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Characterization and Suitability of Reclaimed Automotive Lubricating Oils Reprocessed by Solvent Extraction Technology

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Abstract: The increase in the generation of used automotive lubricating oils is an issue of growing concern, especially in developing countries. Most used oil contains degraded additives and its indiscriminate disposal causes environmental degradation and pollution. This study investigates the characteristics of the reclaimed oil obtained by solvent extraction technology. It further evaluates the suitability of the reclaimed oil for reuse, by comparing its properties with the Society of Automotive Engineers (SAE) quality standards for lube oils. Three samples of used engine oils were collected, recycled and analyzed. Results from this study and other similar studies indicated that the flashpoint is below the SAE specifications. Viscosity index and kinematic viscosity at 40 and 100 °C are found above the SAE specifications. The pour point of the reclaimed oil is found below the standard values while the specific gravity concurs with the SAE standards. Total acid and total base numbers of the reclaimed oil indicated a low acid concentration. The study suggests an improvement on the flash point and the viscosity of the reclaimed oils for better lubricating performance in the automotive engines.

Keywords: automotive; used lubricating oils; recycled; suitability; reuse

1. Introduction

Any petroleum based or synthetic oil that has been used for lubricating purposes and has become unsuitable for its original purpose is known as used oil. Used oil is no longer suitable for use consequent upon the loss of its original properties. This loss occurs due to physical contaminants from the air, fuel combustion, oxidation and additives [1], and chemical reactions during its use. The contaminants in used oil include extraneous, sludge, lacquer and oil-soluble products [2]. Extraneous contaminants are introduced from the surrounding air and it includes contaminants from dust, dirt and moisture and by metallic particles from the engine [2]. Metallic particles are introduced from the wear of the engine. Other contaminants from the engine are carbonaceous particles caused by incomplete fuel combustion, metallic oxides present as corrosion products of metals, water from leakage of the cooling system, water as a product of fuel combustion and fuel or fuel additives and their byproducts, which might enter the crankcase of the engine. These contaminants cause excessive wear, rust of iron or steel, clogging of oil passages, pump valves and other oil handling equipment [3]. The contaminants also damage oil pump, dilute lubricating oil and are capable of reducing viscosity beyond a safe load [3].

Two solutions are provided locally for used oil management. It is either used directly or recycled. It is used directly in construction, transportation, casting and forestry [4]. Direct use of waste lubricating oils still poses a great risk to the environment. Environmental consideration regarding the use of waste lubricating oils remain a subject of interest in some countries to date because, it has now been discovered to account for more pollution than oil spillage [5,6].

Recycling used oil is fast becoming the preferred way to handle used lubricating oils in order to protect the environment and conserve natural resources. Environmental legislation nowadays does not allow used lubricating oil to be discarded into rivers, lakes or ocean or the soil [7]. This is not unconnected with the alarming report of sea pollution from used oil. Since used lubricating oil contains dirt, water and metallic elements due to wear and corrosion processes, the removal of these contaminants is necessary for re-use.

Different extraction processes have been identified for recycling waste lubricating oils. Some of these processes include re-distilling or re-refining [6], ionization radiation [8], solvent extraction and acid treatment methods [8,9]. The re-distilling method is commonly used in developed countries. It involves the use of the distilling process to recycle the used oil into high-quality lubricants and other petroleum products. The ionizing radiation process had been used for different applications such as degradation of organic and biological compounds as well as metal removal from the used lubricating oils [7]. The technology is based on irradiation of the used engine oil in the gamma or x-ray irradiator and the determination of the elemental concentration of the used oil before and after irradiation to obtain the base oil. The technology seems to be a promising process for refining used automotive lubrication oils, however, it stills depends on the conventional recycling process for the removal of some metal impurities and degradation of organic compounds in the used lubricating oils.

