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Modeling and simulation of waste engine oil treatment process using solvent extraction and carbonized-clay adsorption methods

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Abstract

There is the irresistible need to recover refined engine oil from waste engine oil through recycling procedures and treatment methods. To achieve this objective, waste engine oil samples were subjected to acid precipitation, carbonized-clay adsorption and solvent extraction methods. In it, 5000 ml of acid treated engine oil was recovered from the preliminary stage of treatment. Also, carbonized-clay adsorbent was produced from the admixture of activated charcoal from coconut husk and bentonite clay in specific ratios of 50, 100 and 200 %w/w. Actual waste engine oil treatments proceeded with the separate applications of carbonized-clay adsorption and solvent extraction methods on the basis of ratios of carbon-clay, adsorbent-oil and solvent-oil, while using experimental designs proposed by design expert version 7.0. Physicochemical property tests were conducted for waste and refined engine oil samples in order to check efficacies of treatments. The results showed increase in viscosity from 135cP to 185cP for waste engine oil to refined engine oil. Water and heavy metal contents in waste engine oil reduced after treatment, respectively from (1100 ppm, Cu (88.9 mg/l), Fe (322.8 mg/l) and Pb (12.4 mg/l)) to (40 ppm, Cu (8.5 mg/l), Fe (58.6 mg/l) and Pb (8.8 mg/l)). Optimal yields of refined engine oil were respectively 77.8 % and 76.5 %, for carbonized-clay adsorption and solvent extraction methods. Empirical models determined for the treatment processes also showed good correlation coefficients (R^2) of 0.87 and 0.97, between experimental and predicted yields of refined engine oil for carbonized-clay adsorption and solvent extraction methods.

Keywords: Waste Engine Oil; Simulation; Modeling; Solvent extraction; Carbonized-Clay

1. Introduction

Engine oil reduces friction in internal combustion engines used in cars, warships, jet engines, tractors, electric generators, and other industrial devices. Reducing frictional force between engine parts reduce wear and tear which extends engine life [1, 2]. Overexposure to physical, chemical, and mechanical processes degrades it which causes physical qualities including colour, flash point, specific gravity, viscosity, cloud, and pour point to be lost. This engine oil would contain impurities and pollutants, rendering it spent or waste and unsuitable for engine lubrication [3].

As a hazardous waste and severe pollutant to soil and water, inappropriate waste engine oil disposal might harm ecosystems and human health. Waste motor oil recycling include precipitation, filtration, bleaching, distillation, solvent extraction, adsorption, and more.

Solvent extraction is a potential technology for recovering waste motor oil since it efficiently separates useful lubricant components from impurities [4]. This procedure uses an extractive solvent to isolate the required oil fraction from low-grade oils. In precipitation, precipitants are applied to waste engine oil to react and precipitate oil contaminants.

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Distillation removes volatile contaminants and recovers stable, usable oil from the bottom. Adsorption will transfer soluble and dispersed contaminants including volatiles, organic acids, and heavy metals from waste motor oil to the adsorbent, making the recovered oil more refined and reuseable. This technique dissolves oil in a solvent to remove contaminants [5].

The aim of this study is to carry out the modelling and simulation of waste engine oil treatment process using methods of solvent extraction and carbonized-clay adsorption. It would do so with the specific objectives are stated below as follows: collect waste engine oil samples from local mechanic workshops, including other raw materials relevant to the study; carbonize and activate charcoal obtained from coconut husk; select possible solvent for extracting refined engine oil from waste engine oil; subject the waste engine oil samples to both solvent extraction and carbonized–clay adsorption experiments; optimize the experimental process for the waste engine oil recycling using design expert as the simulation tool; and develop an empirical model for predicting the yield of the refined engine oil based on recycling process conditions.

This study will to a large extent reduce the indiscriminate disposal of waste engine oil, which in turn reduces environmental pollution associated with waste engine oil. It will also support effective design of an engineering process plant for the mass production of refined engine oil from waste engine oil materials at an optimal cost. This would help build competence and capability into our local technology.

2. Material and methods

2.1. Materials and Reagent

Waste engine oil was collected from different local mechanic workshops around the University of Port Harcourt neighbourhood, and stored in different cans. The SAE quality grades of the engine oil from where the waste engine oil samples were obtained were high performance SAE 20-50 grades.

