$ [93]. This white liquid ketone smells sweet and strong, like acetone and butterscotch. Both large-scale industrial production and trace amounts of it can be found in nature. It is frequently used as an industrial solvent and is soluble in water. 2-Butanol can be oxidized to create MKE. The dehydrogenation of 2-butanol using a catalyst is catalyzed by copper, zinc or bronze:

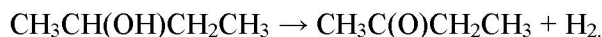
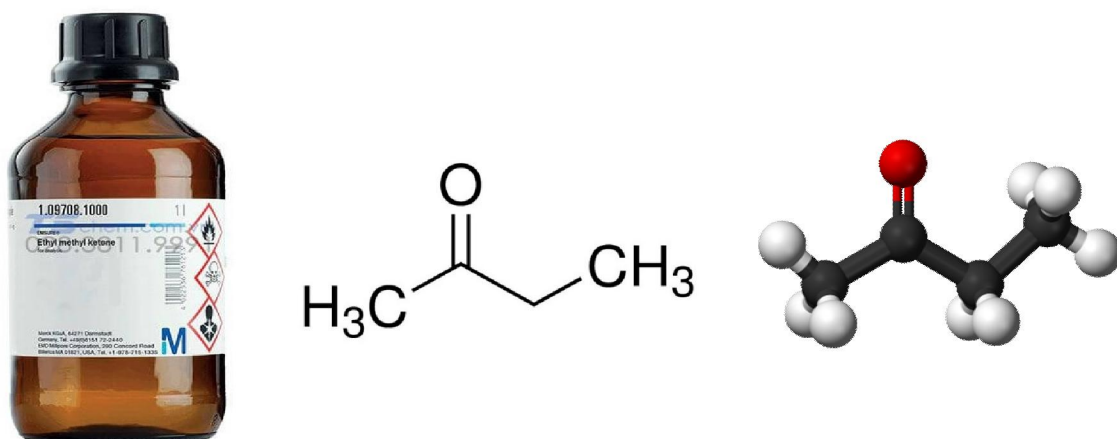


Figure 3.5 Methyl Ethyl Ketone (MKE) sample & bonding structure [93]

3.2.5 Waste lubricating oil filter

In the majority of light-duty applications, CAT Standard Hydraulic and Distribution Filters are made to remain clean and intact. Every time, CAT Filters deliver noteworthy fit and performance.

In these systems, transmission-specific filters are made to retain additional toxins and provide greater servicing intervals. In Figure 3.6 shows filter [94], Your first line of defense against oil pollutants is the CAT 1R-0719 Filter. Repair expenses are decreased when the hydraulic and transmission structures of your equipment are properly lubricated. For this reason, it is crucial that we always keep our equipment clean. Please see the cross-reference section if you want to swap out your non-CAT filter for a real CAT 1R-0719 filter. Please feel free to ask for help if you need it.



Figure 3.6 1R-0719 Caterpillar Oil Filter[94]

3.2.6 Chemical Additives

1(a). TAP 3547T Heavy Duty Engine Oil Additives: To formulate HIGH SPEED 4 Stroke Engine Oil Gasoline Lubricants that fulfill API SF to SN (Multi-grades) performance levels, TAP 3547T was created to satisfy the needs for a cheap and cascable additive system with logistics. Special additives in TAP 3547T provide superior wear and rust control, oil oxidation resistance, and deposit control in all engine types. In Table 3.1 & 3.2 implies the features of TAP3547T [95]. The engine test performance standards for API classification are met by finished oils with the prescribed concentration of TAP 3547T. offers a cost-effective, useful lubricant that may be used at regular drain intervals for older motorcycles and customers in remote or city regions. Dosage percentage: 3.5 to 9.5%.

Benefits of TAP 3547T: Improved friction durability and clutch performance, which allow for smoother operation during the oil's life. Motorcycle oils require ongoing protection against oxidation since motorcycle engines operate hotter than passenger car engines. When

riding a motorcycle in different weather conditions, design flaws can allow water to seep in. So, it needs to have built-in anti-corrosion features. TAP 3547T meets JASO MA/MA2 [95].

Table 3.1 Specification of TAP 3547T

Performance Package	TAP 3547T
Meets Performance Level	API SF to SN
Viscosity Index Improver	Improver for Non-Dispersant V.I.
Base Stocks	Group I/II base oils
SAE Viscosity Grades	15W-40, 20W-40, 20W-50, 10W, 20W, 30W, 30, 40, 50

Table 3.2 Properties of TAP 3547T

Specification	Values	Test Method
Density 25° C, gm/cm ³	1.0	ASTM D 4052
Flash Point C (PM), min	180	ASTM D 92
Viscosity at 100 C, cSt.	80-100	ASTM D 445
Total Base Number (TBN)	120-125	ASTM D 2896

1(b). TAP 8640 Zinc Based Hydraulic Oil Additive: One such chemical additive used for better hydraulic oil performance is zinc-based hydraulic oil additives. Hydraulic oil additives based on zinc are meant to give hydraulic systems better against oxidation, corrosion, and wear. In Table 3.3 implies the features of TAP8640 [95]. They function by covering metal surfaces with a protective layer that guards against corrosion, rust, and wear. The oxidation stability of hydraulic oils can be strengthened by zinc-based additions, stopping the production of hazardous oxidation radicals that over time may impair hydraulic oil performance.

Table 3.3 Technical Specification of TAP 8640

Specifications	Values
Color ASTM	2.5
Appearance	Reddish Yellow Clear Liquid
Viscosity @ 100°C, cSt Min.	8-15
Flash Point, COCC, Min	160 min
Sp. Gravity @ 15°C, gm/cc	0.95-1.0

1(c). TAP 3433 Gear oil additives: In order to cover a wide range of gear oil applications, TAP 3433 has been carefully optimized to provide strong anti-wear and moderate pressure capabilities in addition to thermal, oxidation, and rust aspects (covering copper and copper alloys). TAP 3433 is a universal gear oil additive designed to boost industrial and automotive outcomes. When mixed with the right base stock and the required viscosity grades, TAP 3433 should be blended with highly refined base stocks to satisfy API GL4, GL5, and GL2 as well as IS 8406 (1993).

Performance & Benefits of TAP 3433: Under situations of high shock load, lubricants made with this additive package are effective for heavy-duty enclosed gear drives with splash and the veins type lubrication systems. Additionally, it provides consistent performance for ongoing use at temps as high as 160 °C. Antifriction bearings that are subjected to high shock loads can also benefit from it. Superior thermal stability and oxidation. In table 3.4 implies the features of TAP3433 [96]. Longer gear component life and superior wear protection. Excellent fuel efficiency and all-weather performance because of multigrading. Longer and more delightful drives, and more seamless gear changes. Cut down on operating temperatures and gear friction. Smoother gear changes and less gearbox noise. DOSAGE %: 1.1–3.8 percent [96].

Table 3.4 Technical Specification of TAP 3433

Specifications	Values
Appearance	Bright & Clear Reddish Yellow Liquid
Color, ASTM	3.0 TO 4.0
Viscosity @ 100°C, cSt	3-6
Flash Point, COC°C, min.	95
Sp. Gravity @ 15°C, gm/cc	0.95-1.1
Sulphur content % wt., min	33-37
Cu Strip Corrosion @ 100°C for 3 Hrs	1b

3.2.7 Glass Test Tubes Liquid collector: A limited number of different materials are kept in test tubes, which are tiny glass cylinders with one end closed and the other open for use in lab tests and investigations. Figure 3.7 Shows [97] a test tube; it is an ordinary piece of glassware used in lab. It is made up of a finger-length piece of glass

tubing that is closed at the bottom and opens at the top.

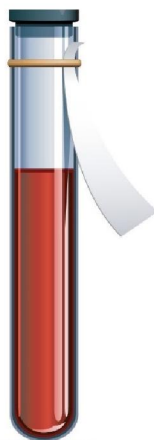


Figure 3.7 Liquid collector Glass Test Tubes [97]

3.2.8 Sample Preparation:

Waste lubricating oil was used as materials for refining in this research work. Waste lubricating oil of different types named Heavy duty mono grade diesel engine oil SAE 50, Automotive Gear oil SAE-90 and Industrial oil ISO VG 68, were collected from M/S. Best Suppliers, Chittagong, Bangladesh. Each type was collected about 20 Liter. Those samples were heated by electric burner and distilled [98].

3.3 EXPERIMENTAL PROCEDURE

First, gather used lubricant trash. Lubricating oil was treated for pests after waste was collected. In figure 3.8 shows [99] experimental procedure. The procedure is used to eliminate the hydrogen division compounds from engine oil because they reduce the viscosity of the oil and water compounds, which reduces the power of a fire stroke and makes the burning process indecipherable. The water droplets in the engine oil are burned away as vapor when the oil is heated to 1250°C in a glass beaker, forming mud-like clay. This is the most significant phase in the engine oil refining process, with a variety of distillation approaches. To refine the old engine oil, we are employing the vacuum distillation technology. Similar to the fractions that arise during the distillation of crude oil, the dehydrated oil is next perpetually supplied into the vacuum distillation plant. The procedure begins with a starting boiling point of 207°C and reaches its maximum heating value of 478°C . The engine solvent is distilled into various parts that fall under the groups of light fuel and diesel. About 12–15% of the spent engine oil will be turned into fuel. With a specified volume of old engine oil and 5–10% bitumen carbon wear metal aromatic

chemicals, the main residue of engine oil will yield 80–75% engine oil. By clearing the engine oil during the refining process, the macroparticles disappear and the oil's original color is restored. There are a variety of additives used for engine oil that are used to raise the oil's viscosity, flash point, and pour point. MKE is a chosen additive to provide engine oil with a standard physical quality. Ninety-six percent of engine oil is used, and four percent of additives are added to improve quality.

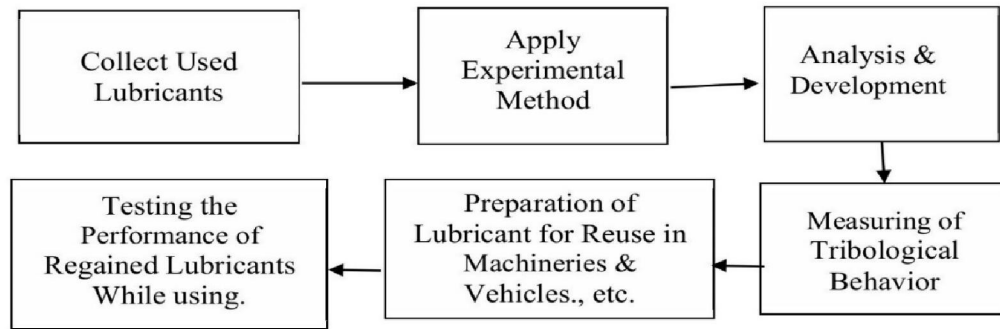


Figure 3.8: Flow chart of experimental procedure [99]

CHAPTER IV
EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In Bangladesh, an enormous quantity of spent motor oil from multiple sources is dumped into the environment as an explosive waste. The disposal of spent motor oil in rivers, lakes, and the Bay of Bengal causes a number of issues; it not only affects water but also puts freshwater and marine life. One million gallons of water, including plants and animals, would be tainted by about one gallon of used motor oil. Automobile engines use lubricant oil to lubricate its moving parts, which lowers friction, guards against wear, removes impurities from the engine, and serves as a cleaning, cooling, and anticorrosive agent. As a result of engine wear, it takes different debris and extra parts. These elements, the majority of which are deadly poisonous, include metals (iron, steel, copper, lead, zinc, etc.) as well as excess barium, sulfur, water, soil, burnt carbon, and ash compounds. Therefore, in able to reuse the engine's oil, these undesirable substances need to be removed. Engine oil contains a lot of additives to prevent bad qualities. Oxidation inhibitors, pour point depressants, coloring objects, anticorrosion agents, and so on are the primary additives for engine oil. The type of oil base stock and the type and quantity of impurities in the lubricant brought on by operations are the primary contributors of used lubricating oil recycling. Both the engine and the air around it are the sources of the pollutants [100].

4.2 DETAILS OF TEST METHOD:

Related test methods described by table 4.1 in below [101]:

Table 4.1: Details of Test Method

Sl.	Test Method	Equivalent Test Method	Test Purpose
01	ASTM D 445	AFNOR T60-100, IP 71-1, SO 3104, DIN 51562, JIS 2283	Kinematic Viscosity of liquids
02	ASTM D 2896	JIS K 2501, IP 276, ISO 3771	Base number potentiometric perchloric acid titration
03	ASTM D 95	AFNOR T60-113, IP 74, ISO 3733, DIN 51582, JIS K 2275,	Water percentage in petroleum products
04	ASTM D 92	IP 36, ISO 2592, AFNOR T60-118, DIN51376, JIS K	Flash point of oils

		2265	
05	ASTM D 2270	IP 226, ISO 2909, AFNOR T60-136	Viscosity index
06	ASTM D 97	IP 15, ISO 3016, AFNOR T60-105, DIN 51597, JIS K 2269	Pour point
07	ASTM D 6304	-	Water percentage in petroleum items.
08	ASTM D 1500	IP 196, AFNOR T60-104, ISO 2049, DIN 51578, JIS K 2580,	Color
09	ASTM D 1298	IP 160, ISO 3675, AFNOR T60-101, DIN 51757H, JIS K 2249H,	Density and Relative Density, Specific Gravity
10	ASTM D 874	IP 163, AFNOR T60-143, ISO 3987, DIN 51575, JIS K 2272	Ash Sulfated Ash from Lubricating Oils and Additives
11	ASTM D 482	AFNOR M07-045, IP 4, ISO 6245, JIS K 2272	Ash from Petroleum Products
12	ASTM D 2896	JIS K 2541, DIN 51400 T6	Sulfur Determination Sulfur by Wavelength Dispersive X-Ray Fluorescence WD-XRF
13	ASTM D 322	JIS K 2541, DIN 51400 T6	Gasoline Diluent in Oils
14	ASTM E2412	-	Condition Monitoring of Used Lubricants

4.3 APPARATUS USING TESTING PURPOSE

1). KV4000 Kinematic Viscosity Bath: Capillary viscometers that have been calibrated are used to monitor flow at well set temperatures under vacuum or gravity. In figure 4.1 shows [102] the kinematic viscosity bath. Easiest, reliable glass capillary viscometers tests are made possible by a consistently hot bath with sophisticated thermostat circuitry and an integrated timing feature within the Touch Screen Control Panel that displays to 0.1 seconds and is accurate within 0.01%. The temperature regulation of the microprocessor between room

temperature and 150 °C (302 °F). Dual digital displays that show the set point and actual bath temperature have a resolution of 0.1 °C and 0.1 °F and are calibrated to 0.01 °C and 0.01 °F. Complies with NF T 60-100, IP 71, 319, ISO 3104, DIN 51550, FTM 791-305, ASTM D445, D2170, D6074, and D6158. The date of last calibration is April 3, 2025 [102].