Acid treatment method involves mixing used lubricating oil with sulfuric acid [10]. The acidified materials will then be neutralized with caustic soda and filtered to remove the precipitate. The filtration eventually gives some clear oil products. One disadvantage of this technology is however, the use of a large amount of sulfuric acid and clay to treat the used oil and this creates substantially hazardous waste by-products, including acid tar and oil saturate clay. Another one is the production of sub-standard base oil. Due to these disadvantages, its application is on the decline and even prohibited in industrialized countries for ecological reasons. Nevertheless, Reference [11] demonstrated how this method could be used under different conditions and variables without bordering on the said disadvantages.

The solvent extraction method is divided into two: Single solvent extraction and multi-components extraction [12,13]. In this method, butanol, propanol and butanone are used to make composite solvents that is mixed with oil. The solvents dissolve the oil fraction leaving the less soluble impurities. The recovered solvents are then liquefied. A major setback to this method is cost. However, Reference [14] employed both single and composite solvents to revive used lubricating oil. The result obtained showed that 1-butanol as a solvent is suitable for recycling used lubricating oil. Reference [15] also utilized a solvent extraction process to recycle used engine oil. The solvent used was a mixture of ethanol, 1-butanol and toluene. The effect of operating parameters (agitator speed for blending, boiler temperature and solvent to used oil ratio) on the recycling process was investigated for optimal conditions. They observed that the maximum recovery for refined oil was 72% using a solvent to used oil ratio of 9:1 at a boiler temperature of 120 °C and agitator speed of 600 rpm. Further study by [16] utilized blends of solvent (toluene, butanol and methanol; toluene, butanol and ethanol and toluene, butanol and isopropanol) and activated alumina to refine used lubricating oils. The solvent blends were evaluated experimentally at oil to solvent proportion of 1:1 to 1:3. Their results confirmed that solvent mixture is able to remove large percentages of sludge from used lubricating oil. The percentage of sludge removal improves with increase in solvent to oil ratios. The refining method was also able to remove a higher percentage of metallic impurities, reduced acid values and enhanced significantly the physical properties of the refined oil. The present study seeks to investigate the characteristics of the reclaimed oils obtained by solvent extraction technology and evaluate its suitability for reuse by comparing it with the Society of Automotive Engineers (SAE) quality standards for lube oils.

1.1. Lubricant Oil Properties

Recycled lubricants must possess certain properties which must meet the lubrication requirements in an engine. These properties include:

a. Viscosity

Viscosity is a very important property for grading lubricants. It is a measure of fluid resistance to flow and is strongly dependent on temperature. A decrease in the viscosity of engine oil indicates that the oil is contaminated [17]. Lubrication oils are identified by the Society of Automotive Engineers (SAE) number. The SAE viscosity numbers are used by most automotive equipment manufacturers to describe the viscosity of the oil they recommend for use in their products. The greater or higher the SAE viscosity number, the heavier or more viscous the lubricating oil [7].

b. Pour Points

The pour point indicates the temperature below which the oil loses its fluidity and will not flow or circulate in the lubricating system. Lubricating oils with low pour points show good quality.

c. Flashpoints

Flashpoint is the temperature to which the oil must be heated under specific conditions to give off sufficient vapour to form a flammable mixture with air. It gives an indication of the presence of volatile compounds in the oil. A decrease in flashpoint reveals that the oil is contaminated through dilution of lubricating oils with unburned fuel [18]. An increase in flashpoint indicates the evaporation of light components from the lubricating oil [17]. The flashpoints also portray the relative measure of safe properties of lubricating oils.

d. Total Acid Number (TAN)

The total acid number is the measurement of acidity in oils used as lubricants. It is one of the crucial chemical properties that gives stability to lubricating oils. Lubricating oil is said to be stable if it can resist oxidation that yields acids, lacquers and sludge [19]. TAN indicates the amount of alkali in milligrams that is required to neutralize the acids in one gram of oil. Normally, acidity increases with the oxidation of lubricating oils [18].

e. Total Base Number (TBN)

Total base number (TBN) is a measurement of basicity and is expressed in terms of the equivalent number of milligrams of alkali (most especially potassium hydroxide) per gram of oil sample. TBN generally ranges from 6 to 80 mg KOH/g in modern lubricants, 7–10 mg KOH/g for general internal combustion engines and 10–15 mg KOH/g for diesel engine operations. Oils and lubricants have a base reserve designed to neutralize the acids produced after the combustion process in order to avoid corrosion of engine components [20]. A low Total base number (TBN) indicates that the oil has to be changed. TBN is determined by acid-base titration using HClO4 as the titrant.

