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Sustainable Recycling of Vehicle Lubricant and Engine Oils for Environmental Protection

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ABSTRACT

The rapid expansion of the global automotive industry has led to increased consumption of vehicle lubricant and engine oils, generating significant quantities of used lubricant oils (ULOs) annually. In many developing countries, improper disposal practice, such as dumping used oils into the sewage system pose severe environmental and public health threats, including water pollution and carcinogenic risks. This study explores a sustainable approach to managing and recycling ULOs within a circular economy framework. It highlights environmentally responsible technologies that enable the transformation of waste oils into valuable products such as re-refined lubricant oils, diesel-like fuels, light gases, and asphalt-like residues. By diverting hazardous waste from landfills and waterways, this recycling process not only reduces ecological damage but also supports resource efficiency and energy recovery. With the advancement of catalytic, thermal, and solvent-based methods, and support from environmental policies, nations can turn hazardous waste into economic opportunity. This contributes directly to the UN Sustainable Development Goals (SDGs) in environmental protection, industrial innovation, and public health.

1. Introduction

Used lubricant oils (ULOs), a byproduct of vehicle and industrial engine operation, represent a hazardous waste stream with serious implications for environmental sustainability and human health. As global vehicle usage rises, so does the demand for lubricant oils, resulting in millions of liters of ULOs generated each year. In many low- and middle-income countries, poor waste handling infrastructure and lack of environmental regulation lead to improper disposal, including illegal dumping and release into sewage systems. These practices contribute to soil and water contamination and introduce toxins into the food chain. Addressing this issue requires innovative solutions that promote recycling and reuse within a sustainable development framework. As can be noted that traffic mobility and electrical machines can produce a huge traffic externality problem such as pollution and missions [1,2]. However, the motivation to own and use a car is becoming

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increasingly important for many commuters [3], which in turn leads to a growing production of waste oil. Fortunately, nearly 30 years ago this project was established in a few countries. For instance, in the Middle East this project can be found in Qatar, UAE, Iran and in Iraq you can find this project in Kurdistan which is located in the North of Iraq. It is same as in Qatar, and UAE which is located in Sulaimani city in Tanjero area relating to the Asia oil group established in 2016.

An interesting aspect of this project is that it yields a variety of valuable products from waste oil, such as gasoil, lubricating oils (types 300 and 350), and residual oils. Unlike traditional refineries that depend on crude oil and often wait for government allocations, this refinery utilizes used oil considered waste to produce new, useful oil products. Notably, while many oil industry projects tend to harm the environment, this initiative contributes positively by promoting cleaner and more sustainable practices. However, there are several challenges commonly faced in developing countries, as outlined in [4]:

I. Lack of public awareness
II. Informal collection systems
III. Poor enforcement of environmental regulations
IV. High investment cost for modern recycling technologies

Addressing these challenges requires strong policy frameworks, public-private partnerships, and investment in technological infrastructure. The following figure (1) shows the rate of Global lubricating oil demand by region.