Figure 4.1 Kinematic Viscosity Bath[102]

2). CAV® 4.2 Dual-Bath Kinematic Viscometer:

For detecting the kinematic viscosity of light-colored and opaque liquids, use the CAV® 4.2 Dual-Bath Kinematic Viscometer (ASTM D445/D446, ISO 3104/3105, IP 71). In figure 4.2 shows [103] the dual-bath kinematic viscometer. For unmanned D445 processing, the CAV® 4.2 is a fully automated, dual-bath, benchtop viscometer with two 14-position sample handlers. The two Unbelohde-style tubes (one for each bath) span a 100-fold viscosity range from 15 °C to 150 °C (with possible changes) between 0.5 mm²/s (cSt) and 10,000 mm²/s (cSt). The date of update calibration is April 3, 2025.



Figure 4.2 Dual-Bath Kinematic Viscometer

3). Metrohm888 Titrand with Touch Control: The 900 Touch Control, 801 Stirrer magnetic stirrer, exchange unit (20 mL), combined "Ecotrode plus" pH glass electrode, dynamic, monotonic, and endpoint titration, four MSB connectors, one galvanically isolated measuring interface, and USB connectors are all included in this high-end titrator with built-in burets drive for the TBN (total base number) test, in figure 4.3 shows Metrohm888 Titrand [104]. The date of recent calibration is April 3, 2025.



Figure 4.3 Metrohm888 Titrand with Touch Control

4). Metrohm 798 MPT Titrino: The 798 MPT Titrino is an all-purpose titrator with an LCD graphical display for the TAN (total acid number) test. Applications and results can be stored, transmitted, and sent using a memory card on the 798 MPT Titrino [105]. In figure 4.4 shows [105] The Metrohm 798 MPT Titrino. Metrodata VESUV software allows for data transfer with a PC. Complete remote control, data collecting, and PC evaluation are made possible by MetrodataTiNet Software. The date of last calibration is April 3, 2025 [105].



Figure 4.4 Metrohm 798 MPT Titrino[105]

5). Metrohm899 Coulometer: The 899 Coulometer is needed for the water pollution (%) test. In figure 4.5 shows Metrohm899 Coulometer. The scope of delivery includes generator and indicator electrodes without diaphragms [106]. The proposed range for testing is 10 μg to 200 mg of absolute water. The best technique for determining the water content of liquids, solids, and gasses in the trace range is coulometry. The date of calibrating is April 3, 2025.



Figure 4.5 Metrohm899 Coulometer with generator electrode without diaphragm [106]

6). Koehler Cleveland Open Cup Flash Point Tester: For all oil products' flash and fire points, with only the case of fuel oils and those with an open cup flash below 79°C (175°F). Complies with ASTM D92 along with its criteria. For flash points that are higher than 79°C (175°F). In figure 4.6 shows [107] Koehler Cleveland Open Cup Flash Point Tester. Uses the Cleveland Open Cup method to identify flash and fire spots. A 1000W nickel-chromium heater with a step-less variable heat control system is included for precise, reliable temperature increase rate setting in accordance with specifications. The date of tuning is April 3, 2025.



Figure 4.6 Koehler Cleveland Open Cup Flash Point Tester[107]

7). ICP-OES Spectrometers: Metal testing occurs with ICP-OES spectrometers. With the capacity to analyze up to 700 samples daily, synchronous spectrum captures in the 175-770 nm bandwidth provide an effective match for sequential ICP and FAA. In figure 4.7 shows ICP-OES Spectrometers. Low running costs: no water chiller required, minimal 0.5 l/min optic purge. Faster right out of the gate: the new LDMOS generator requires less than 10 minutes to warm up, compared to over 30 minutes previously [108]. The date of calibrated is April 3, 2025.



Figure 4.7 ICP-OES Spectrometers [108]

8. Infrared Spectroscopy (FT-IR): This apparatus using to FTIR test of Chemicals and Materials, Pharmaceuticals, Food, Environmental Safety. In figure 4.8 shows [109] Infrared Spectroscopy (FT-IR). Calibration date is 03.04.2025 [109].

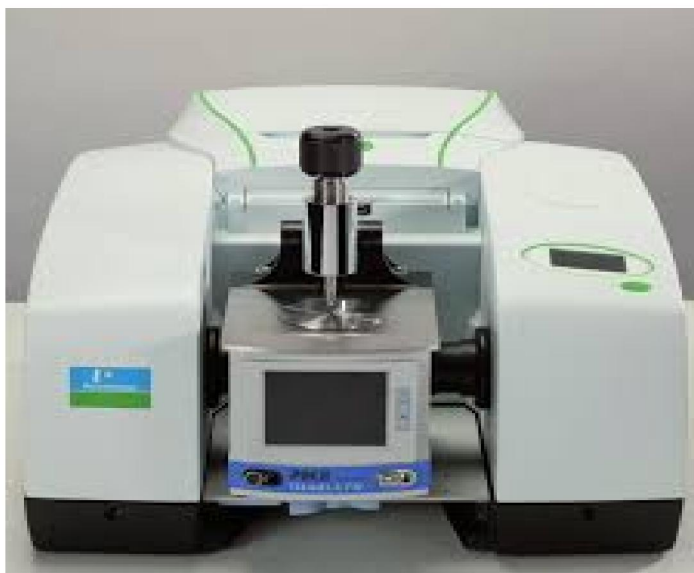


Figure 4.8 Infrared Spectroscopy (FT-IR)

9). Koehler Dual Twin Foaming Test Apparatus: In uses containing noise, high speed gearing, or high-volume pumps, lubricating oil foaming can result in bubbling, overflow, early oxidation, and inadequate friction. In figure 4.9 shows Koehler D892 and D6082 dual twin foaming characteristics test apparatus. It is also measured how long it takes for the foam to collapse to "0" following the aeration phase. For four tests that adhere to ASTM D892 and D6082 control requirements [110]. The precise flow rates of 94 and 200 mL/min to the air diffusers are maintained by four flow meters. Requires the sequence I and III tests to be performed at 24°C using an external chiller. The date of adjusting is April 3, 2025.



Figure 4.9 Koehler D892 and D6082 Dual Twin Foaming Characteristics Test Apparatus
[110]

4.4 SAMPLING SYSTEM

1(a). Sampling Instructions: Acquiring samples is a crucial topic. Only a very small portion of the entire oil capacity, which can reach 100,000 liters, can be seen by a 250 ml sample.

Relevant factors to consider while getting realistic oil samples are as follows:

- a) Sample only when the machine works at room temperature; never when it is cold or stationary, or after quite a bit of fresh oil is added.
- b) If needed, take plans to install custom sampling valves that are open and secure. Take a sample from the engine's main supply line.
- c) For each given piece of equipment, always take a sample from the same spot.
- d) Sample without opening the sample valve in between flushing and sampling, and after flushing a small amount of oil (0.5 to 1.0 l) via the sampling point.
- e) To avoid undesirable disease, if possible, fill the sample direct into the sampling vial.

- f) Only adopt specialist, dry, and clean sampling equipment designed for spent oil sampling.
- g) Before sending the sample vial to the lab, make sure it is correctly sealed and filled to 90% full to prevent leaks [111].

1(b). Sample Information: The tag on the sample bottle must be correct and full in order to ensure the sample gets examined right away. Relevant data include the ship or power plant name, the engine's specific name, the lubricant type, the engine type, the sampling date, and the number of hours of service. Errors or omissions in labeling could cause the sample to be analyzed more slowly and prevent a precise assessment and prescription. Also, it should be made explicit that the shipment contains used oil samples that are intended for destruction testing and have a flash point higher than 60°C; if this is not the case, the samples may be detained during transit because of transport safety issues. If necessary, the majority of labs can now run on a 24-hour turnaround time for testing from the moment the material is received. Pre-labelling sample bottles makes this process much easier and lowers the possibility of mistakes. Yet, it is still important to make sure that the right pre-labeled empty bottle is used, which means that the oil comes from a proper location.

1(c). Sampling Intervals: The usual amount of sampling for oil-based inspections will depend on the outcome of the risk assessment conducted during the maintenance review; however, it is generally advisable to take samples once a month until enough trends have been established to allow for optimizing and, then, to adjust a sampling rate as needed. NB: It is important to be cautious when using a condition monitoring technique, such as oil analysis, as a safeguard. Failures that are not safeguarded will occur in the absence of this. Experience has shown that when failure types, such as bearing fractures or liner scuffing, have very short "mean time to failure" profiles, used oil analysis for CM is less effective. So, taking oil samples at regular intervals typically established by the OEM or the oil supplier is essential to tracking results over time. often these intervals are no more than three months apart [111].

4.5 OIL'S PHYSICAL AND CHEMICAL ASPECTS

- **Kinematic Viscosity:** Commonly stated as a $kV@40^{\circ}C$ or $kV@100^{\circ}C$ test result, viscosity defines a fluid's flow resistance. The SAE J300 Industry Category System defines the viscosity of lubricating oil at 100°C. It is measured in $mm^2 s^{-1}$ or cSt

(centistokes). The primary factors driving changes in oil viscosity during operation are oxidation and pollution.

- **Total Base Number:** The amount of hydrochloric or perchloric acid needed to dilute one gram of oil, expressed in terms of a given number of mg of potassium hydroxide (mg KOH/g), is the alkalinity of a lube the acidity reserve is gauged by the BN.
- **Water Percentage:** Water can come from a variety of sources and infect oil with fresh or salt water. Even in small doses, water in lube oil can be lethal to the engine and is a polluter. generally, infrared spectroscopy or Karl-Fischer titration are employed to determine the water content of used oil instead of the more widely used distillation method.
- **Flash Point:** Fuel infiltration and, to a lesser extent, oil degrade are the primary factors driving changes in flash point. The flash point is the level of heat at which oil vapor can be burnt by a spark or flame. The "Open Cup" and "Closed Cup" types of flash point tests are among the various industry standards.
- **Insoluble:** After a solvent has been added, insoluble material is referred to as solid that may be isolated from the oil by spinning or filter. When additives degrade and oil contamination occurs, the amount of insoluble material increases.
- **Metallic Elements:** Spectroscopic tools are used to measure the oil's metals. This could be X-ray fluorescence spectroscopy, atomic emission, or atomic absorbance. Wear percentages of elements may be misjudged in cases of really high wear since particles larger than 5 to 7 μm are typically not identified by this method because they are not completely vaporizing in the plasma due to mass effects.
- **Total Acid Number:** The AN, earlier known as the Total Acid Number (TAN), shows how many acids exist in the oil. Titration with a basic, like potassium hydroxide (KOH), is how it is checked. The quantity of KOH needed for neutrality, which is reported in mg KOH/g, is used to determine how acidic a lubricant is.
- **Oxidation:** Oxidation is the process by which oxygen combines with molecule of hydrocarbon to create resins and insoluble carbonaceous residues. The oil's oxides absorb at a rate of 1710 cm^{-1} . Absorption value at this wavelength appears by the reported number.
- **Nitration:** The reaction between the oil and NO_x causes nitration, which is influenced by oil degradation. Although nitration is measured using a different infrared spectrum (1620 cm^{-1}), the technique is quite comparable to that of oxidation.

- **Sulphation:** When the oil reacts with SO₂, sulphate byproducts are usually generated from the oxidation of sulphur components of the additives or fuel pollution. Sulphation is visible at an infrared wave of 1150 cm⁻¹.
- **Particle Count:** atypical optical analysis is used to count particles using industry-standard methods (such as ISO 4406, NAS 1638). To ascertain and track the amount of particulate or dirt loading in oil, particle counting is done. This can be ascertained by image analysis of particles that have been filtered out of the oil, light obscurement, or light scattering techniques. The number of particles of varying sizes is the result.
- **Viscosity Index:** The VI, which characterizes the oil's viscosity-temperature interaction, is computed using the two viscosity measurements at 40°C and 100°C. A small change in viscosity with temperature is signified by a high VI.
- **SulfatesAsh:** The number of ash-building additives in the oil is given by the ensuing sulphated ash. This method is not commonly used for used lubricants because it measures the amount of detergent and anti-wear additives in new lubricating oil.
- **Soot:** Explosion, oil deterioration, and, of course, the caliber of oil treatment all affect the value.
- **Asphalts:** Heavy molecules called asphalts come from heavy fuel oil. The quantity of unburned heavy fuel particles is indicated by the asphaltene content. They may leak fuel into the oil or enter the combustion chamber as unburned fuel.
- **Fire Point:** The item will burn instantly at the flash point, which is a lower temperature, but vaporization may not be sufficient to keep the fire going. The lowest temperature at which a fuel's vapor will burn for at least five seconds after its ignition by an open flame is known as the fuel's fire point. Testing to determine whether a fire point is safety essential is necessary even though it is accepted that fire points are around 10 °C higher than flash points.
- **Pour Point:** A high pour point in crude oil usually coincides with a high wax content, which is found in crude that has a greater proportion of plant matter. The temperature at which a liquid loses its ability to flow is known as its pour point.
- **Density:** Known as its cubic mass density, is its mass per unit volume; this value is often referred to as specific weight. Temperature and pressure have an impact on a material's density [112].

4.6 TEMPERATURE'S IMPACT ON OIL VISCOSITY

1(a). Sample of Waste Used Oil SAE-50, SAE-90 & ISO VG-68

Here analysis three sample of waste used oil sample like SAE 50, SAE-90 & ISO VG-68, where ASTM standard Temperature 40 °C & 100 °C. Viscosity of engine oil decreasing by increasing temperature [112]. Figure 4.10 and Table 4.2 shows effect of temperature on viscosity.