1.2. Additives

Additives are added to lubricating oils to impart specific properties to the finished oil. The oils from refining by conventional methods are not completely satisfactory for use as lubricants. Therefore, lubricants are highly refined and their properties are improved by the addition of chemicals [21]. The additives, at a concentration of 12–15 wt %, play a considerable role in obtaining the high quality of the finished oil [21]. Some of these additives include:

a. Antioxidants

Antioxidants reduce the rate of oxidation of lubricating oils during its use, thereby reducing the formation of corrosive oxidized products.

b. Detergents

Detergents are added to the motor oil in order to improve engine performance and to prevent material from depositing on the engine pistons.

c. Antifoam Agents

Foaming of lubricants, [21] is an undesirable effect that can cause enhanced oxidation by the intensive mixture of oil with air.

d. Viscosity Modifiers

Viscosity improvers are a long chain, high molecular weight polymers that cause the relative viscosity of oil to increase at high temperatures than at low temperatures [22]. The commonly used additives are either alkyl polymethacrylates or more generally, copolymers of olefins or hydrogenated diene/styrene copolymer.

e. Pour-Point Depressant

These additives hinder the process of growth of the crystals of paraffin wax, which form in the oil at low temperatures. Polymethacrylates with low molecular masses are usually used.

2. Methodology

2.1. Sampling

100 mL of used Mobil, Total and Visco motor oils were collected from a local service station in Ile-Ife, Nigeria. Each of the oils had been used for two months by saloon cars before collection. 100 mL of each sample oil was poured into three different beakers and labelled as E1 (Mobil), E2 (Total) and E3 (Visco). Samples E1, E2 and E3 were characterized for flash point, pour point, specific gravity, and kinematic viscosity at 40 °C and 100 °C, using the standard lubricating oil test methods in Table 1. Test was conducted at the organic chemistry laboratory of the Department of chemistry, Obafemi Awolowo University, Ile-Ife, Nigeria.

Table 1. Standard lubricating oil testing methods.

S/n	Test	Designation	Apparatus
1	Kinematic Viscosity	ASTM D-445	Viscometer
2	Pour point	ASTM D-97	Pour Point Tester
3	Specific gravity	ASTM D-1298	Density bottle
4	Flash Point	ASTM D-92	Flash Point Tester
5	Total Acid Number	ASTM D664	Potentiometric titrator
6	Total Base Number	ASTM D2896-11	Potentiometric titrator

(a) Flash Point (ASTM D92)

20 mL of each sample was introduced into a beaker and then heated on a Bunsen burner to determine the temperature at which a flash will appear on the surface of the sample. This temperature was measured and recorded as the flashpoint using a thermometer (ETI Instruments, Worthing, West Sussex, UK).

(b) Pour Point (ASTM D97)

20 mL of each sample was introduced into a container and then chilled at a specific rate and checked at intervals of 5 min until the oil stopped flowing. The temperature at which this occurred was recorded as the pour point.

(c) Specific Gravity (ASTM D-1298)

Specific gravity is the ratio of the density of a material to the density of an equal volume of water and it is determined using specific gravity bottle. The specific gravities of oil samples are calculated from the ratio of the weight of oil to the weight of water.

(d) Viscosity (ASTM D445)

The viscosity was obtained using an Ostwald viscometer (ZONWON, Hangzhou, Zhejiang, China). Oil samples were heated separately to attain a temperature of 100 °C and then poured into the bulb of a clean viscometer while immersed in a water bath with a thermostat. The flow time of water and oil samples were measured and recorded when the oils reached the lower and upper marks on the viscometer. The viscosity of oils was determined using the equation below.

$$\frac{\eta_1}{\eta_2} = \frac{t_1 d_1}{t_2 d_2} \tag{1}$$

where η_1 and η_2 are the viscosity of oil and water, t_1 and t_2 are the flow time and d_1 and d_2 are the density of oil and water respectively.