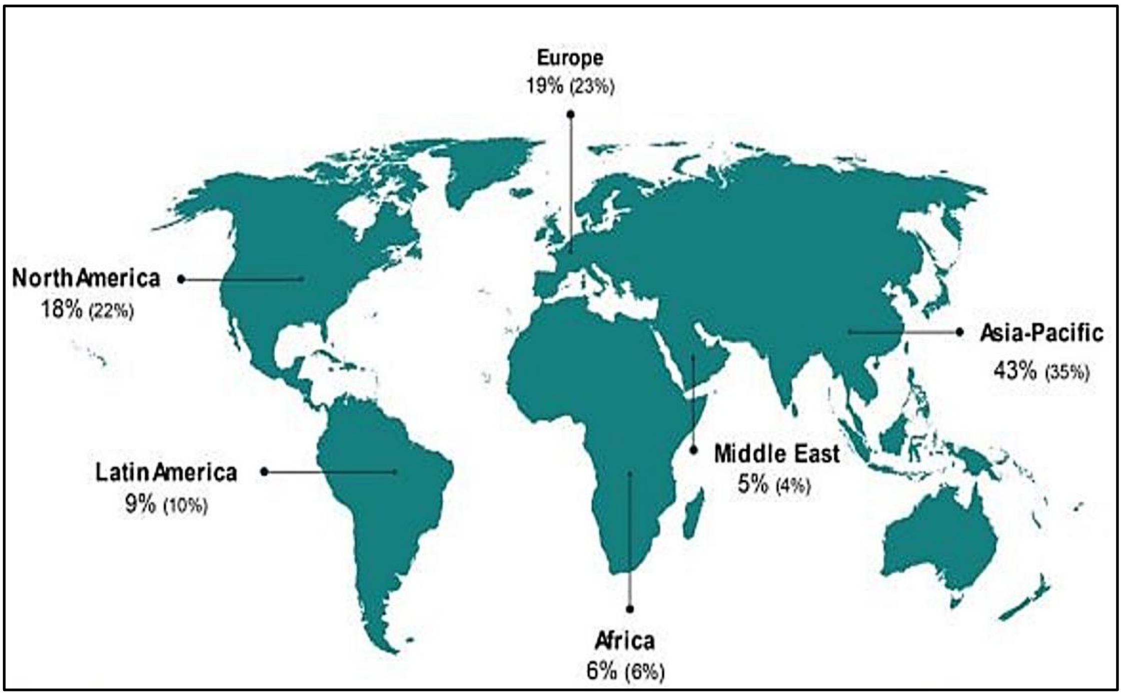

Fig. 1. Global lubricating oil demand by region [5]

According to the literature review the global trends in used oil recycling only 27 % of the sum volume of used lubricating oil, which is rough at 3.8 billion gallons, underwent recycling for the specific objective of generating base oil during the calendar year 2017. In 2016, the Middle East region attained the greatest level of base stock production from WLO, constituting 16 % of the overall output. In the European Union and the United States of America, about 13 % and 12 % of the total base stocks, respectively, are derived from processed used lubricating oil. It is crucial to highlight that the proportion is notably lower for other geographical areas globally [4].

To be specific, the Asia-Pacific region succeeded in generating only 5 % of its base stocks from reprocessed and used lubricating oil, while Latin America and Africa complete 9 % and 1 %, Respectively.

The role of used oil recycling in reducing environmental pollution, from a global perspective a responsible management that is needed for the proper use of residual motor oils, which are a highly polluting material, since they able cause harm to the environment when they are dumped on the ground or in water currents including sewers. As a result, the contamination of groundwater and soil occurs.

The used lubricating oil contains several chemical compounds such as heavy metals, (for example, chromium, cadmium, arsenic, lead, among others), polynuclear aromatic hydrocarbons, benzene and sometimes chlorinated solvents, PCBS, etc. These chemical compounds have a direct effect on human health and several of these products are carcinogenic. A universal concern is the supply of water; used lubricating oils penetrate the ground and automatically contaminate surface and ground water. When they are eliminated in city sewage systems, they end up in wastewater treatment plants, however, presently, because there are very few of these plants in world, the huge majority of these oils end up in the environment and in the surface water, which means most of the plant are environmentally friendly. The distribution for this kind of plants are not more around the global but it is increased decades, if you look back for the figure 1 you see global distribution of the refineries around the world [6, 7].

According to the European List of waste (LoW), which intends to give harmonization of waste classification in the EU, all WLO are absolute hazardous entries in the list. Hence regardless of its composition and/or source, WLO, exhibit at least one hazardous property (HP) listed in the Commission Regulation. The HP may be due to metals, chlorine, PCB, or even polychlorinated terphenyls (PCT) and polybrominated biphenyls (PBB). In addition, unburned fuel and by-products from fuel combustion may cause the accumulation of compounds such as PAH. These compounds consisting of multiple rings such as benzo[a]pyrene are classified as carcinogenic to humans by the International Agency for Research on Cancer [8].

Since lubricant oils are usually toxic and not readily biodegradable, the indiscriminate disposal of WLO into the environment may create serious problems posing a high risk of damage to the soil, water, and air.

The classification of the biodegradability and microbial toxicity of lubricants has been a request to meet the criteria of ecolabelling schemes target at environmental protection. Although it is not an easy procedure, there are some approaches to evaluate biodegradability in different conditions, namely aerobic, anaerobic, freshwater and marine ambient [9].

Stringent regulations on the use, handling, and disposal of these substances are obligatory by various government regulators to alleviate the potential danger to the environment. Nevertheless, referable to the difficulty to mitigate spills and discharges of lubricants, mainly mineral-based oils, the United States Environmental Protection Agency (EPA) introduced a new class of raw materials to create lubricants. These are named environmentally acceptable (EA) materials, which are not toxic and biodegradable, unlike mineral-based oils [10]. The three most common classification of biodegradable base oils that constitute an EA are from renewable resources: vegetable oils, synthetic esters, and polyalkylimide glycols. The aquatic toxicity exhibited by lubricants formulated from EA com'pents is low when compared to mineral oil. Therefore, recycling of vehicle lubricants, review of benefits and sustainability factor is essential.