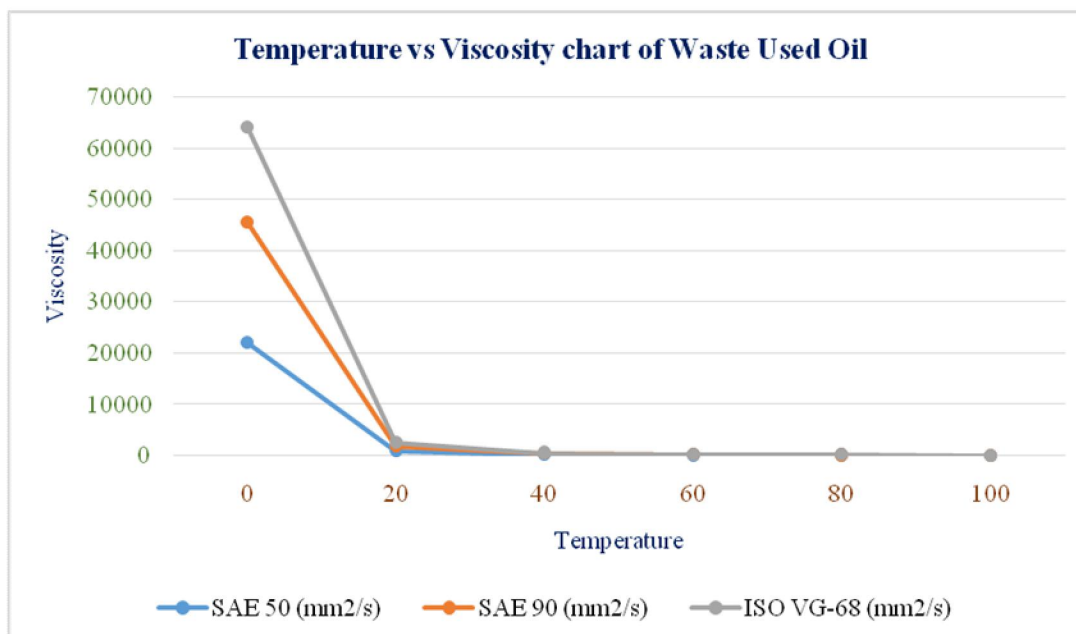


Figure 4.10 Temperature vs Viscosity chart of waste used oil.

Table 4.2 Temperature vs Viscosity table of waste used oil.

Temp °C	SAE 50(mm ² /s)	SAE 90(mm ² /s)	ISO VG-68 (mm ² /s)
0	1810.93	2335.89	853.92
20	981.03	889.33	681.36
40	282	226	83
60	111.91	109.23	61.27
80	74.93	63.27	39.58
100	23	21	10

1(b). Sample of Used Oil (on Treatment) SAE-50, SAE-90 & ISO VG-68

Here analysis three sample of used oil (on Treatment) like SAE-50, SAE-90 & ISO VG-68, where ASTM standard Temperature 40 °C & 100 °C. Viscosity of engine oil decreasing by increasing temperature [112]. Figure 4.11 and table 4.3 shows on treatment effect of temperature on viscosity.

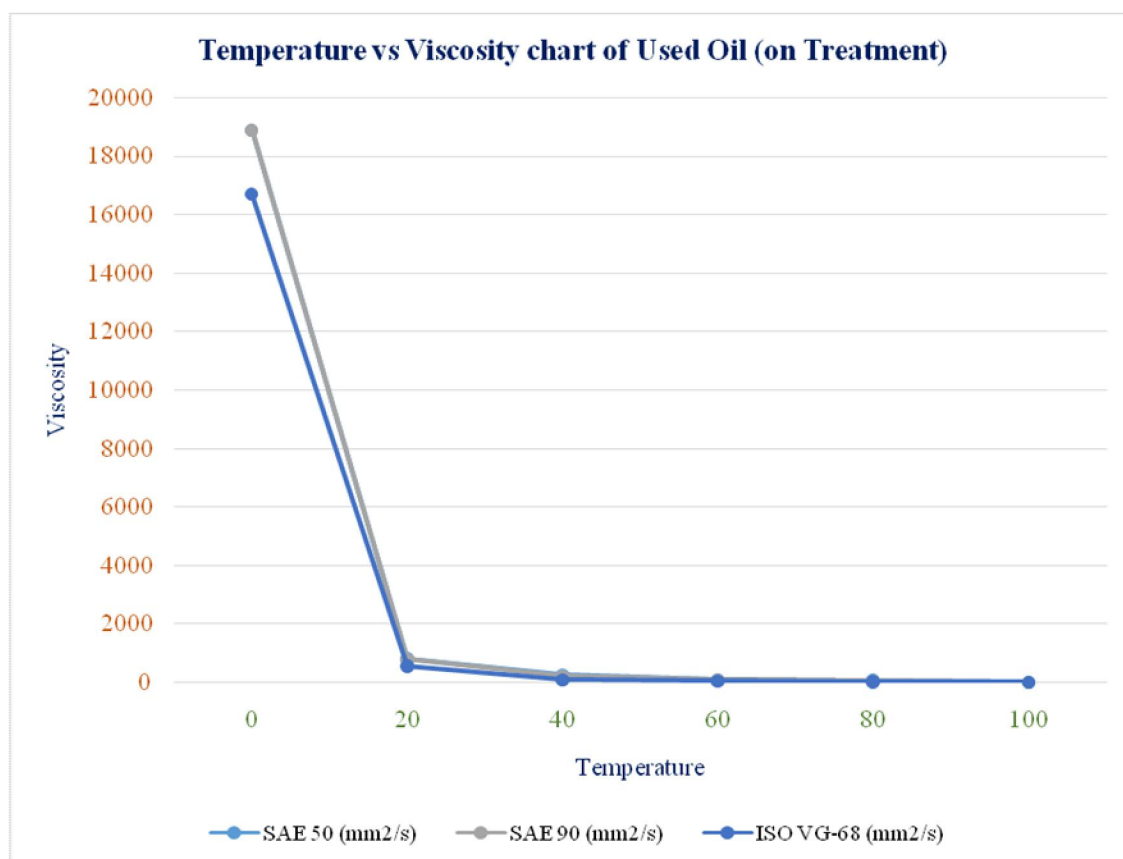


Figure 4.11 Temperature vs Viscosity chart of waste used oil (on treatment).

Table 4.3 Temperature vs Viscosity table of used oil (on treatment).

Temp °C	SAE 50(mm ² /s)	SAE 90(mm ² /s)	ISO VG-68 (mm ² /s)
0	1619.13	2179.36	739.26
20	807.31	798.62	552.39
40	261	213	78
60	89.53	87.39	49.21
80	67.77	43.34	28.54
100	21	19	9

1(c). Refined New Oil SAE-50, SAE-90 & ISO VG-68

Here analysis three sample of refined new oil like SAE-50, SAE-90 & ISO VG-68, where ASTM standard Temperature 40 °C& 100 °C. Viscosity of engine oil decreasing by increasing temperature [113]. Figure 4.12 and table 4.4 shows effect of temperature on viscosity.

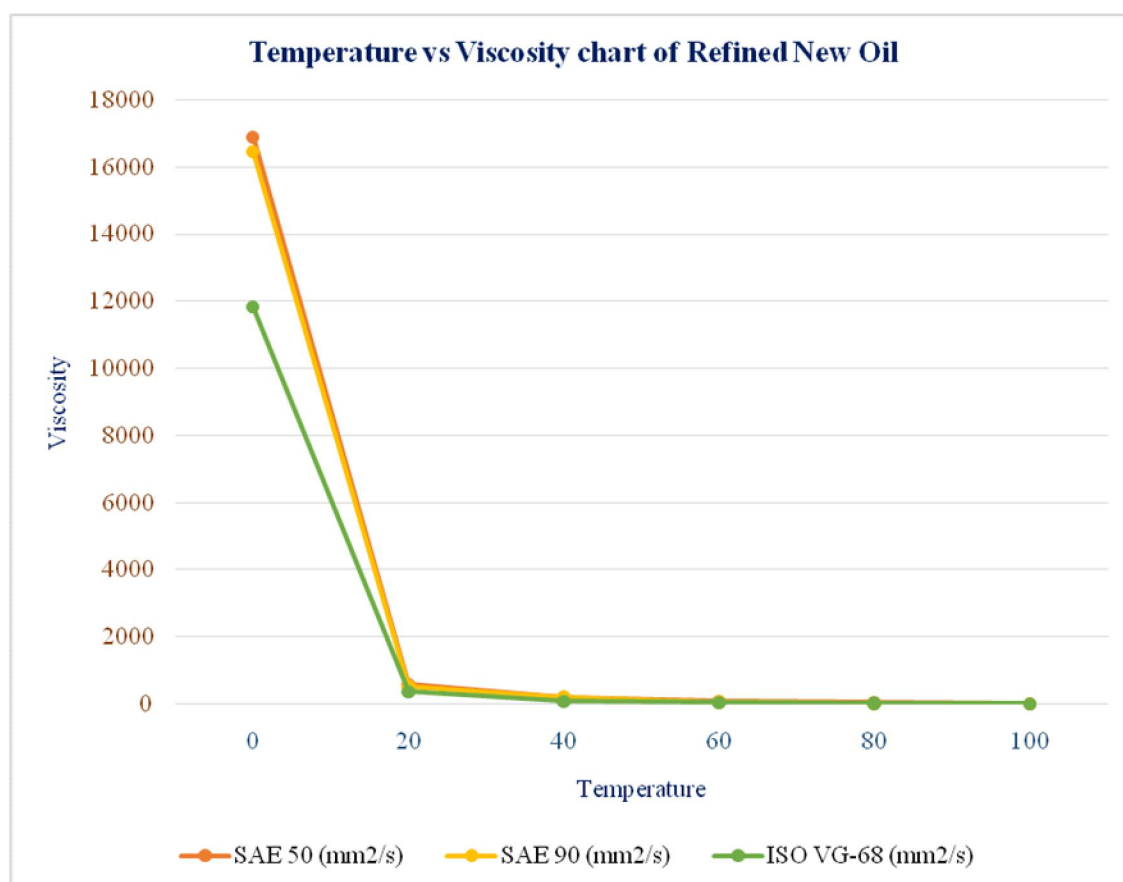


Figure 4.12 Temperature vs Viscosity chart of refined new oil.

Table 4.4 Temperature vs Viscosity table of refined new oil.

Temp °C	SAE 50(mm ² /s)	SAE 90(mm ² /s)	ISO VG-68 (mm ² /s)
0	1439.32	1945.13	623.14
20	586.93	536.29	356.24
40	181	209	69
60	73.57	71.68	37.72
80	49.38	24.37	17.21
100	16	18	8.9

1(d). Fresh Oil Data Analysis of SAE-50, SAE-90 & ISO VG-68

Here analysis three sample of fresh oil like SAE-50, SAE-90 & ISO VG-68, where ASTM standard temperature 40 °C & 100 °C. Viscosity of engine oil decreasing by increasing temperature [113]. Figure 4.13 and table 4.5 shows effect of temperature on viscosity.

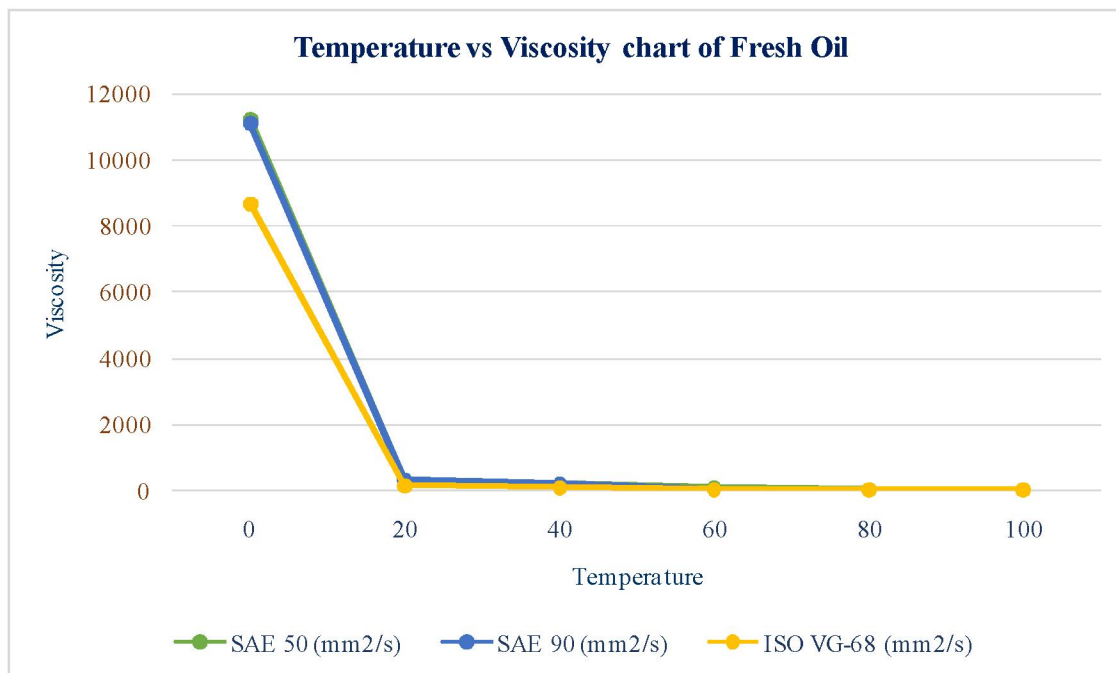


Figure 4.13 Temperature vs Viscosity chart of fresh oil.

Table 4.5 Temperature vs Viscosity table of fresh oil.

Temp °C	SAE 50(mm ² /s)	SAE 90(mm ² /s)	ISO VG-68 (mm ² /s)
0	1123.56	1608.21	454.22
20	322.61	323.37	149.29
40	163.3	203	68
60	63.25	46.21	29.55
80	28.56	21.91	15.23
100	15.53	18	8.8

4.7 PARAMETERS ANALYSIS BETWEEN REFINED AND FRESH BASE OILS

Base oil SN 500, SBS 150 and additives used to manufacture engine oil SAE -50. Base oil SN 500, SN 70, SBS 150 and additives used to manufacture Gear Oil SAE-90. Base oil SN 150, SN 70, SBS 150 and additives used to manufacture Industrial oil ISO VG 68.

