



## Treatment and Recycling of Used Lubricating Oil in Nigeria: Solvent Extraction Approach

A.G. OLAREMU

<sup>1</sup>Department of Chemical Sciences, Adekunle Ajasin University, Akungba - Akoko

\*Corresponding author E-mail address: : [abimbola.olaremu@aua.edu.ng](mailto:abimbola.olaremu@aua.edu.ng)

### Abstract

#### Keywords:

Lubricants, recycling, heavy metals, zeolite, kaolinite, pour point, viscosityindex

*This study investigates the treatment of used lubricating oils sourced from an automobile mechanic's shop. Used lubricating oil, a by-product of machinery lubrication, poses environmental threats when improperly disposed of. Dumping such oil in landfills contributes to land and air pollution and can contaminate groundwater through percolation. Re-refining the used oil is proposed as a solution to mitigate these environmental concerns and offers economic advantages over producing lubricating oil from crude oil refining. The study focuses on re-refining using the solvent extraction method. This research employed two solvent mixtures: the first composed of Toluene, 1-butanol, and Methanol (TBM), and the second comprised Toluene, 1-butanol, and Ethanol (TBE). The initial treatment involved pretreating the used oil using a vacuum filter to eliminate solid impurities such as dust, soot, and metal fragments that may have contaminated the lubricating oil during use. The solvent extraction process commenced by introducing the TBM solvent mixture into the used engine oil at a 3:1 ratio, followed by stirring for 1 hour using a magnetic stirrer. The mixture was allowed to stand for 24 hours. The same procedure was repeated with a different sample using the TBE solvent mixture. The surface mixture containing the solvent and oil was decanted and transferred to a rotary evaporator to separate the oil from the solvent. The efficacy of both treatment methods was experimentally examined, considering various operating parameters such as different adsorbents, acids, and solvents used for treating the used oil. These parameters underwent thorough study and analysis. Quality assessment involved measuring and evaluating key characteristics, including viscosity, specific gravity, pour point, cloud point, metal content, and sulfur content. Upon comparing the results with the standards of fresh lubricating oil, both treatment methods demonstrated significant proficiency. The characteristics of the re-refined engine oil closely resembled those of fresh engine oil, in contrast to the untreated engine oil.*

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### INTRODUCTION

In any country, technology plays a pivotal role in driving development, but Nigeria encounters an ironic challenge. Despite being a crude oil-producing nation, it paradoxically imports petrochemicals and grapples with a tarnished safety reputation (Kulkarni, 2019). The production of base oil, a crucial component in the manufacturing of lubricating oil for vehicles and equipment, entails refining crude oil through a heating process that separates light and heavy hydrocarbons. However, as global non-renewable energy sources dwindle, there is a swift

rise in energy demand, posing a significant economic challenge for Nigeria (Opoku et al., 2019).

Lubricants serve to reduce wear, heat, and friction between mechanical components in contact. Engine oil, commonly known as motor oil, is a prevalent lubricant in automobiles (Sánchez-Alvarracín et al., 2021). The necessity for replacing used engine oil (UEO), contaminated over time with physical and chemical impurities, is crucial. Potential pollutants in UEO include metallic particles from engine wear, carbonaceous particles from incomplete fuel combustion, metallic oxides, water, fuel, fuel additives or by-products, sludge, lacquer, and oil-

soluble compounds. Improper disposal practices, such as dumping and uncontrolled burning of UEO, pose environmental risks due to the presence of lead, zinc, arsenic, chromium, cadmium, and sulfur. Managing waste oil is crucial, especially in transforming spent engine oil into a marketable commodity (Ikhajagbe & Ogwu, 2020; Majekodunmi et al., 2020).

Despite impurities, UEO contains a substantial amount of undepleted base oil. Re-refining is a process that involves treating UEO to eliminate impurities, including dust, moisture, combustion products, corrosion products, and metallic particles, to recover base oil for blending with additives to create new lubricants (Abro et al., 2013). Re-refining UEO reduces the potential environmental impact of waste oil and offers a practical and cost-effective alternative to waste oil incineration, contributing to pollution reduction and economic benefits (Nwachukwu et al., 2012).