Presently, sustainability rules are widely accepted as having an important influence on the sector. Hence, the protection of energy, resources, and the reduction of emissions have become essential priorities. Additionally, there is growing public interest in lubricant production and recovery due to their potential to promote resource conservation and sustainable development [11]. The European Union's present goals of progressing towards a circular economy are crucial for promoting a sustainable, resource-efficient, and competitor economy that functions within the planet's limits [12].

The round economy is based on the notion of prolonging the lifetime of resources and production by keeping them within the system rather than disposing of them. The Waste Frame work Directive (WFD) intent to decrease waste production by following the waste hierarchy, which emphasizes waste avoidance as the most successful plan of action, followed by reuse, recycling, and other recovery methods. In addition, depicts the circular economy model about lubricating oil. The discourse includes multiple facets of economic activity, beginning with the formulation of lubricating oil and progressing to the refining of crude oil for base oil extraction, the product of novel lubricants, consumption trends, the generation of WLO, and the ensuing collection and recycling of WLO. The objective is to decrease disposal, which has detrimental effects, ideally achieving zero waste. Processing suitable metrics for the circular economy and the management of waste lubricating oil is essential. Regeneration is crucial in the circular economy of WLO, highlighting the of importance recycling and resource reuse [13]. Thus, to address the above problems, this research aims to recycle waste oils and get a lot of money without spending much money for the waste oils. There are four main benefits form this recycling of waste oil which are:

1- 3 to 4 products from useless oils.
2- Can easily get waste oils in the market, it is not like (crude oil).
3- Cost of waste oil per litter is very low.
4- Environmentally friendly.

The rest of the paper contain methodology section and the procedure of the recycling, after that the conclusion and recommendations.

2. Methodology

3.1 Case study

A case study focusses on a particular industry, such as automotive, and compare the environmental and economic profit of various recycling methods. For instance, the Asia oil Company which is located in Sulaymaniyah city -Kurdistan/ Iraq, an examination could compare the costs and environmental impacts of re-refining ULO using acid-clay treatment versus a solvent extraction method. The research may also analyze the carrying out of re-refined oil in cars compared to new lubricating oil. Figure 2, illustrates the case study location.