1)a). Solvent Neutral (SN) 500 Base Oil

Base Oil SN 500 is light grade base oil that falls at the upper end of the Grade I base oil norms and is mostly used in the production of oils. Many industrial lubricants, including engine oils, gear oils, transmission fluids, metal working fluids, greases, hydraulic oils, transformer oils, and others, use SN 500 as a basic stock [114]. Figure 4.14 and table 4.6 shows SN500 base oil properties.

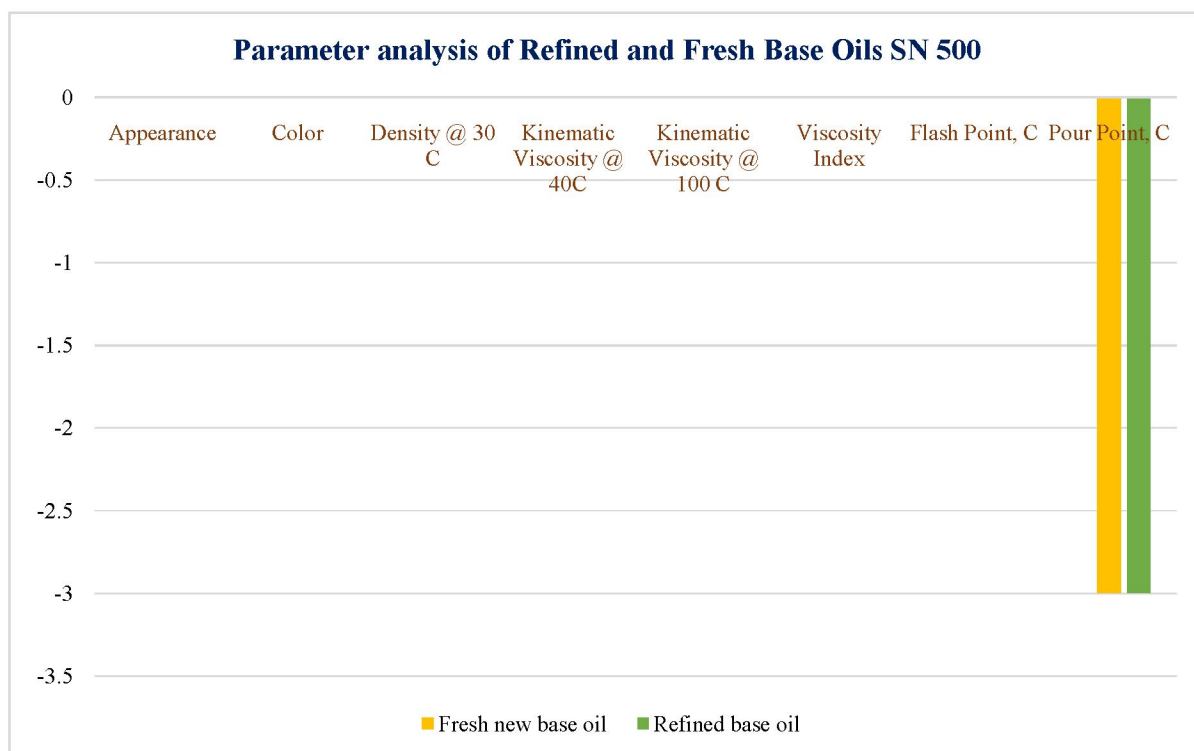


Figure 4.14 Parameter analysis of refined and fresh base oils SN 500

Table 4.6 Parameter analysis of refined and fresh base oils SN 500.

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

1(b). Solvent Neutral (SN) 150 Base Oil

Base oil SN 150 is deemed as a Grade I light. The basis Oil SN 150 serves as a core stock for a variety of industrial lubricants, such as metal working fluids, gear oils, engine oils, hydraulic oils, transformer oils, and greases [115]. Figure 4.15 and table 4.7 shows SN 150 base oil properties.

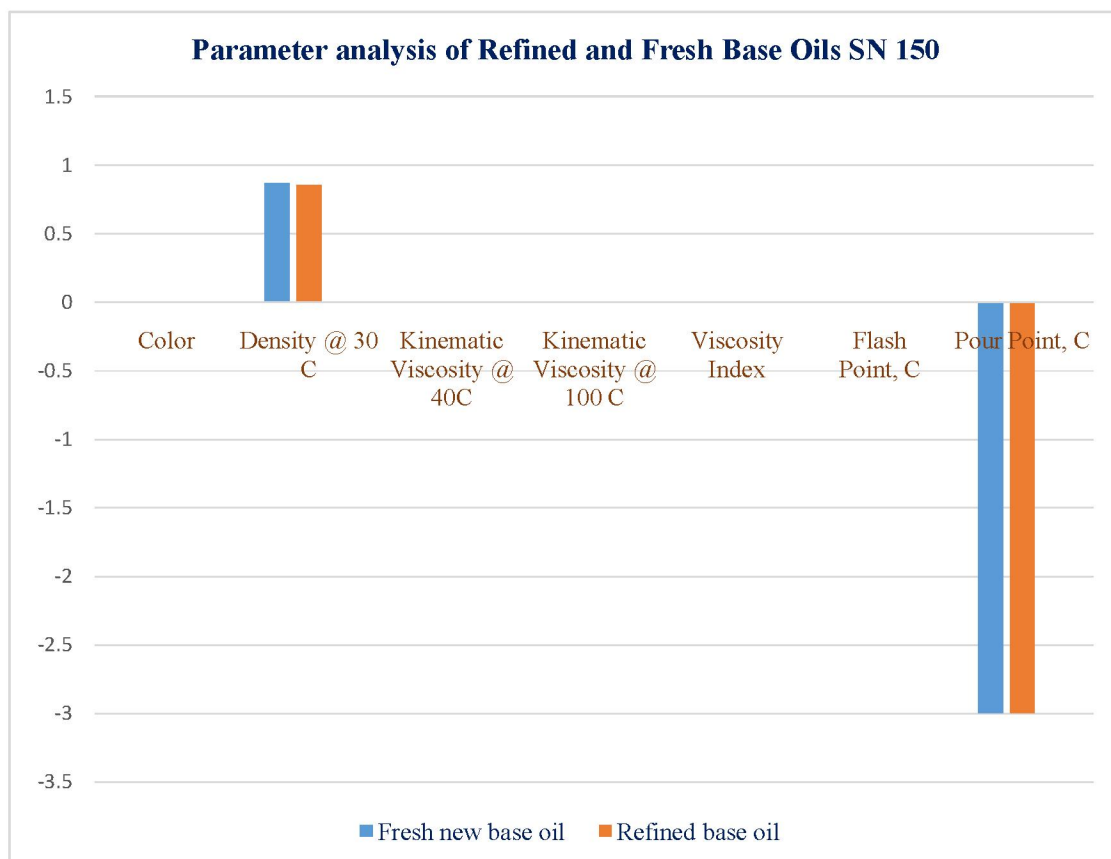


Figure 4.15 Parameter analyses of refined and fresh base oils SN 150

Table 4.7 Parameter analysis of refined and fresh base oils SN 150.

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

1(c). Solvent Neutral (SN) 70 Base Oil

High boiling point, high viscosity index, thermal stability, and high oxidation resistance are attributes associated with SN 70 Base Oil. Figure 4.16 and table 4.8 shows SN 70 base oil properties. High boiling point, high viscosity index, thermal stability, and high resistance to oxidation are traits found in SN 70 base oil. serves as base stock for a variety of industrial lubricants, including greases, hydraulic oils, transformer oils, metal working fluids, gear oils, engine oils, and transmission fluids [116].

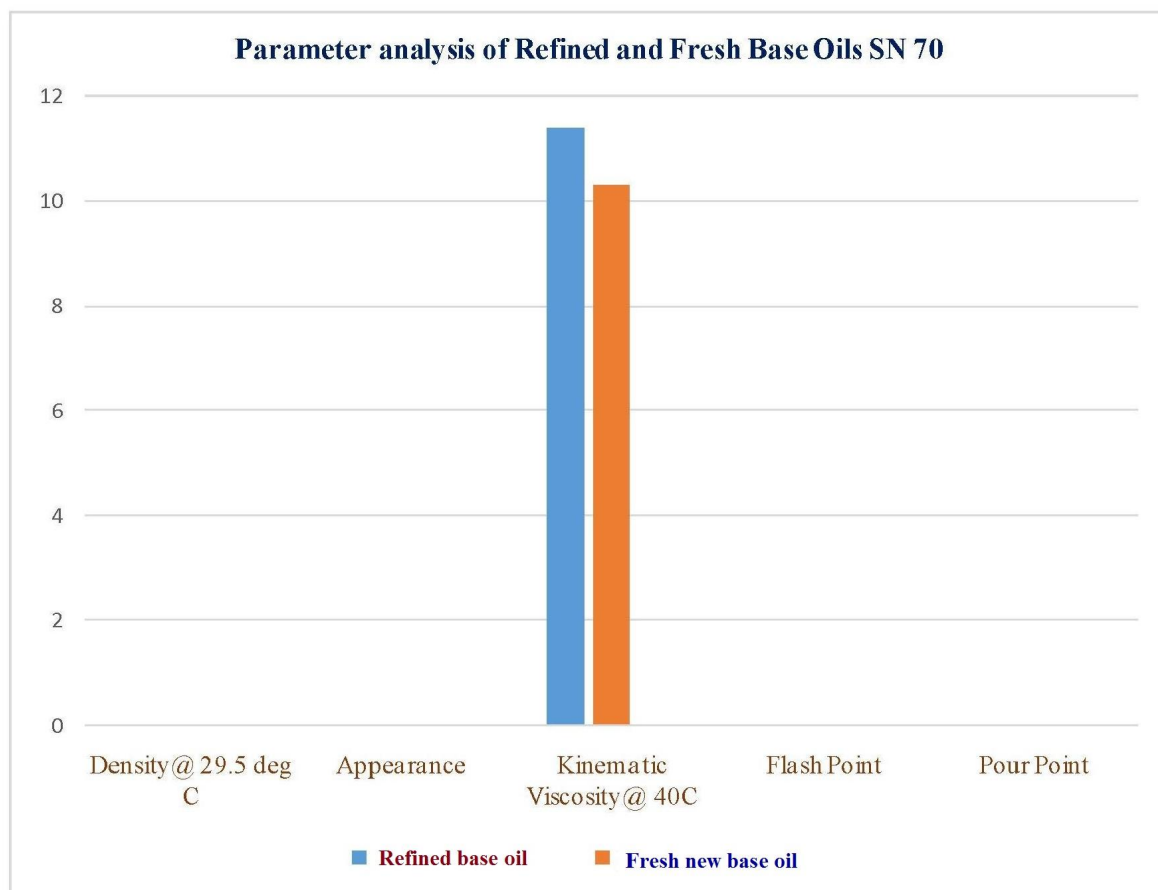


Figure 4.16 Parameter analyses of refined and fresh base oils SN 70

Table 4.8 Parameter analysis of refined and fresh base oils SN 70

Parameters	Test Methods	Fresh new base oil	Refined base oil
Density@ 29.5 deg C	ASTM D 1298	0.841	0.858
Appearance	ASTM D 1500	Bright & Clear	Bright & Clear
Kinematic Viscosity@ 40C	ASTM D 445	10.33	11.40
Flash Point	ASTM D 92	132 deg C (COC)	140 deg C (COC)
Pour Point	ASTM D 97	-18 deg C	-19 deg C

4.8 ECONOMICAL ASSESSMENT

1(a). Thesis expenses:

Assume that 700 L of spent lubricant oil are produced every day. Therefore, we have set up a plant that can make 8,400 L per day, and it will run for 12 hours daily. Table 4.9 shows the details of investment calculation. The annual working days are near 3960 hours, or 330 days. About 94,000 square feet of land needed to establish the plant to the desired size.

Table 4.9: Details of Investment Calculation.

(a). Land buying cost:(assuming)		= 5,44,00,000/-
Total land area 94,000sf, Per Sf price BDT. 600/-		
Total land price = (94000*600)	= 5,44,00,000/-	
(b). Civil construction cost:		= 519,00,000/-
(i) Land Development = 94,000*100	= 94,00,000/-	
Total land area 94,000sf, Per Sf price BDT. 100/-		
ii) Building construction = 5000*2500	= 125,00,000/-	
Total land area 5,000sf, Per Sf price BDT. 2500/-		
(iii) Factory building = 20000*1500	=300,00,000/-	
Total land area 20,000sf, Per Sf price BDT. 1500/-		
Total building cost	= 519,00,000/-	= 195,00,000/-
(c). Vehicles buying:		
(i) Transportation bursar = 3*25,00,000	= 75,00,000/-	
(ii) Delivery purpose = 3*15,00,000	= 45,00,000/-	
(iii) Marketing & Others = 5*15,00,000	= 75,00,000/-	
Total vehicles buying cost	= 195,00,000/-	= 45,00,000/-
d). Storage cost:		
(i) Raw Collecting storage: 5*30,00,000	= 150,00,000/-	
(ii) Base Oil Reserve container: 5*40,00,000	= 200,00,000/-	
(iii)Catalyst expenses (25 tons): 25*400,000	= 100,00,000/-	
Total Storage cost	= 45,00,000/-	= 213,900,000/-
(e). Machinery & Lab Cost:		
(i)Machinery buying (I ₁)	= 30,000,000/-	
(ii) Auxiliary equipment (I ₂) = (I ₁ *20%)	= 60,00,000/-	
(iii) Testing lab equipment (I ₃)	= 150,000,000/-	

(iv) Setup & Installation cost ($I_1+I_2+I_3$) *15%	= 27,90,0000/-	
Total Machinery cost	= 213,900,000/-	
(f) Custom duty & Others cost:		= 26,970,000/-
(i) Machinery import is (if 5% o I_1) tax	= 93,00,000/-	
(ii) VAT collected (custom 7% + local development cost 2.5%)	= 17,670,000/-	
Total Custom duty & Others cost	= 26,970,000/-	
(g). Miscellaneous cost:		= 130,00,000/-
(i) Transportation cost of machinery	= 30,00,000/-	
(ii) Total engineering cost	= 10,000,000/-	
Total Miscellaneous cost	= 130,00,000/-	
Total Investment Cost [BDT]		= 424,670,000/-
Total Investment Cost [BDT] [Note: 1 UDS = BDT 120/-]		= 3,538,916.67

Project in Details estimation:

In table 4.9 showsproject in details estimation.