Waste mineral oils resulting from used lubricating oils can negatively impact the environment and human health. Re-refining used lubricating oil is a valuable approach, decreasing hazardous waste generation and preserving crude oil reserves. Various techniques, including chemical and physical treatments, solvent extraction, and acid-activated processes, are available for re-refining used lubricating oil (Osman et al., 2018). Solvent extraction treatment has shown promising results, addressing shortcomings such as acid sludge generation, lower yield, and oil loss in sludge. Researchers have explored different solvents like 1-butanol, methyl ethyl ketone (MEK), and 2-propanol in studying the re-refining of used lubricating oil (Nour et al., 2021). The properties of re-refined oil, such as pour point, density, viscosity index, and total acid number, are crucial factors determining its suitability as a base oil.

### **Background of Used Oil**

Mismanagement of used oil can cause significant environmental damage, while properly managed used oil is a valuable resource for manufacturing lubricating base oils or other products like fuels (Collins et al., 2017). Leaked or improperly disposed used oil can enter water bodies, polluting them and harming aquatic life. Used oil in municipal water treatment systems can strain processes and lead to blockages. Used lubricating oil contains toxic heavy metals and polycyclic aromatic hydrocarbons (PAHs), posing health and environmental risks (Durrani, 2010).

Globally, lubricant oil consumption is on the rise, especially in developing countries undergoing modernization, leading to increased used oil generation (Jafari and Hassanpour, 2015). Proper management and sustainable recycling processes are crucial to reduce the health and environmental impacts of used oils (Giovanna et al., 2013). The

proper management of used oils involves collecting them from recognized points of generation and ensuring recycling. European countries have different laws and regulations for used oil collection, with the basic principle that generators are responsible for safe collection, storage, and removal of used oils (Giovanna et al., 2013). Two basic approaches to reusing used oil exist: burning it as fuel or re-refining to recover base oil (mineral or synthetic). In the early 2000s, over 80% of recycled used oil in the USA, EU, and Australia was burned, while less than 25% was re-refined (Collins et al., 2017). The choice depends on the contamination level of used oil, with 60 to 65% considered suitable for re-refining based on contamination and viscosity index. Challenges arise from dispersants in lubricating oils, synthetic oils, discarded biodegradable oils, and difficulties in the re-refining process. Recreating depleted additives (refortification) is an economic option but faces limitations with excessive water, additive degradation, oxidation particles, or other oils (Liu et al., 2013).

Lubricants are categorized into seven types, while used oils are classified as black oils, light oils, and lost oils. Black engine oils, or used engine lubricating oils (UELOs), account for over 65% of used oils and are a preferred feedstock due to homogeneity. The Environmental Protection Agency (EPA) distinguishes between "used oil" and "waste oil," as the latter includes more than used oil. Definitions vary, and this work seeks new methods and technologies for used engine lubricating oil, considering both medium to large scale and limited small-scale recycling options (Audibert, 2006; Giovanna et al., 2013; Jafari and Hassanpour, 2015; Nwachukwu et al., 2012).

## **MATERIALS AND METHOD**

### **Methodology**

The oil sample utilized in this study was obtained from a mechanic workshop in Akungba Akoko, Ondo State. This workshop conducts routine preventive maintenance on fleet vehicles and handles maintenance and repair activities for various vehicles and equipment. The used lubricating oil was extracted from a car that had been in use for several months, and a total of four liters of used oil was collected for the samples.

### **Pretreatment of Used Engine Oil Sample**

Utilizing a vacuum pump, a Buchner funnel, and filter paper, the removal of impurities such as sand, metal chips, and other solid particles that had contaminated the used engine oil was facilitated. The Buchner funnel was attached to the filtering flask with a rubber stopper, and the vacuum pump was connected to the filtering flask. The used oil sample was filtered and collected into another container. The

filtrate was then preheated at about 50°C while stirring for an hour.

#### **Solvent extraction**

The solvent extraction method is employed to refine used engine oil by utilizing different solvents that extract impurities present in the oil. Two distinct solvent combinations were utilized in this process. The first solvent mixture, labeled TBE, consisted of an equal combination of Toluene, 1-butanol, and Ethanol, with 40ml of each solvent measured into a beaker. The second solvent mixture, labeled TBM, also comprised an equal combination of Toluene, 1-butanol, and Methanol, with 40ml of each solvent measured into a beaker.