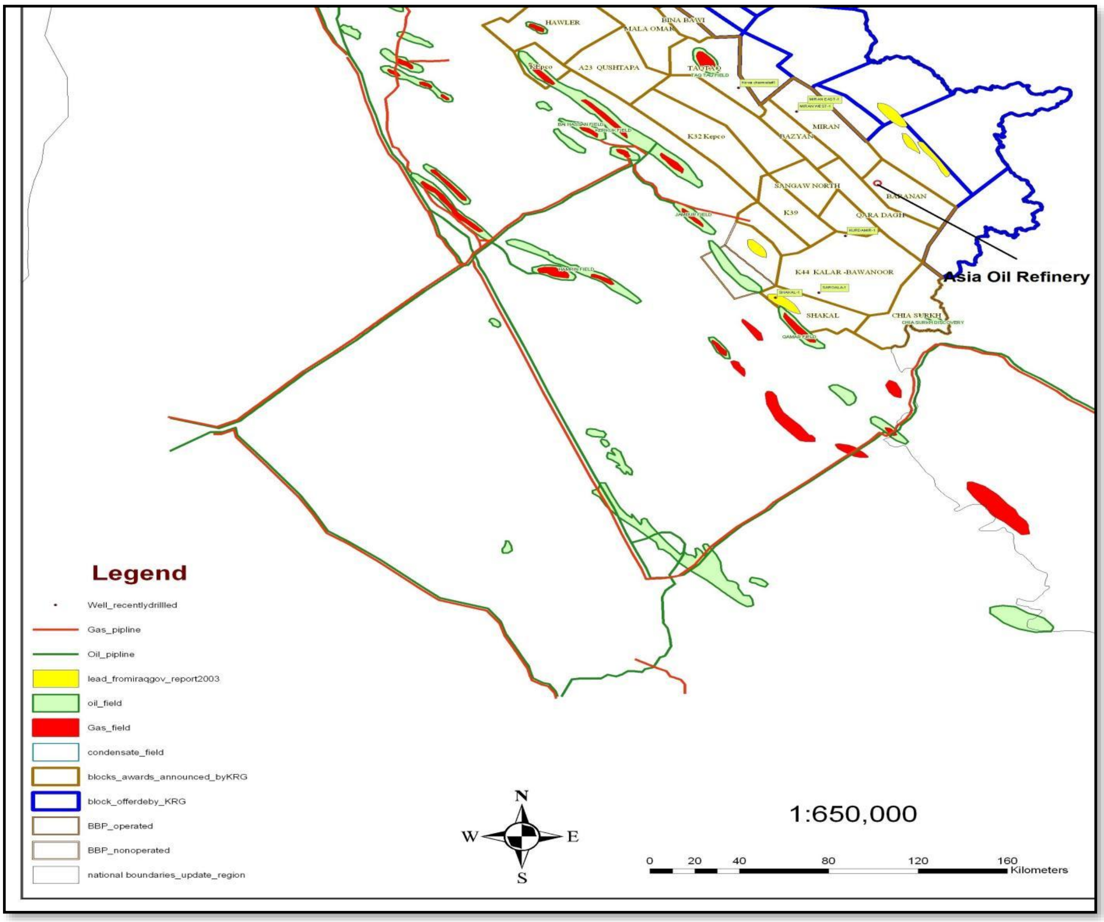

Fig. 2. Asia oil refinery Sulaymaniyah-Iraq

Key Considerations for Recycling:

a. Economic Benefits
b. Technical Feasibility
c. Environmental Impact

3.2 Produce of the refinery

First, Waste oils are collected from the market and placed in specific tanks; after that, they are sent to the refinery. From the refinery, the waste oil is heated to 400°C, where it is separated into three to four products, and some additives or polymers are added.

the products include Gasoil, residual oil and important products are lubricating oil 300 and 350 used for vehicle engines. Figure 3 displays the typical re-refining process [14].

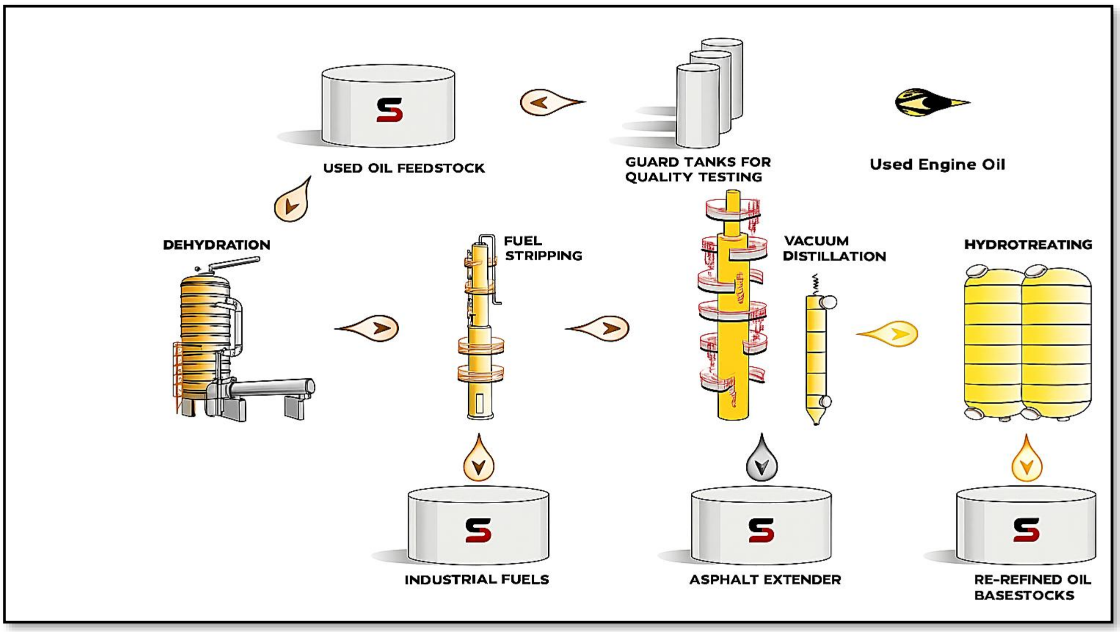

Fig. 3. shows the process clearly

Figure 4 illustrates the sample of the product. The black color is used lubricate oils (ULO) and the yellow color is the new lubricate oil which can be used as a new oil for engine.