Table 4.10 Project in Details estimation

Sl.	Item	Calculated basis
1	Project life (Minimum)	50yrs
2	Construction period	03 yrs
3	Depreciation	Straight line with 5%
4	Salvage value	Zero
5	Income tax rate	10%
6	Inflation	0
7	Capital expenditure	
	1 st year	25% of fixed capital
	2 nd year	30% of fixed capital
	3 rd year	45 of (fixed capital +working capital)
8	Capacity utilization	
	1 st and 2 nd year	55%
	3 and subsequent years	100%

Details of Utilities & Others for 1m³ of used oil processing:

In table 4.9 shows details of utilities & others for 1m³ of used oil processing:

Table 4.11 Details of Utilities & Others for 1m³ of used oil processing

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

Composition of output on the basis of mass:

In table 4.9 shows Composition of output on the basis of mass.

Table 4.12 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/ Others	0. %

Now, based on our survey's yearly operating cost modeling, we saw that the cost of purchasing used oil would be BDT 35/L (including collection, shipping, and other costs).

Here, the current price of waste used oil is BDT 25-30 per Ltr.

- (a). Our annual total usage of oil is equal to $8400 * 330 = 2,772,000 \text{ L} = 2772 \text{ m}^3$;
- (b). The annual cost of buying used oil for 330 days of operation is $8400 * 330 * 35$
= BDT 97,020,000/-
- (c). The cost of industrial power is BDT 12 per unit.

Details of Yearly operating cost:

In table 4.9 shows details of yearly operating cost:

Table 4.13 Details of Yearly operating cost

Sl	Description	Amount (BDT)
1	Electricity Consumption = $(2772 * 90 * 12)$	= 29,93,760.00
2	Catalyst removal = $(2772 * 0.4 * 330)$	= 365,904.00
3	Cost of Hydrogen = $(27,72,000 * 0.002 * 100)$	= 554,400.00
4	Cost of Fuel = $(6488.03 * 40)$ The total amount of heat needed is equal to $(18000 * 4.2) = 75600$ kJ. Consider that furnace oil has a heating value of 38 MJ/Kg The total quantity of fuel needed is equal to $(75600 \text{ kJ} / 38 \text{ MJ} * 2772) = 5514.82$ kg. The furnace oil's specific gravity in this case is 0.85. Thus, the total fuel amount is equal to $(4476.31 \text{ kg} / 0.85)$, or 6488.03 L.	= 259,521.00
5	Labor cost for (30 staffs) = $(18000 * 12 * 30)$	= 64,80,000.00
6	Miscellaneous Extra expenses	= 12,00,000.00
7	Maintenance cost = $(I_1 * 4\% + I_2 * 3\%) = (1200,000 + 180,000)$	= 13,80,000.00
8	Depreciation cost = $(I - 0) / N$ per Year (Assuming the straight-line depreciation with zero salvage value after 50 years.)	= 8,40,000.00
9	Insurance and other fees are 2% of total investment	= 84,93,400.00
10	Financial cost is 7% of capital investment	= 29,726,900.00
Total operating cost [BDT]		= 59,853,885.00
Total operating cost [USD] [Note: 1 UDS = BDT 120/-]		= 498,782.375

1(b). Overview of revenue outcome:

Unit selling price of refined oil is BDT.135/Ltr. Assuming, during 1st and 2nd year only 75% of oil is sold. In table 4.9 showsoverview of revenue outcome.

Table 4.14 Overview of revenue outcome

1	Revenue of 1 st and 2 nd year, =(8400*330*0.75*135*0.75)	= 210,498,750.00
2	Revenue of remaining 48 years= (105,249,375*48)	=5,051,970,000.00
3	Yearly variable cost per unit (1m ³)=(733,31,400/2772)	=26,454.00
4	First and second year net revenue= (selling cost - total operating cost) = (210,498,750-59,853,885)	= 150,644,864.00
5	Income after the 10 % tax deducted= (150,644,864 - 15,064,486)	= 135,580,378.00
6	For remaining 48 years = (10,103,940,000-1010,394,000)	= 9093,546,000.00
Net Revenue for 50 Years (BDT)		= 9304,044,750.00
Net Revenue for 50 Years (USD) [Note: 1 UDS = BDT 120/-]		= 775,33,706.25

1(c). Project Economic Viability Report

(i). Payback Period: Without taking the time value of money to account, the payback period is the number of years needed to recoup the investment made in a project.

Here, Payback period (PP) = {5 years + (480.88/961.91)}

= 5.49years

= 5 years and 6 months

(ii). Discounted payback period calculation for Interest rate = 10%.

The number of years needed to recoup project investment when taking time value of money into account is known as the discounted payback period.

Here, Discounted Payback Period (DPP) = {6 years + (499.78/912.09)}

= 6.54 years

= 6 years and 4 months

(iii). Net Present Worth (NPW) for Interest rate = 10%:

Net Present Worth $NPW(10\%) = \{(-483.36 - 1087.56)/(1.1 - 845.88)/(1.1^2 + 501.081)/(1.1^3 + 501.081)/(1.1^4 + 976.89) * (P/A, 10\%, 16) * (P/F, 10\%, 4)\}$
 $NPW(10.25\%) = \text{BDT. } 3,425.05;$

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

(iv). Internal rate of return (IRR): The interest rate earned on the unrecovered project balance invested is known as the internal rate of return (IRR), and it should be zero at the end of the project. The project's net present value is set to zero in order to compute the internal rate of return. IRR is the interest rate at which the project's net present value drops to zero. In figure 4.17 and table 4.15 shows variation of net present worth with interest rate.

$$NPW(I) = 0$$

$0 = \{-483.36 - 1087.56/i - 845.88/i^2 + 501.08/i^3 + 501.08/i^4 + 976.89 \times (P/F, i, 4) \times (P/A, i, 16)\};$ We now compute the various PW values at various the table is displayed below. Excel is used to perform the computations [116].

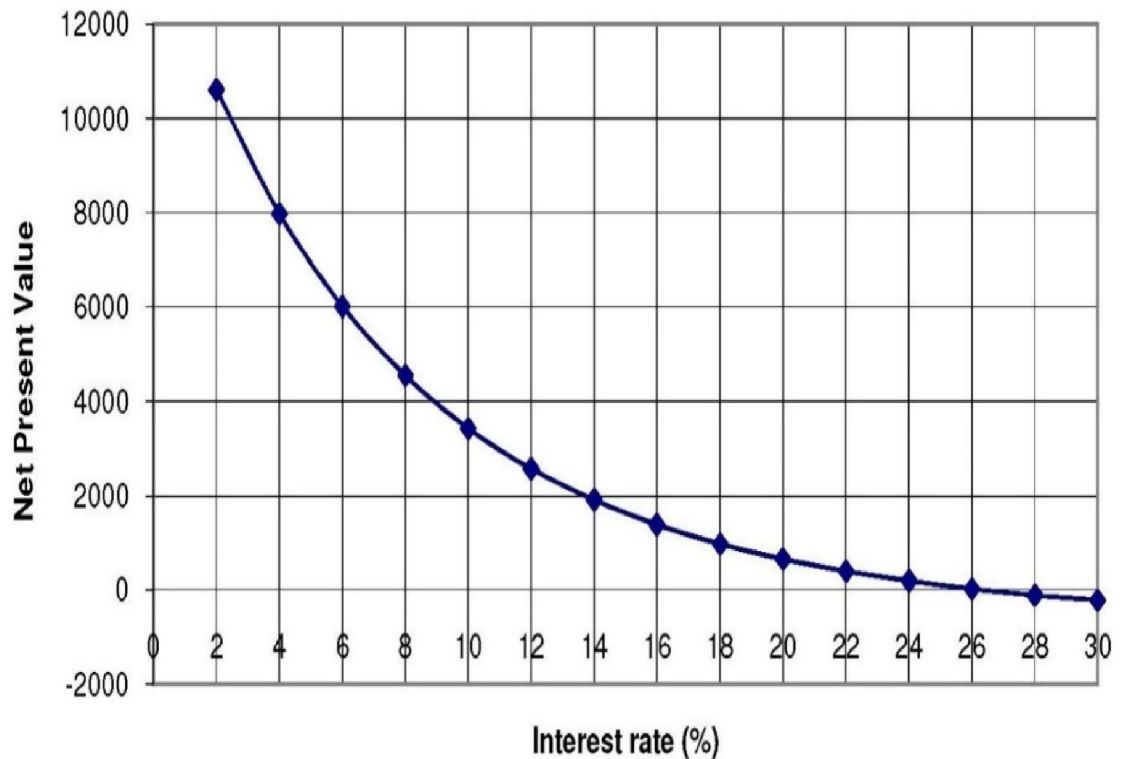


Figure 4.17 Variation of net present worth with interest rate

Table 4.15 Variation of net present worth with interest rate

S.N.	Interest rate (I %)	NPW (Lakhs)
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

From the calculation IRR is found to be ~ 23%, which is far greater than MARR. Thus the project is feasible.

4.9 OUTCOMES AND CONVERSATION

The experiments from three distinct sources for each technology were examined and the average results were taken into thought, in order to point out the results of vacuum distillation techniques for recycling spent oil. The fresh oil's technical brochure provided the information. The lubricating oil's density, flash point, pour point, viscosity, viscosity index, and total acid number were all tracked.

(a). Viscosity:

The viscosity is decline with temperature increases. Figure 4.18 shows the viscosity analysis of used, refined& fresh oil. For, sample of used oil SAE-50 viscosity at 40°C is 282, SAE-90 viscosity at 40°C is 226, ISO VG viscosity at 40°C is 83, and viscosity at 100°C respectively 23, 21, 10. For, sample of used oil (on treatment) SAE-50 viscosity at 40°C is 261, SAE-90

viscosity at 40°C is 213, ISO VG viscosity at 40°C is 78, and viscosity at 100°C respectively 21, 19, 9. For, sample of refined new oil SAE-50 viscosity at 40°C is 181, SAE-90 viscosity at 40°C is 209, ISO VG viscosity at 40°C is 69, and viscosity at 100°C respectively 16, 18, 8.9. Final viscosity of refined new oil is closed to fresh virgin oil SAE-50 viscosity at 40°C is 163.3, SAE-90 viscosity at 40°C is 203, ISO VG viscosity at 40°C is 68, and viscosity at 100°C respectively 15.53, 18, 8.8 [116].

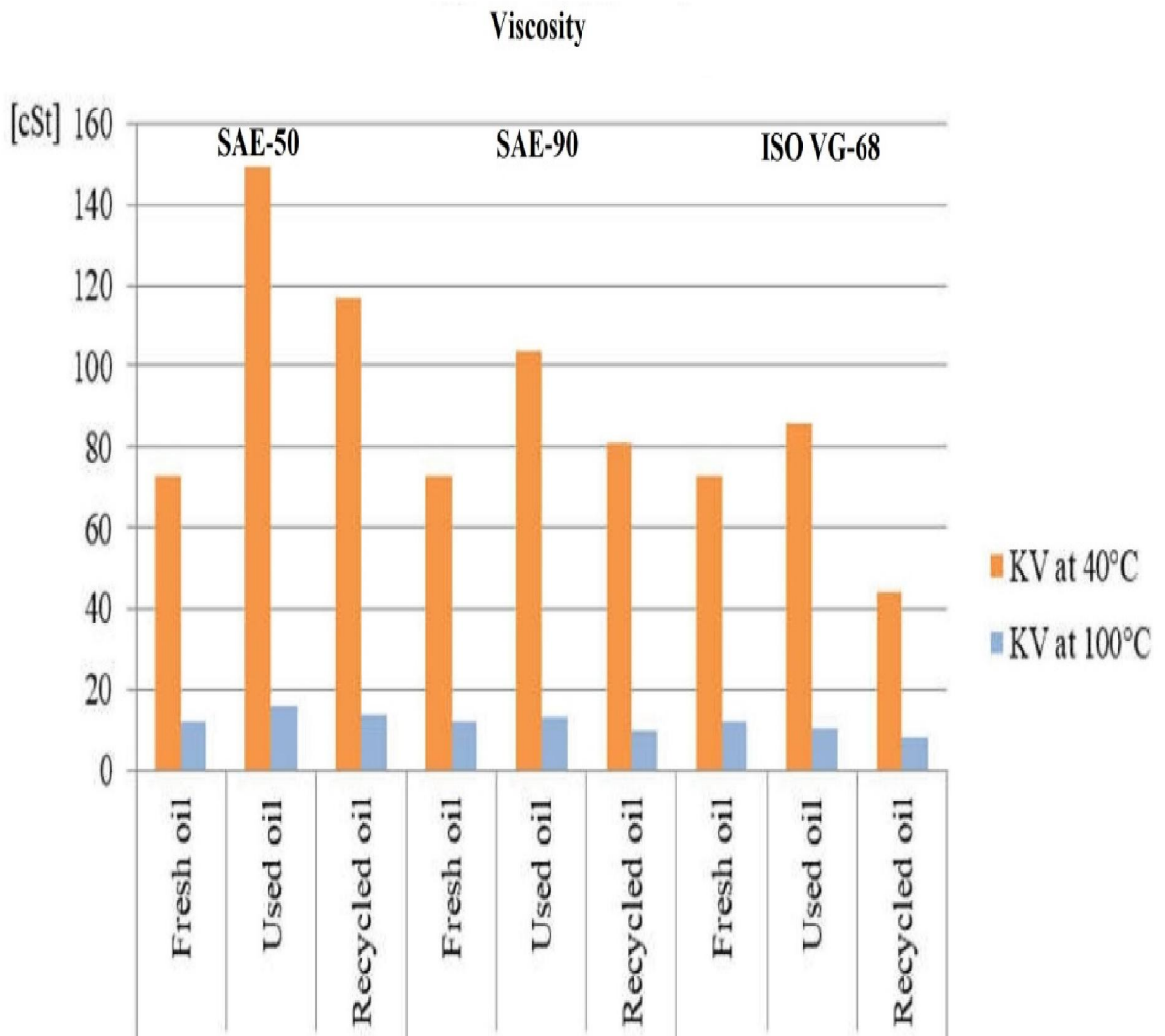


Figure 4.18 Viscosity Analysis of Used, Refined & Fresh oil.