Coconut husk was obtained from de-husked coconuts at the local market near the University of Port Harcourt. These husks were sun dried, gathered together and stored in a sack bag. Other materials include bentonite clay (obtained from Chuz chemicals). Chemical reagents and solvents used for the study are also presented as Sulphuric acid (65 % w/w, MandB), Ethanol (95+ %w/w, Aldrich), NaOH (65%w/w, Fischer), Distilled water (pure state, Uniport), $CaCl_2$ (95 %w/w, Aldrich) and CaO (high purity, BulkCem).

2.2. Equipment

Relevant equipment used in the laboratory for carrying out this study and their respective functions are presented in Table 1. However, equipment not mentioned in the list will be explained in the appropriate sections.

Table 1 List of equipment and their functions

Equipment	**Function**
Hydrometer	Density and specific gravity measurement
Viscometer (Rotational and capillary glass type)	Viscosity measurement
Furnace/Oven	Measurement of water and ash content
Tubular furnace	Carbon production and test
Electric heater	Heating device
Vacuum pump	Vacuum distillation
Mixer	Mixing and agitation
Atomic Absorption Spectrophotometer, AAS.	Detecting and measuring concentrations of metals in liquids.
Distillation column and Condenser	For distilled vapours and cooling.
Shaker	Particle size measurement.
Centrifuge	Oil separation from clay
Thermometer	Measuring temperatures

Glass beakers	For holding samples and other laboratory uses.
Graduated cylinder	Sample volume measurement
Crucibles	For holding solid samples include ash and charcoal.
Tong	Holding hot beakers
Hand gloves	Personal protection
Nose masks	Personal protection
Safety cloth and coverall	Personal protection

2.3. Preparation of Materials

This section outlines the methods used to carry out the preparation of materials required for the study: acidification of waste engine oil, carbonization of coconut husk and activation of carbonized bentonite clay (or carbonized-clay).

2.3.1. Acidification of waste engine oil

This is a preliminary treatment for the waste engine oil sample, first level impurities were removed by chemical precipitation and de-asphalting. In it, 20 ml of H_2SO_4 (65%w/w) was added into a 250 ml beaker containing 150 ml waste engine oil, amidst vigorous agitation with the aid of a mechanical stirrer or mixer operating at 360 rpm for a period of 1 h. The content was then allowed to rest for another 6 h, during which precipitates were observed to have settled at beaker bottom. Thereafter, the acidified waste engine oil was washed with 10 ml of NaOH (65%w/w), then filtered to recover the filtrate and discards the sediments. This procedure was repeated several times in order to produce about 5000 ml of acid treated waste engine oil.

2.3.2. Carbonization of coconut husk

The sun-dried coconut husk was chopped into pieces, weighed and inserted into a tubular furnace, which was fired with the aid of combustion in excess air. The burning was monitored for a period of 2 h until the entire fibers were completely burnt into charcoal. The charcoal was further crushed into fines and sieved with the aid of a shaker to recover charcoal of size range: 0.5 mm to 3 mm from the un-carbonized chaff.

2.3.3. Activation of carbonized-clay

Mixtures of bentonite clay and charcoal from coconut husk were prepared in the ratios of clay to charcoal of 2:1, 1:1 and 1:2 to form carbonized-clay adsorbent samples A, B and C respectively.

100 ml of H_2SO_4 (65% w/w) and 10 mg of $CaCl_2$ (95 %w/w) were both added to each 500 mg of the carbonized-clay sample, amidst thorough mixing and mashing. The samples were then slowly dried in an oven at 110^{o}C for 15mins. After cooling, they were washed thoroughly with distilled water, in order to remove its acid content. The washed carbonized-clay samples were again oven-dried at 90^{o}C to remove residual moisture, and followed by pulverization of the activated carbonized-clay into fine particulates.

2.3.4. Characterization of engine oil sample

The methods of characterization presented here were used for both the waste and refined engine oil samples. Physicochemical properties considered include: Density, viscosity, pour point, cloud point, flash point, acidity or neutralization number and ash content. Others were coking test, water content and metal content.

Density: A hydrometer was used for the density measurement. In it, a given volume of oil sample was measured into a graduated cylinder, wherein a hydrometer was inserted into the cylinder from the top. The device was allowed to float in the oil until the point when oil level in cylinder coincides with the hydrometer instrument. That point is read as the specific gravity or density of the oil sample.

Viscosity: A rotational viscometer (equipped with digital meter and memory device) was used for the measurement. Oil sample at 40°C was measured into a cup, while the viscometer spindle at 600 rpm was inserted into the oil cup followed by shearing. After a few seconds, a stable digital value of dynamic viscosity was directly read from the instrument digital meter. This procedure was repeated thrice; while a mean value was taken from the triplicate.