The TBM solvent mixture was mixed with the pretreated used engine oil in a closed vessel at a solvent-to-oil ratio of 3:1. The entire mixture was stirred for one hour using a magnetic stirrer, followed by allowing it to stand for 24 hours. Subsequently, the mixture was decanted to obtain the clear surface oily layer containing the solvent and oil. This layer was transferred into a rotary evaporator to separate the solvents from the re-refined oil. The same process was repeated using the TBE solvent mixture. The resulting separated re-refined oil was collected into a sample bottle for further processing.

#### **Quality Test Procedure**

##### **Density**

The density of a substance is determined by dividing its mass by its volume. In this experiment, a 20ml density bottle underwent washing and oven drying for 1 hour. Subsequently, it was placed in a desiccator for 30 minutes and then weighed, with the weight of the empty density bottle being recorded. Following this, 20ml of each sample was measured, weighed, and recorded. The density was calculated by dividing the recorded mass of the oil by its volume.

As a reference, the density of both the virgin engine oil and the untreated used engine oil was also measured in the same manner.

##### **Cloud point**

For each refined lube oil sample, 20ml was poured into a beaker and placed in an ice-cold container. The samples were allowed to chill at a specified rate, and the temperature was recorded when the wax component separated, turning into a solid form, known as the cloud point. The same procedure was repeated for the virgin engine oil and untreated used engine oil.

##### **Pour Point:**

Similar to the cloud point procedure, the pour point was determined by further chilling the samples until the oil ceased to flow or pour. The temperature at which this occurred was recorded. This process was also repeated for the virgin engine oil and untreated used engine oil.

##### **Sulfur Content:**

Sulfur content analysis was conducted using a spectrophotometer in a process known as Sulfur Analysis. One milliliter of each sample was introduced into a cuvette and attached to the spectrophotometer. The instrument emitted rays, and the radiation passing through the solution was measured. The concentration of sulfur was determined based on the obtained radiation count. Acid/clay treatment methods were applied to samples B and C, and the resulting re-refined lube oil was analyzed and recorded.

##### **Viscosity Index:**

The analysis was performed using a Viscometer. Oil samples were poured into a beaker, placed in the viscometer, and a size number four spindle was attached. The viscometer, set to 60rpm, provided a reading on the screen, which was recorded. This process was repeated for virgin engine oil and untreated used engine oil.

##### **Metal Content:**

Metal content in re-refined lube oil was determined using atomic absorption spectroscopy (AAS). Samples containing metals were dissolved in water or acid when insoluble. The cathode lamp for the elements was positioned, and the characteristic wavelength for each element was selected using a wavelength selector. A standard solution was prepared for each element, and the absorbency of the samples in solution was measured against a blank solution using the instrument.

##### **Specific Gravity:**

The procedure for determining specific gravity involved weighing a preheated empty density bottle and recording the weight. Water was poured into the bottle to determine the density of water, and the bottle containing water was weighed. The specific gravity of each sample was calculated by dividing its density by the density of water.

$$\text{Specific gravity} = \frac{\text{Density of oil sample}}{\text{Density of Liquid (H}_2\text{O)}}$$

**RESULTS**

**Table 1** shows the effects of different solvent on the physical properties of used engine oil, while, Table 2 shows the effects of solvents on metal and sulphur content of used oil

**Table 1: Effects of different solvent on the physical properties of used engine oil**

	Virgin engine oil	Used engine oil	Used engine oil + Toluene + 1-butanol + Methanol	Used engine oil + Toluene + 1-butanol + Ethanol
Viscosity index	120.0	200.0	100.0	89.9
Density	0.877	0.897	0.872	0.855
Specific gravity	0.878	0.898	0.873	0.856
Cloud point(°C)	12°C	16°C	12°C	14°C
Pour point (°C)	-3°C	1°C	-3°C	-1°C