(b). Viscosity Index:

The viscosity index of refined new oil SAE-50 is 95, SAE-90 is 95, ISO VG is 99 and closed to fresh virgin oil SAE-50 is 96, SAE-90 is 97, ISO VG is 100 [116]. Figure 4.19 shows viscosity index analysis of used, refined & fresh oil.

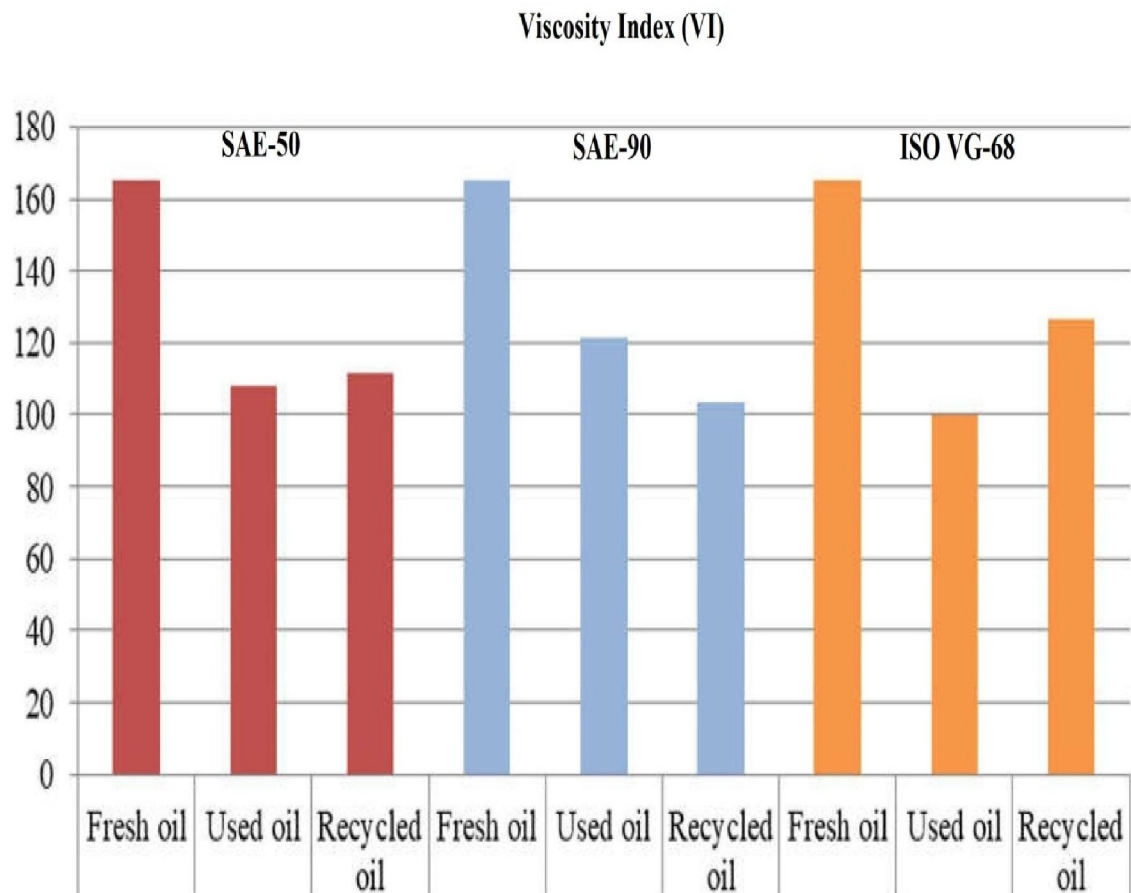


Figure 4.19 Viscosity Index Analysis of Used, Refined & Fresh oil.

(c). Flash Point:

The Flash point of refined new oil SAE-50 is 261, SAE-90 is 221, ISO VG is 219 and closed to fresh virgin oil SAE-50 is 268, SAE-90 is 226, ISO VG is 224 [116]. Figure 4.20 shows flash point analysis of used, refined & fresh oil.

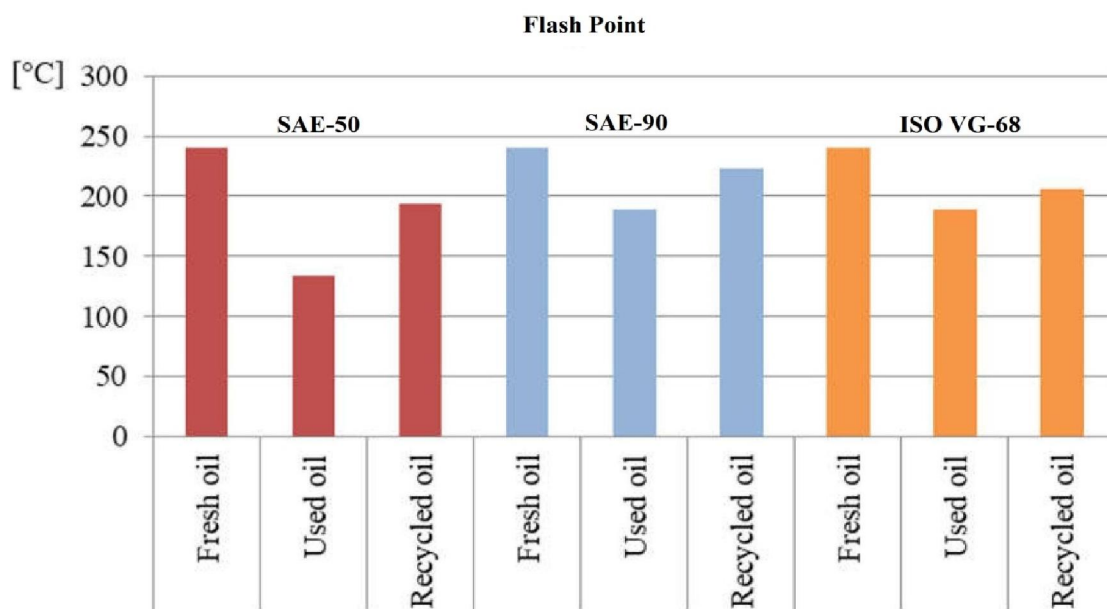


Figure 4.20 Flash Point of Used, Refined & Fresh oil.

(d). Pour Point:

The Pour point of refined new oil SAE-50 is -19, SAE-90 is -22, ISO VG is -13 and closed to fresh virgin oil SAE-50 is -18, SAE-90 is -21, ISO VG is -12 [116]. Figure 4.21 shows pour point analysis of used, refined & fresh oil.

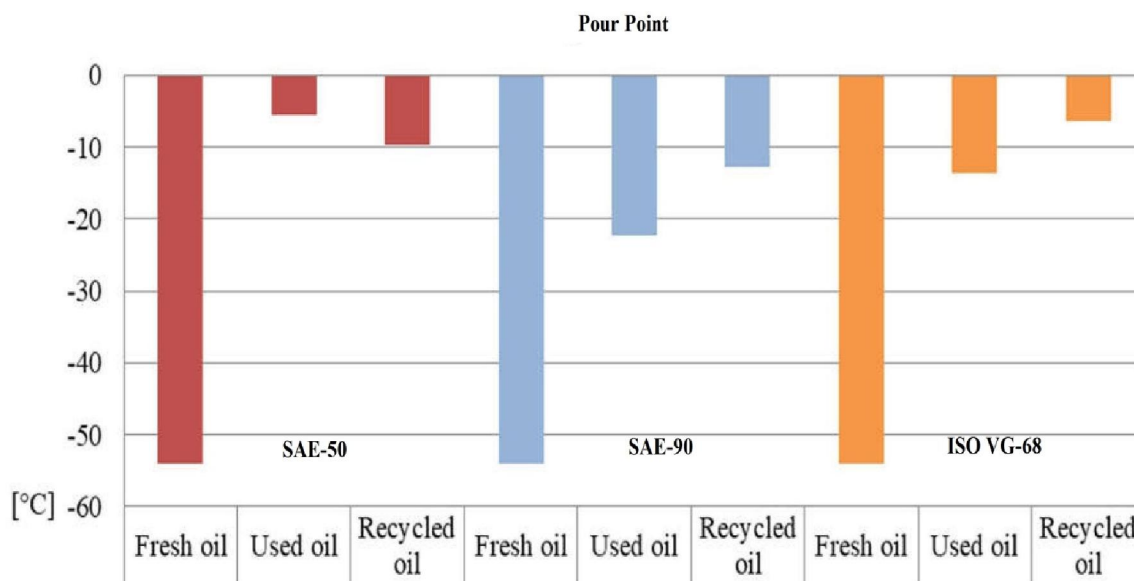


Figure 4.21 Pour Point of Used, Refined & Fresh oil.

(e). Density:

The density of refined new oil SAE-50 is 0.890, SAE-90 is 0.891, ISO VG is 0.873 and closed to fresh virgin oil SAE-50 is 0.898, SAE-90 is 0.911, ISO VG is 0.881 [116]. Figure 4.22 shows density analysis of used, refined & fresh oil.

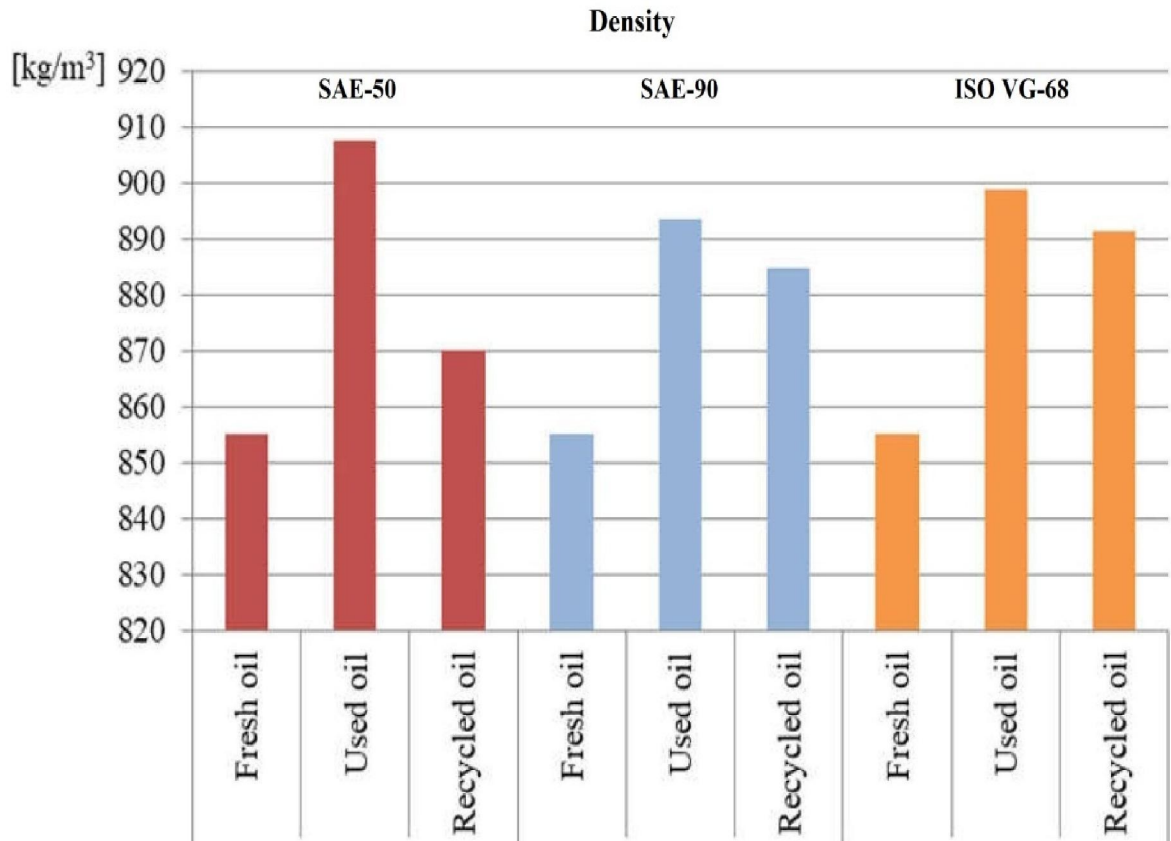


Figure 4.22 Density of Used, Refined & Fresh oil.