Alternatively, a capillary glass viscometer was also used for the measurement. A ball bearing of 5 mm diameter was dropped into the capillary glass tube containing engine oil, and with the aid of stop-watch, the time of fall from top to bottom of glass tube was measured. This procedure was also repeated thrice in order to obtain a mean time of fall, t. The Dynamic viscosity was estimated using equation 1. Also, the kinematic viscosity, υ is obtained by dividing the dynamic viscosity, μ by engine oil density.

$$\mu = K(\rho_b - \rho)t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where; μ = viscosity (cP); ρ_b = density of ball bearing; ρ = density of engine oil; Sample; t = mean time of fall (s); K = instrument constant.

Viscosity Index: This parameter measures the extent at which fluid viscosity is affected by temperature change. The higher the viscosity index, VI, the more will engine oil viscosity decrease as temperature increases, and vice versa. Standard procedure according to ASTM D-2270 was followed for the measurement. Thus, at standard temperature condition of 40 ^{o}C, two reference oils viscosities of between 0 and 100 were selected from table, and named L and H. The viscosity of test oil sample was measured as U. Use equation 2 to estimate the viscosity index (VI) of the test oil sample:

$$VI = \frac{(L-U)}{(L-H)} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Flash Point: This is the ignition temperature of oil vapour. The flash point of oil was determined by heating it at constant pressure until it produced enough vapour to make an ignitable combination with air. Since test engine oil was in an open cup, its temperature was progressively elevated and monitored using a thermometer. A test flame was swept over the cup using matches at prescribed intervals until the test oil sample vapour ignited. The flash point is the temperature at which fire sparks.

Neutralization Number: The test for Neutralization Number or Total Acid Number (TAN) of the used oil sample was conducted using ASTM D-974. It is the quantity in milligrams of potassium hydroxide (KOH) per gram of oil necessary to neutralize acidity. Two grams of used oil sample was weighed and mixed with 100 mL of the titration solvent (toluene and isopropyl alcohol containing a small amount of water) and 0.5 mL of the indicator solution (*p*-naphtholbenzein) and swirled until the sample was entirely dissolved by the solvent. The mixture assumes a yellow-orange colour and titrated with 0.1 M KOH solution in increments and mixed vigorously near the end point i.e. green colour; to observe the end point of dark-coloured oil, the flask is shaken vigorously to produce momentarily slight foam and the colour change occurs under a white fluorescent. The neutralization number or Total Acid Number (TAN) is calculated as;

$$TAN\left(\frac{mg\ KOH}{g\ sample}\right) = \frac{[(A-B)\times M\times 56]}{W} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where; A = KOH solution required for titration of the sample, mL,
B = KOH solution required for titration of the blank, mL,
M = Molarity of the KOH solution, and
W = mass of sample used, g.

Coking Test: The test followed the ASTM D524 standard for coking test measurement. It is the amount of carbon residue obtained as oil is heated to a high temperature in the absence of air is called coking test. In it, 3 g of used oil is measured on a crucible and put into a tubular stainless-steel apparatus which was inserted into a tubular furnace. The apparatus was then flashed with N_2 gas so as to make the environment inside inert. The test is conducted at 550°C for thirty minutes. Finally, the remaining residue is measured to calculate its percentage of the initial sample.

$$\%\ Carbon\ Residue\ = \frac{m(carbon\ residue)}{m(initial\ sample)} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Ash Content: ASTM D-482 standard was followed. The ash content is the measure of the amount of incombustible material present in a lubricant which can be determined by measuring the amount of ash after combustion of oil in a furnace. In it, measured amount of oil sample is put in a crucible and burned for 5 h in the furnace at 800°C. Mass of the remaining ash was measured and its percentage is calculated by dividing it with initial mass of the sample.

$$\%\ Ash = \frac{mass\ of\ ash}{mass\ of\ initial\ sample} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Water Content: This is the amount of water present in the lubricant. It is estimated by putting a measured amount of sample in an oven at 120°C for 1 h. The dehydrated sample is then reweighed to calculate the loss.

$$\%\, Water = \frac{(mass\ of\ initial - mass\ of\ final)\ sample}{mass\ of\ initial\ sample} \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Heavy Metal Content: A fast sequential atomic absorption spectrophotometer (AAS) was used for the measurement according ASTM D-4628-2 standard. Before the analysis, the oil sample was heated to 60 °C and stirred to ensure homogeneity of the sample, it was then mixed with ten volumes of kerosene. Sets of standardized organo-metals from (Cu, Fe, Pb) and 4-cyclohexylbutyric acid salts were prepared, and metal concentrations were determined by introducing the test solutions of engine oil samples into the flame of the AAS, and recording the responses. Metal concentrations were determined from the calibration curve that is obtained from standard solutions.