(e) Total Acid Number (ASTM D974)

Measurement of Total acid number (TAN) in the study was done using the procedure specified by [23]. About 10 g of lubricating oil was dissolved in a mixture of toluene and 2-propanol solution with a small amount of water. The dissolved solution was then titrated with 0.1 mol/L/potassium hydroxide 2-propanol solution using potentiometric titrator to obtain the total acid number, with the equation given below.

$$\text{Total acid number (mg/g)} = (\text{EPI} - \text{BLI}) \times \text{TF} \times \text{CI} \times \text{KI/S} \tag{2}$$

where EPI is the titration volume; BLI is the blank level (0.052 mL); TF is the factor of reagent (1.000); CI is the concentration conversion efficiency (It is equivalent to potassium hydroxide in 1 mL of 1 mol/L potassium hydroxide-2 propanol solution and equal to 5.611 g/mL); KI is the unit conversion coefficient (1); while S is the sample size.

(f) Total Base Number (TBN, ASTM D2896-11)

TBN was determined by an acid-base titration using HCIO4 as the titrant in the potentiometric titrator (KEM, Shinjuku-ku, Tokyo, Japan). 10 g of reclaimed oil samples were weighed and diluted in a mixture of chlorobenzene and acetic acid as described by [24]. The solution was then titrated in the potentiometric titrator to obtain a total base number of the oil samples using the equation below:

$$\text{TBN (mgKOH/g)} = \frac{0.1(^{eq}/_{L}) \times (V_{titrant} - V_{blank})(mL)}{1 \times m_{sample\ (g)}} \times 56.11\ (g/mol) \tag{3}$$

where m_{sample} is the mass of the sample, $V_{titrant}$ is the volume of the titrant, V_{blank} is the volume of the sample with blank or zero solvent and eq/l is the equivalent volume. It represents the unit for the volume of the titrant (HCIO4).

2.2. Processing

The collected oil samples were allowed to settle at room temperature for 24 h and dehydrated to remove solid particle constituents and the water added to the oil during combustion. Solvent extraction treatment was then carried out on the oil samples using composite solvent of butan-1-ol and n- Hexane, potassium hydroxide (KOH) and activated charcoal. 100 mL each of oil samples were mixed with a composite solvent (70% of butanol and 30% of n-hexane) with 3 g of potassium hydroxide (KOH) at a solvent to oil ratio of 5:1. The mixture was thoroughly stirred for about 30 min and heated on the heating mantle at 60 °C and at atmospheric pressure for 30 min to remove the light hydrocarbons. The mixture was then allowed to settle in a separation flask for 24 h. The oil-solvent mixture of sample E1, E2 and E3 were separated from the sludge and then heated at 120 °C to remove the solvent in the mixture as shown in Figure 1a. The oil collected from the oil solvent mixture was mixed with 12 g of activated charcoal and then heated at 150 °C for 1 h 30 min. Figure 1b shows oil adsorption process with activated charcoal.

(**a**) (**b**)

Figure 1. (**a**) Solvent extraction and (**b**) Adsorption process with activated charcoal.

The heated mixture was then left for 2 h to allow gravity settling. It was then filtered with a filter paper to recover base oil from adsorbent mixture. Figure 2a,b show the used and reclaimed oils respectively.

(**a**) (**b**)

Figure 2. (**a**) Used oil and (**b**) Recovered oil.

Physical properties (kinematic viscosity, specific gravity, flash point and pour point) of the recycled oils E1, E2 and E3 were obtained using the same test methods explained above. These properties were compared with the Society of Automotive Engineers (SAE) standard properties for lubricating oils to determine the suitability of the recovered oils for re-use.