4.9.1 Appearance analysis and actual output:



Figure 4.23 Samples of used oil



Figure 4.24 Samples of on treatment used oil



Figure 4.25 Samples of refined oil

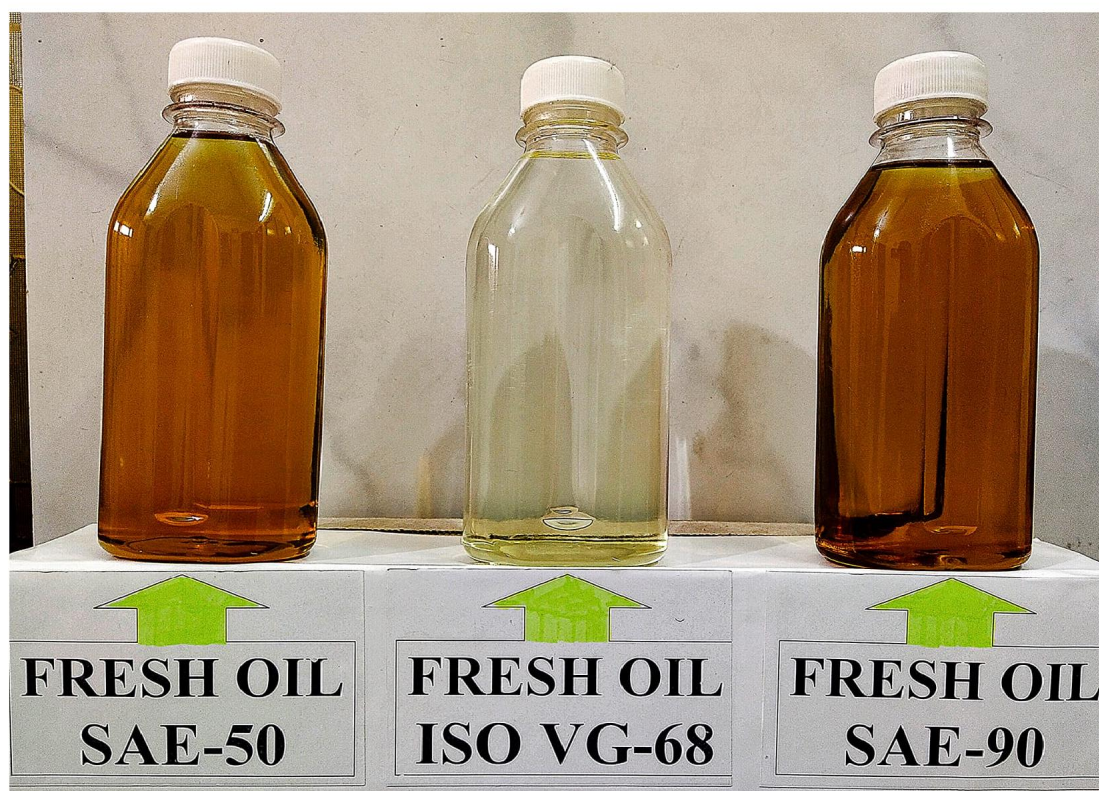


Figure 4.26 Samples of fresh oil

CHAPTER V
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

Due to their high hydrocarbons content, waste to energy is now an ideal means for using these fire-prone substances in light of rising costs of fossil fuels and disposal issues, such as water contamination in the ground from spent lubricants. The results of the final analyses show that we produced engine oil with considerably better features that are equivalent to the base oil, indicating the viability of the recommended approach. A review of experimental research, all techniques effectively eradicated impurities from spent lubricating base oil and recovered the oil to a level close to that of lubricants made from new lubricant stocks. One of the biggest approaches to recycling is distillation; however it has a disadvantage in that the solvents used in recycling are costly. Lubricating oil misuse poses serious threats to the natural world. Hence, it is essential to manage spent oil properly. For a nation like Bangladesh that depends entirely on lubricating oil imports, refining is the best choice for managing used oil. The whole quantity of used oil that will be produced in the various industrial and automotive sectors is determined by our data collecting and analysis. The amount of oil that can be collected in 2028/2078, assuming an 80% collection efficiency, is 8400L per day. Moreover, assuming that around 5% of the solid particles are filtered and settles. It is therefore suggested that a plant process 8400L per day. Mechanisms for distillation refining have been studied by me. We have chosen distillation processes from a variety of approaches due to their better productivity, capacity to handle oils of various grades, and green credentials.

Numerous techniques were used in the economic evaluation of the chosen procedure. Payback term = 05 years 06 months, discounted payback period = 06 years 04 months, net present value = BDT 3425.05, and internal rate of return = 23% are the results of the computation. The project's financial viability was evident from the earlier figures.

5.2 RECOMMENDATIONS

- (a). As soon as feasible, the government should implement the appropriate laws and guidelines for the efficient management of used oil.
- (b). To encourage people to use refined lubricating oil and to educate them about the damaging consequences of faulty handling of spent lubricant, awareness drives ought to be started.
- (c). A collection system must to be set up to gather spent lubricating oil statewide as well. A countrywide inquiry into the potential for re-refining spent lubricating oil should be performed. The plant should be designed in detail.

REFERENCES

1. Francois, A. "Waste Engine Oils Refining and Energy Recovery", 1st ed.; Elsevier Science and Technology Books: Amsterdam, The Netherlands, 2006.
2. Whisman, M.L.; Reynolds, J.W.; Goetzinger, J.W.; Cotton, F.O.; Brinkman, D.W. Re-refining makes quality oils. *Hydrocarb. Process*, 1978.
3. "Used Oil. A Renewable Resource and an Environmental Pollutant" by David Layzell.
4. Motshumi J. Diphare, Edison Muzenda, Tsietsi J. Pilusa and Mansoor Mollagee "Lubricating Oil Treatment Techniques" ICEAFS 2013.
5. S. Arnaout, "Options for vehicle waste oil management", Lebanon, Ministry of Environment, 1997.
6. J. D. Udonne, "A comparative study of recycling of used lubricating oils" *Journal of petroleum and Gas Engineering*, vol2.
7. Benito, J. M., Ríos, G., Ortea, E., Fernández, E., Cambiella, A., Pazos, C. and Coca, J., (2002) *Desalination*, 147, 5-10.
8. Bowman L.O., "Used Oil Management Update" ' H.P., Feb. 1982, pp. 86-89 [4] Whisman M.L., et. al., "Re-refining Makes Quality Oils", H.P., Oct. 1978, pp. 141-145.
9. Brandvik P.J., Evaluation letter on Master Dissertation by Victoria Broje entitled "Modeling of the oil spills and contingency measures in the Arctic with emphasis on the Pechora Sea region", 2001.
10. Canizares P. et al., 2004, Gutierrez G et al., 2007, Lobo A et al 2000, Benito J. et al., 2006, Treatment of waste oil-in-water emulsions from copper metalworking industry by vacuum evaporation: effect of operating conditions.
11. D. Church, "Used Oil Recovery, Reuse and Disposal in New Zealand: Issues and Options," Ministry for the Environment Manatū Mō Te Taiao, 2000
12. Della Bona A., Shen C. and Anusavice K.J., Work of adhesion of resin on treated lithiadisilicate-based ceramic, *Dental Materials*, Volume 20, Issue 4, May 2004.
13. F.Fitchner, "Environmental Overview on Used Oil Management," Stuttgart, Germany, unpublished 1997
14. Hetsroni, G., Mosyak, A., Pogrebnyak, E., Sher, I. and Segal, Z., (2006), *International Journal of Multiphase Flow*, 32, 159-182
15. Hournac R., "Good Lubes Need Good Base Oils", H.P., Jan. 1981, pp. 207-211.

16. AK Azad, "An experimental study of recycling of used lubrication Oils using distillation, acid and activated charcoal with clay methods," *International Communications in Heat and Mass Transfer*, Volume 28, Issue 3, March 2014.H.V..
17. Jensen, H.V. and Joseph Mullin, MORICE-New Technology for Mechanical Oil Recovery in Ice Infested Waters, *Marine Pollution Bulletin* v.47, 2003.
18. Jokuty, P., Whiticar, S., McRoberts, K., Mullin, J., Oil adhesion testing recent results. *Proceedings from the Nineteenth Arctic Marine Oil spill Prog. Tech. Seminar. Canada*, 1996.
19. Lee Y., Fang T., Yang Y. and Maa J., The enhancement of drop wise condensation by wet ability modification of solid surface, *International Communications in Heat and Mass Transfer*, Volume 25, Issue 8, November 1998.H.V.
20. Motshumi J. Diphare, Edison Muzenda, Tsietsi J. Pilusa and Mansoor Mollagee (2013) processing of used lubricating oils 2nd International Conference on Environment, Agriculture and Food Sciences (ICEAFS'2013) pp 106 – 109.
21. S. Arnaout, "Options for Vehicle Waste Oil Management in Lebanon," Beirut, Lebanon: Transtec Fitchner Consortium, Ministry of Environment, 1997.
22. M. Shakirullah, I. Ahmad, M. Saeed et al., "Environmentally friendly recovery and characterization of oil from used engine lubricants," *Journal of the Chinese Chemical Society*, vol. 53, no. 2, pp. 335–342, 2006.
23. J. L. A. Filho, L. G. M. Moura, and A. C. S. Ramos, "Liquid-liquid extraction and adsorption on solid surfaces applied to used lubricant oils recovery," *Brazilian Journal of Chemical Engineering*, vol. 27, no. 4, pp. 687–697, 2010
24. F. O. Cotton, "Waste lubricating oil: an annotated review," REVISION DEB3001439 of Annotated Review 1997 BETC/IC 79/4, CORP; Source- Department of Energy, Bartlesville, Okla, USA, 1997.
25. A. Hamad, E. Al-Zubaidy, and M. E. Fayed, "Used lubricating oil recycling using hydrocarbon solvents," *Journal of Environmental Management*, vol. 74, no. 2, pp. 153–159, 2005
26. M. k. Jha, "Re-refining of used lube oils: an intelligent and eco-friendly option," *Indian Chemical Engineering*, vol. 473, pp. 209–211, 2005.
27. R. R. F. Kinghorn, *An Introduction to the Physics and Chemistry of Petroleum*, John Wiley

- & Sons, New York, NY, USA, 1983.
28. J. D. Udonne, "A comparative study of recycling of used lubrication Oils using Distillation, acid and activated charcoal with clay methods," *Journal of Petroleum and Gas Engineering*, vol. 2, no. 2, pp. 12–19, 2011.
 29. M. Scapin, "Recycling of used lubricating oils by Ionizing, linking hub," *Elservier.com/retrieval/pii/30969806X0700182X*, 2007.
 30. J. Rincon, "Regeneration of used lubricant oil by polar solvent extraction," *Industrial & Engineering Chemistry Research*, vol. 44, no. 12, pp. 4373–4379, 2005.
 31. S. Boyde, "Green Lubricants. Environmental benefits and impacts of lubrication," *Green Chemistry*, vol. 4, no. 4, pp. 293–307, 2002. Chevron Lubricating oil FM ISO 100.
 32. F. Awaja and D. Pavel, "Design aspects of used lubricating oil redefining," *Books.google.com.ng/books?isbn= 044452228X*, p. 114, 2006. (Accessed on May 03, 2024)
 33. <https://www.recyclingproductnews.com/article/25604/used-oil-recycling-good-for-the-environment-good-for-business.html> (accessed on 21 January 2025)
 34. R.R. Mohammed, Inaam A.R. Ibrahim, Alladdin H. Taha and Gordon McKay, 'Waste Lubricating Oil Treatment by Extraction and Adsorption', *Chemical Engineering Journal*, Vol. 220, pp. 343 – 351, 2013.
 35. R.R. Mohammed, Inaam A.R. Ibrahim, Alladdin H. Taha and Gordon McKay, 'Waste Lubricating Oil Treatment by Extraction and Adsorption', *Chemical Engineering Journal*, Vol. 220, pp. 343 – 351, 2013.
 36. F. Mohellebi, 'Analyse et Régénération des Huiles Usagées', Thèse de Doctoratd' Etat, Département Génie Chimique, Ecole Nationale Polytechnique, Octobre 2021.
 37. D.L. Bachelder, 'Recycling Used Engine Oil by Re-refining', California 2005 used oil/ HHW Conference, San Diego, California, USA, 2005.
 38. N. Umesi, 'Recycling Used Lubricating Oil of an Internal Combustion Engine', Technical Report, 1995.
 39. J. Lukic, A. Orlovic, M. Spiteller, J. Lovanovic and D. Skala, 'Re-Refining of Waste Mineral Insulating Oil by Extraction with n-Methyl-2-Pyrrolidone', *Separation and Purification Technology*, Vol. 51, N°2, pp. 150 – 156, 2006.
 40. http://www.mem-algeria.org/fr/legis/envir_decret_06-170.htm [8] F. Audibert, 'Les Huiles

- Usagées: Re-raffinage et Valorisation Energétique’, 2003. (Accessed on February 03, 2025)
41. Don M. Pirro; Martin Webster; Ekkehard Daschner (2016). *Lubrication Fundamentals* (Third Edition, Revised and Expanded ed.). CRC Press. ISBN 978-1-4987-5290-9. (print) ISBN 978-1-4987-5291-6 (eBook)
 42. Spikes, H. (2004-10-01). "The History and Mechanisms of ZDDP". *Tribology Letters*. 17(3): 469–489. doi:10.1023/B:TRIL.0000044495.26882.b5. ISSN 1023-8883.
 43. *Guide to ASTM Test Methods for the Analysis of Petroleum Products and Lubricants-2nd Edition*; R. A. Kishore Nadkarni; ASTM Stock No. MNL44–2nd
 44. Spikes, Hugh (2015-10-01). "Friction Modifier Additives". *Tribology Letters*. 60 (1): 5. doi:10.1007/s11249-015-0589-z. hdl:10044/1/25879. ISSN 1023-8883.
 45. Bartels, Thorsten; Bock, Wolfgang; Braun, Jürgen; Busch, Christian; Buss, Wolfgang; Dresel, Wilfried; Freiler, Carmen; Harperscheid, Manfred; Heckler, Rolf-Peter; Hörner, Dietrich; Kubicki, Franz; Lingg, Georg; Losch, Achim; Luther, Rolf; Mang, Theo; Noll, Siegfried; Omeis, Jürgen (2003). "Lubricants and Lubrication". *Ullmann's Encyclopedia of Industrial Chemistry*.
 46. *Proceedings ‘Regional Workshop on Re-refining Waste Oil Technology’*, Organisation UNIDO, Caire, 25 - 28 Janvier, 1993.
 47. Donnet, C.; Erdemir, A. (2004). "Historical developments and new trends in tribological and solid lubricant coatings". *Surface and Coatings Technology*. 180-181: 76–84. doi:10.1016/j.surfcoat.2003.10.022.
 48. Nalam, Prathima C.; Clasohm, Jarred N.; Mashaghi, Alireza; Spencer, Nicholas D. (2010). "Macrotribological Studies of Poly(L-lysine)-graft-Poly(ethylene glycol) in Aqueous Glycerol Mixtures". *Tribology Letters*. 37 (3): 541–552. doi:10.1007/s11249-009-9549-9.
 49. Salimon, Jumat; Salih, Nadia; Yousif, Emad (2010). "Biolubricants: raw materials, chemical modifications and environmental benefits". *European Journal of Lipid Science and Technology*. 112: 519–530. doi:10.1002/ejlt.200900205.
 50. Sessions, Ron (1985). *The Turbo Hydra-Matic 350 Handbook*. 20. ISBN 9780895860514.
 51. National Non-Food Crops Centre. NNFCC Conference Poster. Improved winter rape varieties for biolubricants
 52. "Powder-free Anti-tack Processing Aids For Rubber Parts and Materials". McLube Release Agents & Lubricants. Retrieved 2018-03-12.