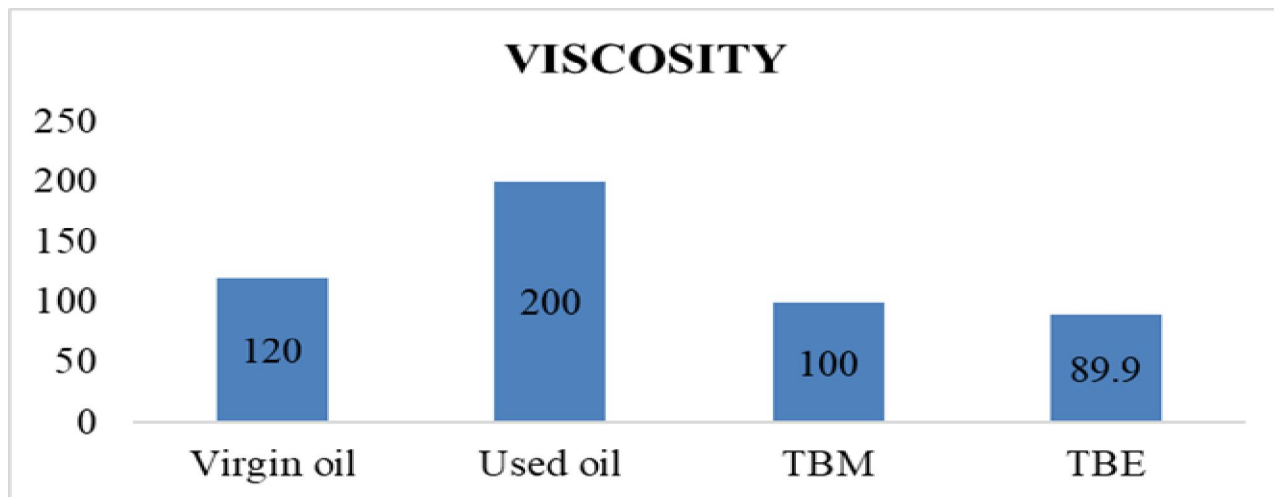
**Table 2: Effects of different solvent on the metal content of used engine oil**

	Virgin engine oil	Used engine oil	Used engine oil + Toluene + 1-butanol + Methanol	Used engine oil + Toluene + 1-butanol + Ethanol
Copper (Cu)	3.133	4.025	4.725	4.983
Chromium (Cr)	3.312	3.120	2.074	3.149
Iron (Fe)	0.894	1.123	1.035	1.035
Nickel (Ni)	0.596	0.857	0.826	1.011
Lead (Pb)	4.823	5.013	6.122	6.124
Aluminum (Al)	0.210	0.219	0.284	0.327
Zinc (Zn)	2.683	3.173	3.012	2.891
Sulphur (S)	4.012	2.960	1.895	2.655

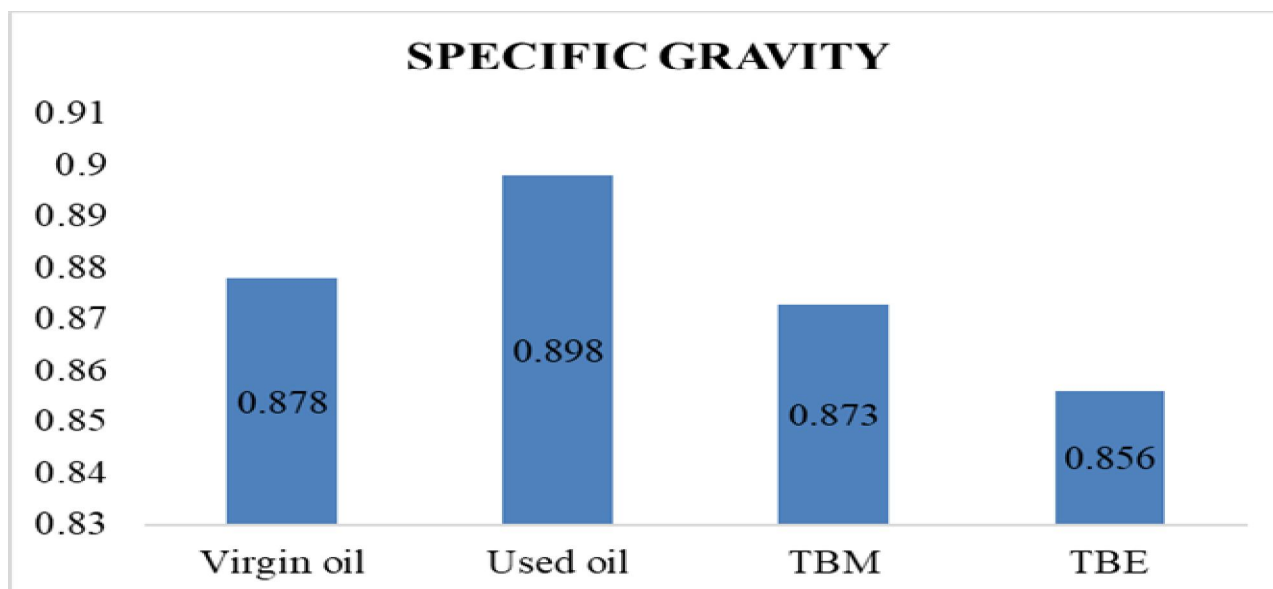
**Effects of Choice Of Solvent On Re-Refined Engine Oil**

The solvent extraction method employs various solvents to eliminate impurities from used engine oil. These solvents work by selectively dissolving undesirable aromatic components, extracting impurities present in the used engine oil, and leaving behind the desired saturated components, such as alkanes, as a distinct phase.