3. Results and Discussion

3.1. Physical Properties of the Used Engine Oil

Table 2 shows the physical properties obtained for the used engine oil samples E1, E2 and E3. At room temperature, the used oil was dark liquid (Plate 3a). Specific gravity obtained for the used Mobil oil (E1), used Total oil (E2) and used Visco motor oil (E3) were 0.910, 0.928 and 0.8997 respectively. In comparison with the specification of lube oil for SAE20, 30 and 40, the specific gravity of the used oil is higher indicating the presence of contaminants in the oil, thus rendering it ineffective. Viscosity at 40 °C (cSt.) for used Mobil oil, used Total oil and used Visco oil was 105.31, 121.58 and 112.5 respectively, while the values for SAE20, 30 and 40 are 37, 88 and 110 cSt. respectively. Viscosity of the used lubricating oil below the standard specification for lube oil renders it unfit for recycling. However, viscosity values of the used engine oils under study can be improved significantly.

Table 2. Physical properties of the used oil samples.

	Oil Samples			Lube Oil		
Specifications	**E1**	**E2**	**E3**	**SAE20**	**SAE30**	**SAE40**
Specific gravity @15.56 °C	0.9100	0.9280	0.8997	0.8700	0.8801	0.8826
Kinematic viscosity at 100 °C (cSt)	11.40	12.41	11.83	5.65	10.15	11.50
Kinematic viscosity at 40 °C (cSt)	105.31	121.58	112.5	37.0	88	110
Viscosity index	94	92	93	95	94	96
Flash point (°C)	195	212	220	224	226	268
Pour point (°C)	−15	−11	−21	−10	−10	−12

Viscosity values of the used oils are higher than the values for SAE20, SAE30 and SAE40 due to oxidation and contamination. These factors are also responsible for the higher viscosity values obtained at 100 °C. As also expected, the flash points of the used oils are lower to the value of the virgin oils due to contamination or dilution of the lubricating oils by unburned fuel. The pour point of the used oil is however higher than the values obtained for the virgin oils.

3.2. *Quality Characteristics of the Reclaimed Oils*

Reclaimed oil of 70 mL was recovered from the used engine oil after solvent extraction for a process conditions of 5:1 solvent to used oil ratio, 60 °C heating temperature and 30 min process time. Table 3 shows the physical properties obtained for reclaimed oils from the three oil samples. These properties are used to evaluate the quality characteristics of the reclaimed oils. Results obtained for the three reclaimed oil samples showed specific gravity of 0.8865, 0.8844 and 0.8053 for E1, E2 and E3 respectively. Due to the removal of contaminants from the used engine oils during recycling processes, the reclaimed oils have lower specific gravities. The specific gravities of the used engine oils have been reduced by 0.01, 0.04 and 0.09 for the reclaimed oil E1, E2 and E3 respectively.

Table 3. Properties of the reclaimed base oil.

	Oil samples			Lube Oil		
Specifications	**E1**	**E2**	**E3**	**SAE20**	**SAE30**	**SAE40**
Specific gravity @15.56 °C	0.8865	0.8844	0.8853	0.8700	0.8801	0.8826
Kinematic viscosity at 100 °C (cSt)	14.19	15.33	14.52	5.65	10.15	11.50
Kinematic viscosity at 40 °C (cSt)	138.92	165.10	154.1	37.0	88	110
Viscosity index	99	93	91	95	94	96
Flash point (°C)	222	216	239	224	226	268
Pour point (°C)	−9	−9	−11	−10	−10	−12
TAN (*MgKOH/g*)	0.305	0.533	0.445	-	-	-
TBN (*MgKOH/g*)	8.42	6.45	10.10	-	-	-

The viscosity of the engine oil decreases due to thermal degradation in the engines, bearings, cylinders and gear sets. The reclaimed oil exhibited higher kinematic viscosity values at 40 and 100 °C compared to the used oils. Results obtained for the viscosity at 100 °C for E1, E2 and E3 are 14.19, 15.33 and 14.52 cSt respectively. An increase of 2.79, 2.92 and 2.69 cSt is observed for the reclaimed oil sample E1, E2 and E3 respectively. Similarly, the kinematic viscosity at 40 °C for E1, E2 and E3 is seen to have increased from the initial values of 105.21, 121.58 and 112.5 to 138.92, 165.10 and 154.1. Reference [22] explain that higher viscosity number indicates that the lubricating oil is more viscous or heavier. Higher viscosity value of the reclaimed oil would enhance its lubricating performance as virgin oil for use in automotive engines.