2.4. Design of Experiment

This study made use of design expert to in order accommodate the influence of the experimental variables (or factors) and design factor levels on the number of experimental runs for each method being studied: carbonized-clay adsorption and solvent extraction. The experimental variables considered were defined as follows:

Carbon-clay ratio: It is the ratio of amount of carbon obtained from coconut husk to the amount of bentonite clay in the adsorbent mixture. The ratio is fixed at 1:2, 1:1 and 2:1. Mixing or blending the adsorbents will increase adsorption capacity and performance of adsorption of the waste engine oil treatment.

Adsorbent ratio: It is the ratio of amount of carbonized-clay (adsorbent) to the amount of waste engine oil being treated. The ratio is fixed at 3:20, 1:5 and1:4. The adsorbent drives the removal of metals and organic impurities from the waste engine oil samples.

Solvent ratio: It is the ratio of quantity of solvent applied to the quantity of waste engine oil being treated. The ratio is fixed at 2:1 to 11:1. The solvent will create the required surface area for extraction.

Therefore, the proposed matrices for the experimental design for both solvent extraction and carbonized-clay methods are presented as shown in Tables 2 and 3.

Table 2 Experimental design for solvent extraction treatment

Solvent Ratio (v/v)	**Ethanol**
2	Run 1
4	Run 2
5	Run 3
6	Run 4
7	Run 5
8	Run 6
9	Run 7
10	Run 8
11	Run 9

Table 3 Experimental design for carbonized-clay treatment

Carbon-clay ratio (%w/w)	**Adsorbent-oil ratio (%w/v)**		
	15	20	25
50	Run 1	Run 2	Run 3
100	Run 4	Run 5	Run 6
200	Run 7	Run 8	Run 9

2.5. Experimental Treatment of Waste Engine Oil

2.5.1. Carbonized-clay adsorption Treatment

In line with specifications from design expert, actual quantities of adsorbent-oil ratios (based on 15, 20 and 25%w/v) and carbon-clay ratios in the adsorbent (based on 50, 100 and 200 %w/w) were prepared and administered for the experimental runs as shown in Table 3. For run 1, 200 ml of acid treated waste engine-oil sample was dosed with 30 mg of carbonized-clay adsorbent (ratio 50%w/w or 1:2) amidst vigorous mixing in a 250 ml beaker at 250 rpm. The content was allowed to rest for another 8 h, after which it was filtered to recover the engine oil as filtrate. The filter medium was a filter cloth which squeezes out residue engine oil. The yield was recorded, while AAS was used to check the residual metal concentrations. This procedure was repeated for other runs in line with design expert specifications. Optimal yield of engine oil from the adsorption treatment was also measured.

2.5.2. Solvent Extraction

High purity ethanol was used as solvent. The solvent-oil ratio was followed as specified for in the respective runs in the design expert. A soxhlet extractor was used for the extraction. 100 ml of acid treated waste engine oil was used as treatment quantity for all the runs. For run 1, 100 ml waste engine oil was extracted with 200 ml ethanol solvent. With a heating mantle base, the soxhlet extractor operated at constant temperature of 60 ^{o}C amidst agitation for 1 h contact time. The extract was collected at extractor overhead via a condenser unit. The solvent was recovered by distillation. The quantity of oil recovered was measured as yield of extraction in millilitre volume. This procedure was repeated for all the runs.

2.6. Response Surface Modelling

In the RSM modelling environment (MINITAB), the procedure is to enter into the worksheet with a single column of measurement for the response variable (i.e. yield of engine oil), and also enter a column of data for each predictor variable (i.e. carbonized-clay, adsorbent-oil and solvent-oil ratios respectively). Then follow the stat > regression > regression > fit regression model path, and click model in order to specify the interaction and polynomial terms. Then enter your response and predictor variables including other terms of the model. Thus, fit regression model can be categorical and continuous predictors. Under predictor, press control (ctrl) key and select carbonized-clay ratio, X_1 and adsorbent-oil ratio, X_2, or solvent-oil ratio, X_3, for solvent extraction method. Using interactions through order, choose 2 for carbonized-clay adsorption method and 1 for solvent extraction method; click add, and then click ok in order to output the model expression and the related statistics.