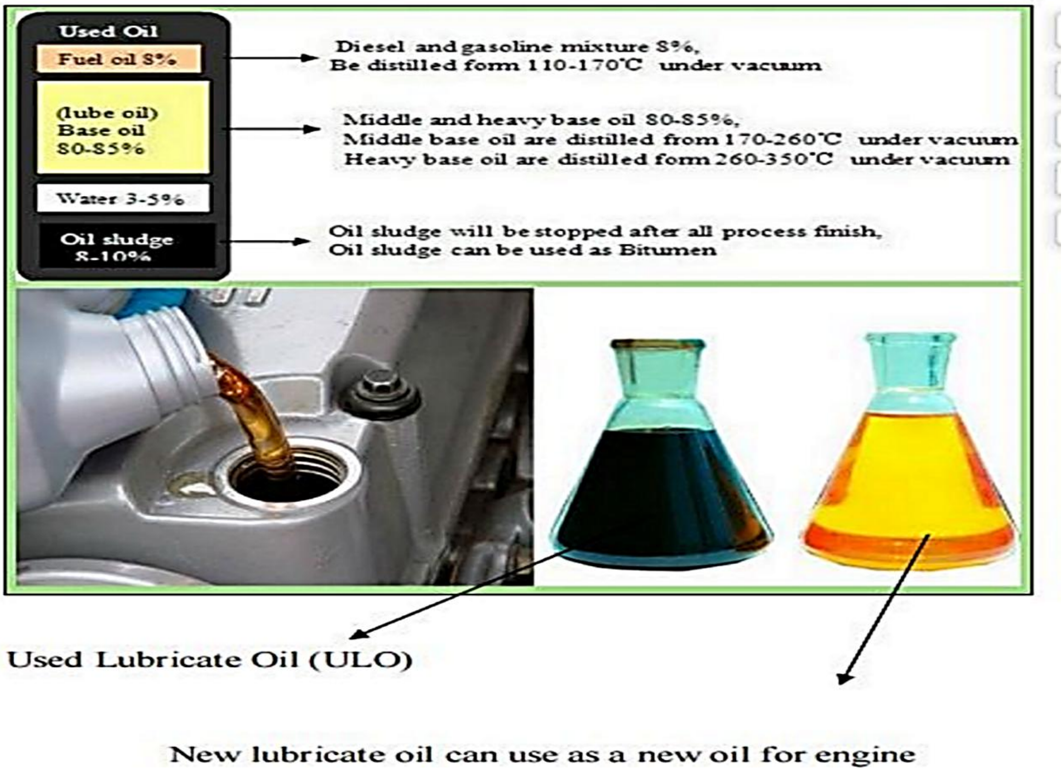

Fig. 4. One of the samples of product

3.3 Procedure of Project

The project comprises two main components: the refinery unit and the utility station. In the refinery section, all essential equipment required for product separation is installed, similar to a conventional base oil refinery. This includes a reboiler, decanter, condenser, vacuum system, and a Thermae Wiped-Film Evaporator (TWFE). The process begins by feeding Used Lubricating Oil (ULO) into the system, where it undergoes a chemical treatment at high temperatures and pressures. This results in the separation of several products, including asphalt, gasoline, small amounts of water, residue, and lubricating oils such as SN 150, SN 300, and SN 500. In the final stage of the process, additives such as polymers and hydrochloric acid (HCl) powder are incorporated to enhance product quality.

The utility station consists of two main parts: the boiler unit and the cooling tower. The boiler, powered by gasoline, heats thermic oil, which in turn transfers heat to the refinery as required during the process. The boiler can reach temperatures of up to 350–400°C. The cooling tower system supplies chilled water to the refinery via one pipeline, while another line returns used water to be cooled and recirculated. As part of paper future vision, it is aim to establish a state-of-the-art refinery dedicated to reducing waste oils and contributing to a cleaner, more environmentally friendly Iraq. Although such projects require significant investment, ULO in my country is inexpensive and readily available due to its classification as waste. This presents an excellent opportunity to not only clean the environment especially in oil-producing countries but also generate substantial revenue by converting waste materials into high-value products [15]. In addition to this, development of a circular economy by creates employment opportunities, and promotes ongoing research into the effective reuse of waste oil [16, 17]. Figure 5 shows the process of recycling used oil into useful products. Used oil is chemically treated and distilled to produce diesel, light and heavy base oils. These are then filtered, blended, and stored. Sludge by-products are cooled and collected separately.