Viscosity index is a measure of the resistance of engine oil to deformity at high temperature. Results obtained show viscosity index of 99, 93 and 91 for reclaimed oil E1, E2 and E3 respectively. An increment of 5, 1 and 0 values are observed over the initial values of 94, 92 and 93 respectively for the used oil samples. Reclaimed oil E1 shows higher viscosity index at high temperature while minor and no improvement have been observed in the viscosity index of the reclaimed oil E2 and E3 respectively. This may be attributed to the nature of oil, car type and oil usage.

The flashpoint values obtained for the reclaimed oil samples are higher than those of used oil as shown in Table 3. Flashpoint values of 222, 216 and 239 °C were obtained for reclaimed oil E1, E2 and E3 respectively compared to the value of the used oil of 195, 212 and 220 °C. Flashpoint gives an indication of the presence of volatile compounds in the oil. It also gives a relative measure of the safety properties of lubricating oils. The low flashpoint observed in the used oil is an indication that the oil is contaminated with unburned fuel. The reclaimed oil samples E1, E2 and E3 gained flashpoint values of 27, 4 and 39 °C respectively through the recycling process.

Higher pour point values were also obtained for the reclaimed oil samples in comparison with values obtained for the used oils. Pour points of −9, −9 and −11 °C were obtained for the reclaimed oil E1, E2 and E3 respectively compared to the value of −15, −11 and −21 °C for the used oil. Pour point indicates the temperature below which the oil loses its fluidity and will not flow or circulate in the lubricating system. Pour points value for the used oils are far below the value specified for lube oil for SAE20, 30 and 40 which are −10, −10 and −12 °C respectively. The reclaimed oil, however, returned values very close to the specified SAE values.

Total acid number (TAN) of 0.305, 0.533 and 0.445 were obtained for the three reclaimed oil sample E1, E2 and E3 respectively. These values indicate that the acid concentration in the reclaimed oil is very low and thus, eliminate the cause of corrosion in the automotive engines. Furthermore, higher values of total base number (TBN) were obtained for the three reclaimed oil samples E1(8.42 mgKOH/g), E2(6.45 mgKOH/g) and E3(10.10 mgKOH/g) respectively. TBN generally ranges from 6–80 mg KOH/g in modern lubricants, 7–10 mg KOH/g for general internal combustion engines and 10–15 mg KOH/g for diesel engine operations. Values of Reclaimed oil E1 and E3 are found within the range specified for general internal combustion engines.

3.3. Suitability of the Reclaimed Oil for Reuse

Figures 3–5 compare the properties of the reclaimed oil samples E1, E2 and E3 with the standards specified by the Society for Automotive Engineers for lube oil [9]. The flashpoint for SAE20, SAE30 and SAE40 are 224, 226 and 268 respectively. The reclaimed oil sample E1 and E2 have a flashpoint of 222 and 216 °C. These values are very close to the flashpoint of SAE20 and SAE30. The reclaimed oil sample E3 has a flashpoint of 239 °C which is higher than the flashpoint for SAE20 and SAE30 and therefore may be classified under SAE40. Kinematic viscosity for SAE20, SAE30 and SAE40 at 40 °C are 37, 88 and 110 cSt respectively. The reclaimed oils E1, E2 and E3 have higher kinematic viscosity of 138.92, 165.1 and 154.1 at 40 °C and 14.19, 15.33 and 14.52 respectively at 100 °C compare to the value of SAE20(5.65), SAE 30(10.15) and SAE40(11.50). Similar studies by [16] revealed that higher viscosity of the refined oil is due to possible removal or conversion of impurities in the used oil. Further, the viscosity index is higher (99) for the reclaimed oil (E1) compared to SAE20 (95), SAE30 (94) and SAE40 (91). The reclaimed oil E2 and E3 have lower viscosity index (93 and 91) closer to the value for SAE 30 and SAE 40 indicating that the reclaimed oils could have high resistance to deformity at higher temperature as the virgin oils. Also, an increase in the viscosity at higher temperatures as observed above for the reclaimed oil samples could result in lower oil consumption and less wear.