As depicted in **Figure 1**, it is evident that the viscosity index of the re-refined engine oil has been successfully restored to a satisfactory level. The sample treated with Toluene, 1-butanol, and methane (TBM) exhibits a higher viscosity index of 100, closely resembling that of the fresh oil. This observation indicates that the TBM mixture has a more pronounced effect in restoring the viscosity index of the used oil compared to the TBE mixture.



**Figure 1: Effect of different solvents on the viscosity index of used engine oil using the solvent extraction method.**



**Figure 2: Effect of different solvents on the specific gravity of used engine oil using the solvent extraction method.**

As depicted in Figure 6, it is evident that the viscosity index of the re-refined engine oil has been successfully restored to a satisfactory level. The sample treated with Toluene, 1-butanol, and methane (TBM) exhibits a higher viscosity index of 100, closely resembling that of the fresh oil. This observation indicates that the TBM mixture has a more pronounced effect in restoring the viscosity index of the used oil compared to the TBE mixture. Analyzing the chart above reveals that the specific gravity of untreated used engine oil is significantly higher than that of both the fresh engine oil and the treated engine oil. Additionally, both samples exhibit specific gravity values closely aligned with that of the fresh engine oil.

Specifically, the sample treated with Toluene, 1-butanol, and methane (TBM) has a specific gravity of 0.873, closely resembling the fresh engine oil value of 0.878. The elevated specific gravity of used engine oil is attributed to the presence of contaminants such as solids, metals, or oxidation products. Consequently, it can be deduced that the TBM mixture is more effective and exerts a greater influence in restoring the specific gravity of used engine oil compared to the TBE mixture. This efficiency stems from the TBM mixture's ability to dissolve contaminants present in used engine oil. A similar trend is observed in the study by Naife et al. (2022), where the use of 1-propanol and heptane as solvents led to the removal of contaminants and a subsequent reduction in the specific gravity of the re-refined oil.

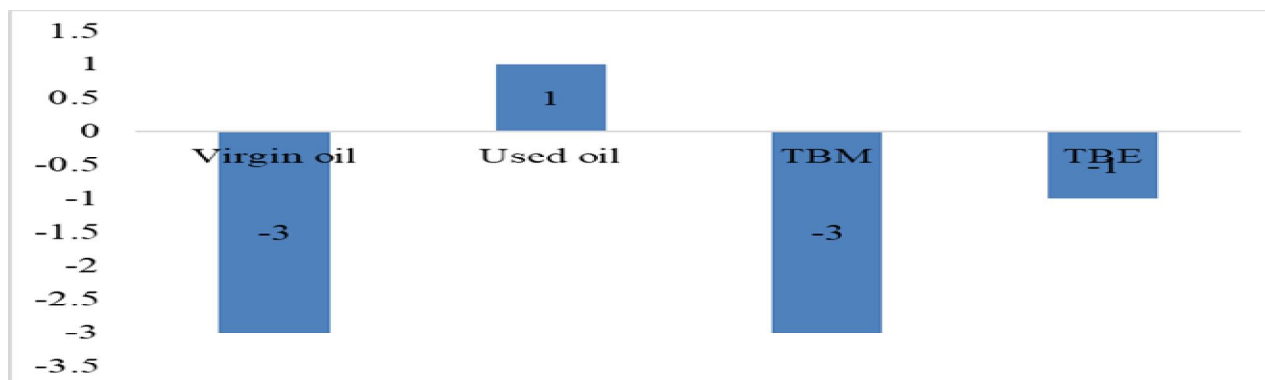


Figure 3: Effect of different solvents on the pour point of used engine oil using the solvent extraction method.