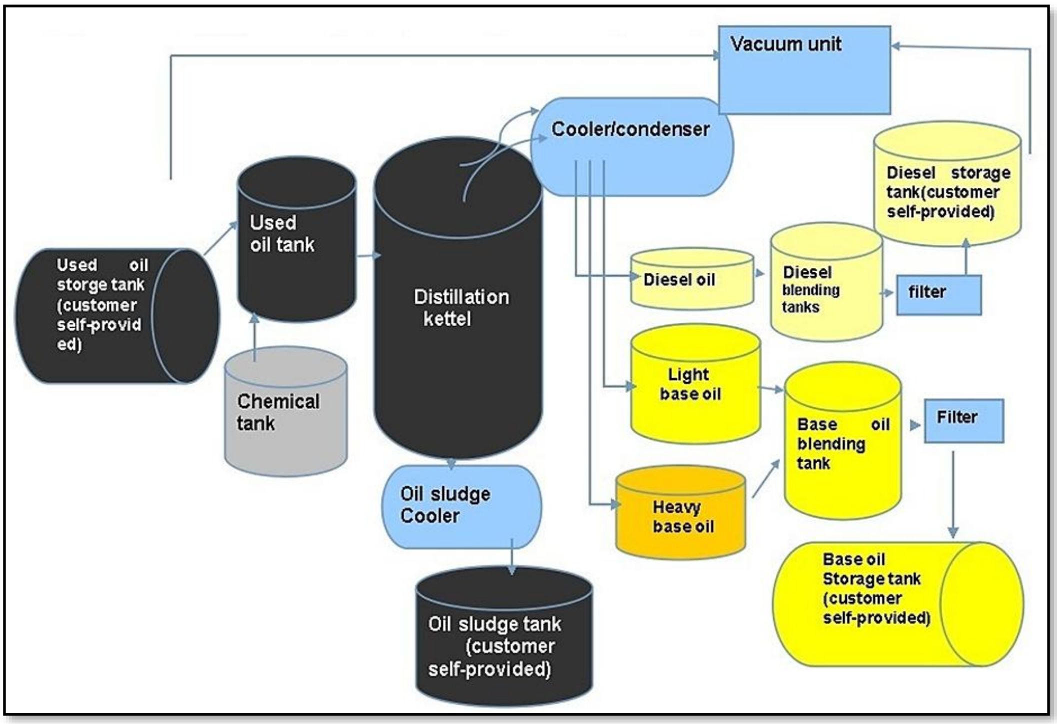

Fig. 5. Producing many compounds from used oils

3.4 Technically working of the project

There are two types of projects dealing with this recycling:

1. Heating way: this type is very basic and useful, they bring the ULO for heating and cooling. After that, acid and polymers are added to obtain new lubricating oils, specifically lubricating oil 300 and 350, along with some Naphtha. The cost for this type is about 10000 dollars which is very cheap to establish a big project like this. The figure 5 shows the map for this type [18].