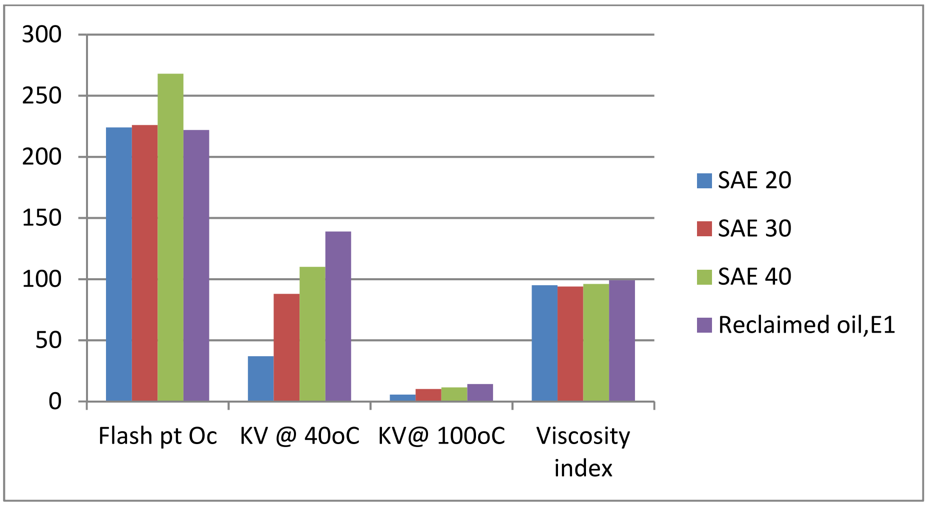

Figure 3. Comparison between SAE 20, SAE 30, SAE 40 and reclaimed oil (E1).

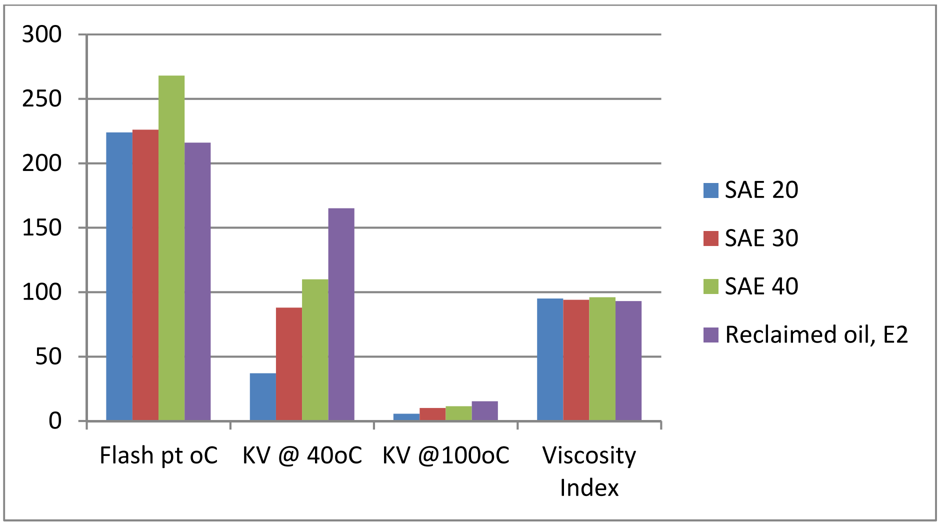

Figure 4. Comparison between SAE20, SAE 30, SAE 40 and reclaimed oil (E2).