53. Williams Crouse & Donald L. Angling , Automotive Mechanics, Tenth edition, 2007, Tata McGraw-Hill, New York, ISBN-10:0-07-0634351.
54. Francois Audibert, Waste Engine Oils Re-refining & Energy Recovery, October 2006, Elsevier science & technology books, ISBN: 0444522026
55. Firas Awaza & Dumitru Pawel, Design Aspects of Lubricating Oil Re-refining, First edition 2006, Elsevier science & technology books, ISBN-10: 0- 444-52228-X
56. M. V. Joshi & V.V. Mahajani Process Equipment Design , MacMillan India, third edition 1996, SBN 0333 92418 5
57. J. R. Backhurst and J. H. Harker, Process Plant Design, first edition 1973, Heinemann Educational Books Ltd, London
58. US Patent number US2006/0231378 , Thin Film Evaporator, by Glasl Wolfgang, Siebenhofer Matthaeus & Koncar Michael
59. Solvent extraction technology for used oil treatment, Published by ReTap, December 1995
60. Assessment of opportunities to increase the recovery and recycling of waste oil by D. J. Graziano and E. J. Daniels
61. US Patent number 4512878 ,Used Oil Re-refining, by Lioyd E. Reid, Keith C. Yao
62. Waste-oil-market-forecast2024-2030-n-akhila-8m5fc/ First edition 1973, Heinemann Educational Books Ltd, London
63. US Patent number 4941967 , Process for Re-refining Spent Lube Oil, by Leonardus M.M. Mannetje& Ashok S. Laghate
64. US department of energy, waste oil: technology, economics and environment, health and safety considerations, January 1987
65. Don M. Pirro; Martin Webster; Ekkehard Daschner (2016). Lubrication Fundamentals (Third Edition, Revised and Expanded ed.). CRC Press. ISBN 978-1-4987-5290-9. (print) ISBN 978-1-4987-5291-6 (eBook)
66. Cutler ET (2009). “Conserve Lube Oil: Re-refine” Hydrocarbon processing Vol.265, March.
67. Spikes, H. (1 October 2004). "The History and Mechanisms of ZDDP". Tribology Letters. 17 (3): 469–489. doi:10.1023/B:TRIL.0000044495.26882.b5. ISSN 1023-8883. S2CID 7163944.
68. Concawe (1985). “The collection, Disposal and Regeneration of waste oil and related

- Materials. Concawe Report”. No. 85/53.
69. World petroleum Congress, Moscow, p. 112. Whisman ML, Reynolds JW, Goetzinger JE, Cotton FO (1978). “Re- refining Makes quality Oils”. *Hydrocarbon Process.*, pp. 141-145
 70. Asseff PA (1961). “Lubricating Oil Additive, Description and Utilization, Lubricol Corp, Wickliff, Ohio, pp. 140-142
 71. Scapin MA (2007). Recycling of used lubricating oils by ionizing, linking hub, elservier.com/retrieval/pii/30969806X0700182X
 72. Machinery Lubrication /Read/31107/Oil-Lubricant-Additives (accessed on March 04, 2025)
 73. Firas A, Dumitru P (2006). Design aspects of used lubricating oil re- refining, books.google.com.ng/books?isbn=044452228X, p. 114.
 74. Bromilow LG (1990). “Supply and Demand of Lube Oil: An update of the Global Perspective”. Am 20 – 27 Presented at the 1990 NPRA Annual meeting.
 75. Spikes, Hugh (1 October 2015). "Friction Modifier Additives" (PDF). *Tribology Letters*. 60 (1): 5. doi:10.1007/s11249-015-0589-z. hdl:10044/1/25879. ISSN 1023-8883. S2CID 137884697.
 76. Donnet, C.; Erdemir, A. (2004). "Historical developments and new trends in tribological and solid lubricant coatings". *Surface and Coatings Technology*. 180–181: 76–84. doi:10.1016/j.surfcoat.2003.10.022.
 77. Mortier RM, Orszulik ST (1994). “Chemistry and technology of lubricant VCH publishers, Inc. New York, pp. 108-112
 78. Nalam, Prathima C.; Clasohm, Jarred N.; Mashaghi, Alireza; Spencer, Nicholas D. (2010). "Macrotribological Studies of Poly(L-lysine)-graft-Poly(ethylene glycol) in Aqueous Glycerol Mixtures" (PDF). *Tribology Letters*. 37 (3): 541–552. doi:10.1007/s11249-009-9549-9. hdl:20.500.11850/17055. S2CID 109928127.
 79. Georgel WC, La TGG (1977). “Extended Engine Oil Life Through New Technology”, Seminar paper at the National Petroleum Refiners Association 1977 Annual meeting, Mar 27 – 29, San Francisco, Carlifornia.
 80. National Non-Food Crops Centre. NNECC Conference Poster. Improved winter rape varieties for biolubricants Archived 4 February 2015 at the Wayback Machine.
 81. Rincon J (2005). Regeneration of used lubricant oil by polar solvent extraction, pubs.acs.org/doi/abs/10.1021/ie040254.

82. Bennet AY (1960) "An Engine Test for predicting the performance of engine Lubricants".
83. Hamad A (2005). Used lubricating oil recycling using hydrocarbon solvents, linking hub. Elsevier.com/pii/S01479704.
84. Cooke VB (1982) "The Role of Additive in the Automobile Industry, ASLE.
85. Don M. Pirro; Martin Webster; Ekkehard Daschner (2016). Lubrication Fundamentals (Third Edition, Revised and Expanded ed.). CRC Press. ISBN 978-1-4987-5290-9. (print) ISBN 978-1-4987-5291-6 (eBook)
86. Coyler CC (2000). "Gasoline Engine Oils: Performance, Evaluation and Classification", 10th
87. Spikes, H. (1 October 2004). "The History and Mechanisms of ZDDP". Tribology Letters. 17 (3): 469–489. doi:10.1023/B:TRIL.0000044495.26882.b5. ISSN 1023-8883. S2CID 7163944.
88. Iarc (1984) Iarc Monographs "Risk of chemicals to humans", vol 33, IARC, Lyon, France.
89. Gergel WC, La TGG (1977). "Extended Engine oil Life through New technology", Seminar paper at the National Petroleum Refiners Association 1977 Annual meeting, March 27 – 29, San Francisco, California.
90. Spikes, Hugh (1 October 2015). "Friction Modifier Additives" (PDF). Tribology Letters. 60 (1): 5. doi:10.1007/s11249-015-0589-z. hdl:10044/1/25879. ISSN 1023-8883. S2CID 137884697.
91. Donnet, C.; Erdemir, A. (2004). "Historical developments and new trends in tribological and solid lubricant coatings". Surface and Coatings Technology. 180–181: 76–84. doi:10.1016/j.surfcoat.2003.10.022.
92. Nalam, Prathima C.; Clasohm, Jarred N.; Mashaghi, Alireza; Spencer, Nicholas D. (2010). "Macrotribological Studies of Poly(L-lysine)-graft-Poly(ethylene glycol) in Aqueous Glycerol Mixtures" (PDF). Tribology Letters. 37 (3): 541–552. doi:10.1007/s11249-009-9549-9. hdl:20.500.11850/17055. S2CID 109928127.
93. Thrash LA (1991). "Annual Refinishing Survey: Oil and Gas J. (March 18), p. 84.
94. NORIA COMPANY, 2008: Lubrication and Oil Analysis Dictionary, <http://www.noria.com/dictionary/>.
95. ASTM STANDARD, 2005: Standard Test Method for Low Temperature, Low Shear Rate, Viscosity/Temperature Dependence of Lubricating Oils Using a Temperature Scanning

- Technique, ASTM International, West Conshohocken, PA, 2005, DOI: 10.1520/D513305, www.astm.org.
96. STEWART, R. M., 1977: The Relationship Between Oil Viscosity and Engine Performance A Literature Search. The Joint SAE ASTM Symposium on The Relationship of Engine Oil Viscosity to Engine Performance, Detroit, February 28 March 4, pp 524.
 97. National Non-Food Crops Centre. NNFCC Conference Poster. Improved winter rape varieties for biolubricants Archived 4 February 2015 at the Wayback Machine.
 98. Abdalla, N., Fehrenbach, H., Ecological and energetic assessment of re-refining waste oils to base oils, Heidelberg, June 2017;
 99. FRISO, D. and BOLCATO, F., 2004: Rheological properties of some newtonian food liquids. *Rivista di Ingegneria Agraria* 2, 7580.
 100. Ahamad, M. T., ChadraSekhar, B. P., Mohan, P. N., Joshi, K. S., Sree, T. D. R., Recycling and Analysis of Spent Engine Oil, *International Journal of Scientific & Engineering Research*, Volume 6, Issue 11, pag. 711-715, November-2015;
 101. MANN, D., 2007: Motor Oils and Engine Lubrication. Motor Oil Engineers, L. L. C., Detroit. MARCOTTE, M., TAHERIAN, A. R., TRIGUI, M.,
 102. FITCH, E. C., 2002: Temperature Stability. *Machinery Lubrication Magazine* 3, 3539.
 103. Contributed papers and technical reports: C. Kajdas. Modern waste oil recycling technologies. An overview. Plock, Poland
 104. Akilimali, F. C., Feasibility study of recycling used lubricating oil, University of Dodoma, July 2017;
 105. Akpomie, K. G., Dawodu, F. A., Potential of a low-cost bentonite for heavy metal abstraction atom binary component system, *Beni-Suef University Journal of Basic and Applied Sciences*, Volume 4, Issue 1, pag. 1-13, March 2015;
 106. Rincon, J., P. Canizares, and M.T. Garcia, Regeneration of used lubricant oil by ethane extraction. *The Journal of supercritical fluids*, 39 (3): p. 315-322.
 107. Asim Das., A comparative study of recycling of used lubrication oils using distillation, acid and activated charcoal with clay methods. *Journal of Petroleum and Gas Engineering*, 2011. 2 (2): p. 12-19.
 108. Andrews, L., *Compendium of Recycling and Destruction Technologies for Waste Oils*, United Nations Environment Programme, 2008;

109. Boadu, K. O., Joel, O. F., Essumang, D. K., & Evbuomwan, B. O., A Review of Methods for Removal of Contaminants in Used Lubricating Oil, *Chemical Science International Journal*, 26(4), pag. 1-11, 2019;
110. Fuentes, M., et al., Pyrolysis and combustion of waste lubricant oil from diesel cars: decomposition and pollutants. *Journal of Analytical and Applied Pyrolysis*, 2007. **79**(1): p. 215-226.
111. Emam, E. and A. Shoaib, Re-Refining of Used Lube Oil, I-by Solvent Extraction and Vacuum Distillation Followed By Hydrotreating. *Petroleum & Coal*, 2013. **55**(3): p. 179-187.
112. Diphare, M. J., Muzenda, E., Pilusa, J., Mollagee, M., A Comparison of Waste Lubricating Oil Treatment Techniques, 2nd International Conference on Environment, Agriculture and Food Sciences (ICEAFS'2013), August 25-26, Kuala Lumpur, Malaysia, pag. 106-109, 2013;
113. Hegazi, S. E. F., Mohamd, Y. A., Hassan, M. I., Recycling of Waste Engine Oils Using Different Acids as Washing Agents, *International Journal of Oil, Gas and Coal Engineering*. Vol. 5, No. 5, pag. 69-74, 2017;
114. Henry, M., Re-refining and recycling of used lubricating oil and natural resource conservation in Ghana, *ARPN Journal of Engineering and Applied Sciences*, vol. 10, pag. 797-801, 2015;
115. Lam, S. S., Russell, A. D., Chase, H. A., Pyrolysis Using Microwave Heating: A Sustainable Process for Recycling Used Car Engine Oil, *Ind. Eng. Chem. Res.*, pag. 10845-10851, 2010;
116. Ogbeide, S. O., An Investigation To the Recycling Of Spent Engine Oil, *Journal of Engineering Science and Technology Review* 3 (1), pag. 32-35, 2010;
117. Bhaskar, T., et al., Recycling of waste lubricant oil into chemical feedstock or fuel oil over supported iron oxide catalysts. *Fuel*, 2004. **83**(1): p. 9-15.
118. Hamad, A., E. Al-Zubaidy, and M.E. Fayed, Used lubricating oil recycling using hydrocarbon solvents. *Journal of environmental management*, 2005. **74**(2): p. 153-159.
119. Osman, D. I., Aia, S. I., Taman, A. R., Recycling of used engine oil by different solvent, *Egyptian Journal of Petroleum* 27, pag. 221-225, 2018;
120. Rincon, J., Canizares, P., Waste oil recycling using mixtures of polar solvents, *Ind. Eng.*

- Chem. Res., pag. 7854-7859, 2005;
121. Siddiqui, T. F., Environmental pollution in petroleum refineries, Bahria University Karachi, 2015;
 122. Regional Activity Centre for Cleaner Production (C/CP) Mediterranean Action Plan, Possibilities for the recycling and reuse of used oils, 2000;
 123. PurePath Green Technology, [\(https://www.purepathtech.com/literatures/recycling-of-used-motor-oil/Citations \(5\)\)](https://www.purepathtech.com/literatures/recycling-of-used-motor-oil/Citations%20(5)) (accessed on January 24, 2025)

20%

SIMILARITY INDEX

16%

INTERNET SOURCES

9%

PUBLICATIONS

6%

STUDENT PAPERS

PRIMARY SOURCES

1	wwwfuchscom-94ba.kxcdn.com Internet Source	1 %
2	hcu.portal.gov.bd Internet Source	1 %
3	www.researchgate.net Internet Source	1 %
4	lubricants.repsol.com Internet Source	1 %
5	docplayer.net Internet Source	1 %
6	matyoc.com Internet Source	1 %
7	www.ijser.org Internet Source	<1 %
8	index-lubricants.repsol.com Internet Source	<1 %
9	www.makinalube.ae Internet Source	<1 %
10	www.tribonet.org Internet Source	<1 %
11	www.kuwaitdanalubes.com Internet Source	<1 %
12	www.deckmanoil.com Internet Source	<1 %