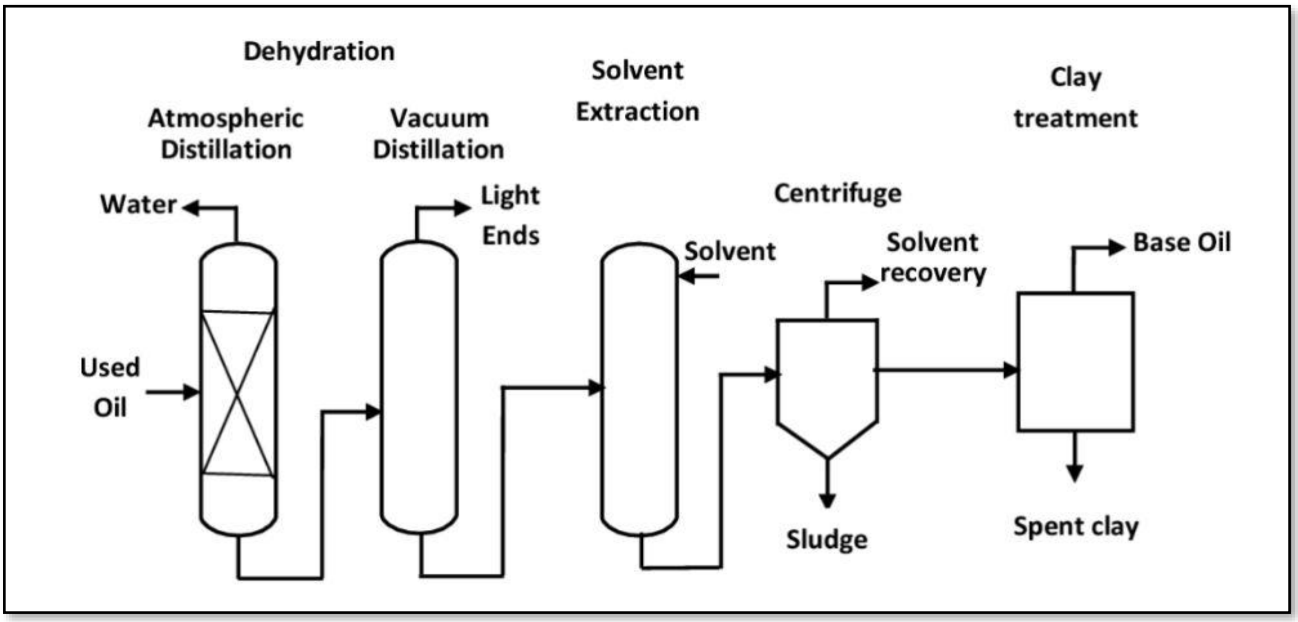

Fig. 6. Basic equipment's using in type

2. Refinery project: This is a complex and capital-intensive project, with an estimated cost of around one million dollars. It produces a wide range of outputs, including gasoil, lubricating oils (300 and 350 grades), residual oils, naphtha, and some water [19]. The project also emphasizes the use of advanced methods and technologies for recycling lubricating oil to support sustainable reuse [20].

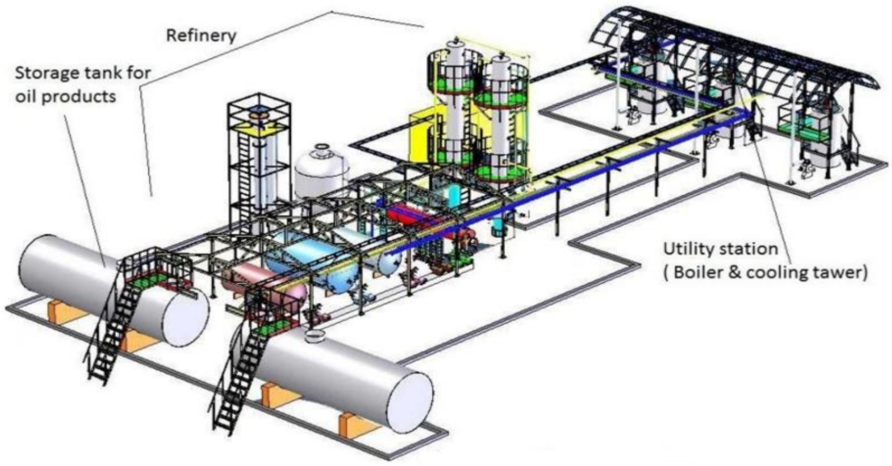

Fig. 7. The refinery machine

4. Productions after refinery process

One barrel of ULO is purchased for $25, and the processing is completed within 48 hours, yielding the following products:

- ✓ 70% lubricate oil 300 & 350
- ✓ 15% residual
- ✓ 10% gasoline
- ✓ 3% water
- ✓ 2% loses

Note; all prices mentioned in dollars, they converted from the country of Iraqi Dinar to USD. One barrel of lubricant oil in the market = 150$ and 75$ for the gasoline and residual.

- ◆ Selling the product in 5-liter bottles yields higher profit margins.

One barrel = 44 bottles 5 liters.

One bottle of lubricant oil = 6.5 $

44* 6.5= 286$

What is the cost for spending all process?

- ❖ 25$ for buy the ULO
- ❖ 20$ for adding the materials like polymers + acid
- ❖ 5$ for transportation ULO

Two shafts are required to operate continuously for 24 hours, resulting in a production output of 160 barrels per day. In addition, five employees are needed.

Total cost for one-barrel ULO:

25$ for ULO + 5$for transportation= 30$ + 20$ for adding the materials

Total income for one barrel recycle ULO

150$ for lubricant oils 7.5$ for gasoil and residual.

Total income for one bottle of lubricant oil = 6.5 $

44* 6.5= 286$.

Figure 8 shows the wasted oil and the new product with the percentages.