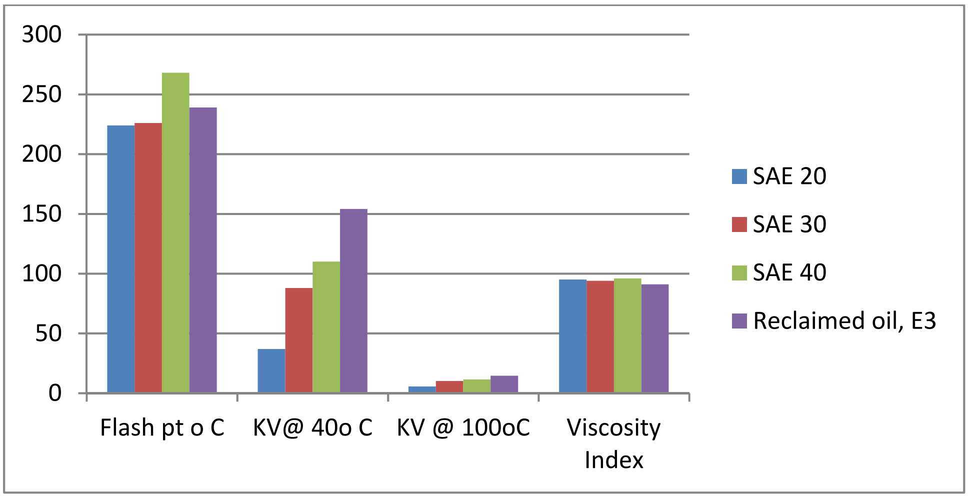

Figure 5. Comparison between SAE20, SAE 30, SAE 40 and reclaimed oil (E3).

In Table 4, properties of the recycled lubricating engine oils by solvent extraction for different studies are compared with the present works and SAE standards.

Table 4. Comparison of results by solvent extraction for different studies with SAE standards.

S/No	Properties	Authors and Processing Methods					Standards		
		Composite Solvents [17]	Single Solvent [17]	Solvent Extraction [3]	Solvents Plus Activated Alumina [16]	Composite Solvents Plus Activated Charcoal Present Work	SAE 20	SAE 30	SAE 40
1	Flash points	150	130	210	-	222	224	226	268
2	Viscosity index	-	-	97	155.15	99	95	94	96
3	Pour point	−15 °C	−18 °C	−13 °C	0	−9	−10	−10	−12
4	Specific gravity	0.88	0.858	0.697	0.8825	0.8865	0.87	0.8801	0.8826
5	Viscosity @ 40 °C	94	98	98.7	72.08	138.92	37	88	110
6	Viscosity @ 100 °C	-	-	11.2	11.59	14.19	5.65	10.15	11.50

The flash point temperature for all studies are below the SAE specifications. However, in the present work, the flash point is still high enough to maintain the safety properties of the lubricating oil due to its closeness to the standard value. Viscosity index and kinematic viscosity at 100 °C in all the studies are found above the SAE specifications. This may possibly increase the resistance of the recycled oil to deformation at high temperature. Kinematic viscosity at 40 °C are found above SAE 20 and 30 specifications for all studies except SAE 40. The pour point temperatures in similar studies are found above SAE specifications. The present study shows pour point temperature below the standard value. Lubricating oils with low pour points shows its good quality. The specific gravity of the recycled oil in all studies concur with the specification for the Society of automotive engineers. This shows a possible reduction of contaminants in the reclaimed oil.

4. Conclusion

The study presents the use of solvent extraction technology for recycling used automotive lubricating oils and examines the suitability of the reclaimed oil for reuse in automotive engines. Investigation and comparison of the properties of the reclaimed oil samples with SAE specifications for lube oils indicate that the flash point of the reclaimed oil is lower than the value specified for SAE20, SAE30 and SAE40. Viscosity index of the reclaimed oil is found above SAE specifications. The Pour point of the reclaimed oil are found below the standard values while the specific gravities concur with SAE standards. Viscosity of the reclaimed oil is higher at 40 and 100 °C than the values specified by the society for automotive engineers. Total acid and total base number indicate a low acid concentration in the reclaimed oil. The study suggests an improvement on the flash point and the viscosity of the reclaimed oils for better lubricating performance in the automotive engines.

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