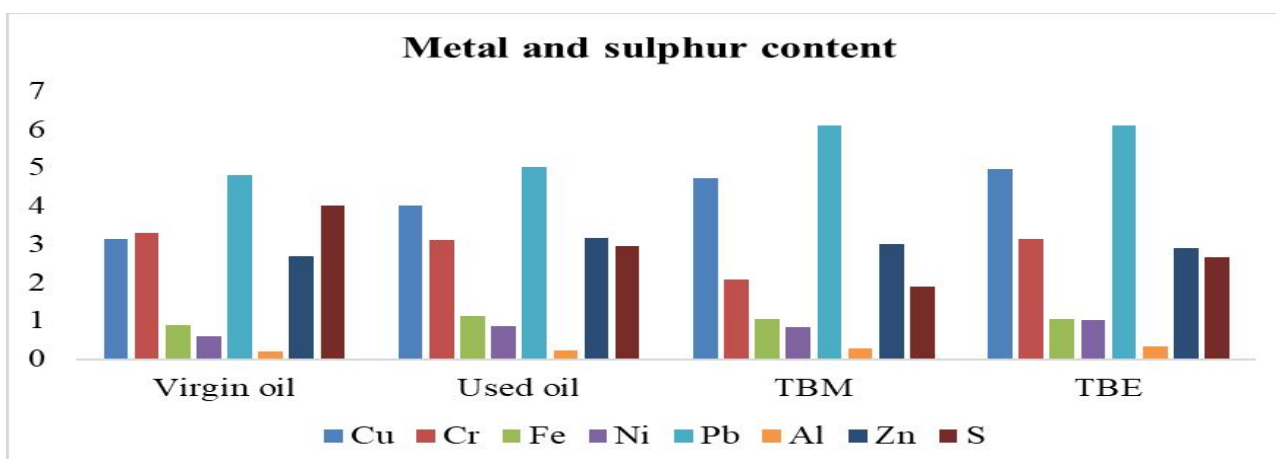


Figure 4: Effect of different solvents on the metal and sulphur content of used engine oil using the solvent extraction method.

The chart above illustrates an enhancement in the pour point of samples treated with solvents compared to the pour point of untreated used engine oil. Particularly, the sample treated with the Toluene, 1-butanol, and methane (TBM) mixture exhibits a pour point identical to that of the fresh engine oil. Conversely, the pour point of the used oil shows minimal impact from the Toluene, 1-butanol, and ethanol (TBE) mixture. According to research by Naife et al. (2022), the pour point of used oil tends to increase due to elevated paraffin and wax content. Therefore, it can be inferred that the TBM mixture is more proficient in reducing the paraffin and wax content of used engine oil compared to the TBE mixture.

Examining Figure 4 reveals a reduction in the concentration of wear elements and contaminants, such as Cr and Fe. Notably, wear elements and contaminants like Cu, Ni, Al, and Zn appear to be unaffected or only mildly affected by the treatment process. However, the concentration of Lead (Pb) has significantly increased in the re-refined oil, indicating that the solvents do not exhibit a substantial positive effect on the metal content of the used lubricating oil. The concentration of sulfur, classified as an additive element, is observed to have decreased, with the samples treated with Toluene, 1-butanol, and methane (TBM) experiencing the highest reduction. This reduction in sulfur concentration could be further improved by incorporating additives into the re-refined oil.

## CONCLUSION

The research affirms that the solvent extraction method is an effective process for removing contaminants from used lubricating oil. The recovered oil demonstrates a quality comparable to fresh oil, suggesting its potential for reuse. The findings indicate that the solvent mixtures, Toluene, 1-butanol, and Ethanol (TBE) and Toluene, 1-butanol, and Methanol (TBM), are capable of dissolving and absorbing sludge and contaminants, thereby ensuring the removal of impurities in the re-refined oil.

Standard chemical and physical tests were conducted to determine the properties of used engine oil. The characterization revealed contamination with light fuel from external sources and/or oil degradation by-products, oxidation and polymerization products, extraneous water, soot and carbon from incomplete fuel combustion and breakdown of oil components, organic acids and soaps of heavy metals, and wear metals from engine parts.

The results indicate that the mixture containing Toluene, 1-butanol, and Methanol (TBM) outperformed the properties of the fresh virgin oil. In contrast, the second mixture containing Toluene, 1-

butanol, and Ethanol (TBE) yielded relatively poorer results when compared to the TBM solvent.

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