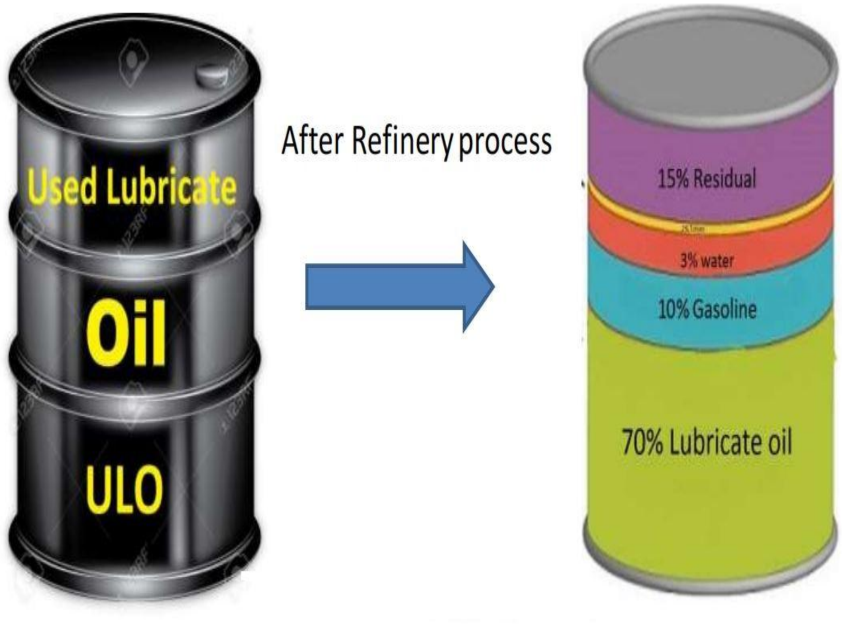

Fig. 8. The process from used oils to hydrocarbon products

4. Conclusions

This study highlights two key benefits. The foremost advantage is the recycling of used oils, which is crucial given their harmful environmental impact. Additionally, the process yields new lubricating oils along with three or more valuable by-products. The recovery of gasoline and other residual fuels from these otherwise waste oils is striking and underscores the importance of such projects for all countries with vehicles and lubricant oil consumption.

In markets this lubricate oil is at a high price and it is used every day for cars, electrical machines and mechanical machines in factories as well. Nowadays, big benefits come from those kinds of factories. For example, in UAE it is big business and in Iraq -Kurdistan/ Sulaymaniyah city Asia oil group exports a high number of lubricant oils to all cities in Iraq, Syria, Lebanon, Turkey and inside Kurdistan as well.

Recycling used lubricant vehicle and engine oils presents a double opportunity: to decrease environmental pollution and promote resource recovery. With the progress of catalytic, thermal, and solvent-based methods along with supportive environmental policies nations can change a hazardous waste into a sustainable resource.

4.1 Recommendations:

- Governments should establish legal frameworks that hold producers responsible for managing used oils.
- Priority must be given to investing in clean and efficient recycling technologies.
- Awareness campaigns should be launched to educate mechanics, vehicle owners, and recyclers about safe disposal and proper collection methods.
- International cooperation is essential to support developing countries through knowledge sharing and infrastructure development.

4.2 Future studies

Future research should explore machine learning (ML) to address the complexity of lubricant oil recycling. ML can improve yield prediction, process optimization, and quality control. Prior studies demonstrate its potential [21], and deep learning for high-accuracy classification [22]. From a planning perspective, future studies could also examine how urban and regional waste management systems can integrate systematic collection, monitoring, and recycling of vehicle oils. This includes designing efficient collection networks, setting up recycling hubs, and linking policies with industrial demand to ensure that used oils are captured and processed sustainably rather than discarded improperly. These approaches together could help predict recycled oil quality, optimize refinery operations, detect impurities in input oils, and support circular-economy planning. Applying ML and integrated planning would enhance efficiency, reduce environmental risks, and strengthen sustainable lubricant oil markets in regions such as Iraq and Kurdistan.

Author Contributions

For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, H.M. and K.I.; methodology, H.M.; validation, H.M., K.I.; formal analysis, H.M. and K.I.; investigation, K.I.; resources, H.M; data curation, H.M and K.I.; writing—original draft preparation, H.M.; writing—review and editing, H.M.; K.I. and R.A.; visualization, K.I supervision, R.A. project administration, R.A; funding acquisition. All authors have read and agreed to the published version of the manuscript." Authorship must be limited to those who have contributed substantially to the work reported.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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