Based on a full factorial design, second order model in quadratic response format was developed for carbonized-clay adsorption method of treatment, while a first order model in linear response format was developed for solvent extraction method of treatment. These proposed equations are shown in equations 7 and 8.

$$Y = a_0 + \sum_{i=1}^{n} a_i X_1 + \sum_{j=1}^{n} b_j X_2 + \sum_{i=1}^{n} a_{ii} X_1^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots 7)$$

and

$$Y = p_0 + \sum_{i=1}^{n} p_i X_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where, Y = response variable; X_1, X_2, X_3 = Predictor variables; a_0, a_i, a_{ii}, b_j and p_0, p_i = constant coefficients.

2.6.1. Goodness-of-fit

The accuracy of the generated models is determined by method of goodness-of-fit. The R^2 determine the degree of correlation between experimental and predicted data, the percentage deviation (p) measures the level of variance between experimental and predicted results. Standard error of estimate (SE) measures the error associated with the measurement. Analysis of variance (ANOVA) determines the degree of regression between the variables. If $R^2 = 1$, it means all plotted data aligns to form a smooth curve, if $R^2 < 1$, it means some of the plotted points are out of the curve, but if $R^2 = 0$, means there is no correlation or a case of highly scattered data is evident. For this study, a percentage deviation of 5% and below shall be considered as insignificant difference.

Coefficient of Correlation (R^2)

Coefficient of correlation for a regression model can be determined using the spearman product moment correlation coefficient (SPMCC) for the engine oil treatment process. The formula for SPMCC equation is given as shown in equation 9.

$$R^2 = P_{Y_eY_p} = \frac{N(\sum Y_eY_p)-(\sum Y_e \sum Y_p)}{\sqrt{\left(N(\sum Y_e^2)-(\sum Y_e)^2\right)-((N\sum Y_p^2)-(\sum Y_p^2))}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where, Y_e = experimental yield of refined-engine-oil (%); Y_p = predicted yield of refined-engine-oil (%) and N = number of runs.

Percentage Deviation (D)

Percentage deviation, D measures the accuracy associated with the prediction from the empirical model. In this case, the accuracy of the predicted yield of refined-engine-oil compared to its experimental yield is being determined. Percentage deviation is estimated using equation 10.

$$\%\, D = \left(\frac{Y_P - Y_e}{Y_e}\right) \times \frac{100}{1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where, Y_p = predicted yield of refined-engine-oil; Y_e = experimental yield of refined-engine oil.

3. Results

3.1. Experimental results

The experimental results obtained from this study are presented in Tables and Figures as follows.

Table 4 Physicochemical properties of waste and refined engine oil samples

Properties	**Waste Engine Oil**	**Refined Engine Oil (with carbonized-clay adsorption)**	**Refine Engine Oil (with solvent extraction)**
Flash point	210	225	220
Dynamic viscosity @ 600 rpm at 40^o C (cP)	135	195	185
Kinematic viscosity @ 40 ^{o}C (cSt)	160.34	222.7	211.2
Cloud point	>15	>15	>15
Pour point, ^{o}C	>15	>15	>15
Specific gravity @ 40 ^{o}C	0.90	0.876	0.876
Water content. ppm	1100	84.4	40
Ash content, %	1.8	0.4	0.45
Heavy metals: Cu (mg/l) Fe (mg/l) Pb (mg/l)	 88.9 322.8 12.4	 3.5 53.6 7.2	 8.5 58.6 8.8

Table 5 Results from using carbonized-clay adsorption method

Experimental run	Carbon-clay ratio (%)	Adsorbent-oil ratio (%)	Yield of engine oil (%)
1	50	15	77.8
2	50	20	74.1
3	50	25	70.8
4	100	15	69
5	100	20	65.2
6	100	25	65.1
7	200	15	61.4
8	200	20	60.0
9	200	25	55.8

Table 6 Results of solvent extraction on waste engine oil

Run	Solvent to Used-engine-oil ratio	Yield of engine oil (%)
1	2	52.2
2	4	56.5
3	5	59.7
4	6	61.9
5	7	63.3
6	8	64.8
7	9	72.5
8	10	74.3
9	11	76.5

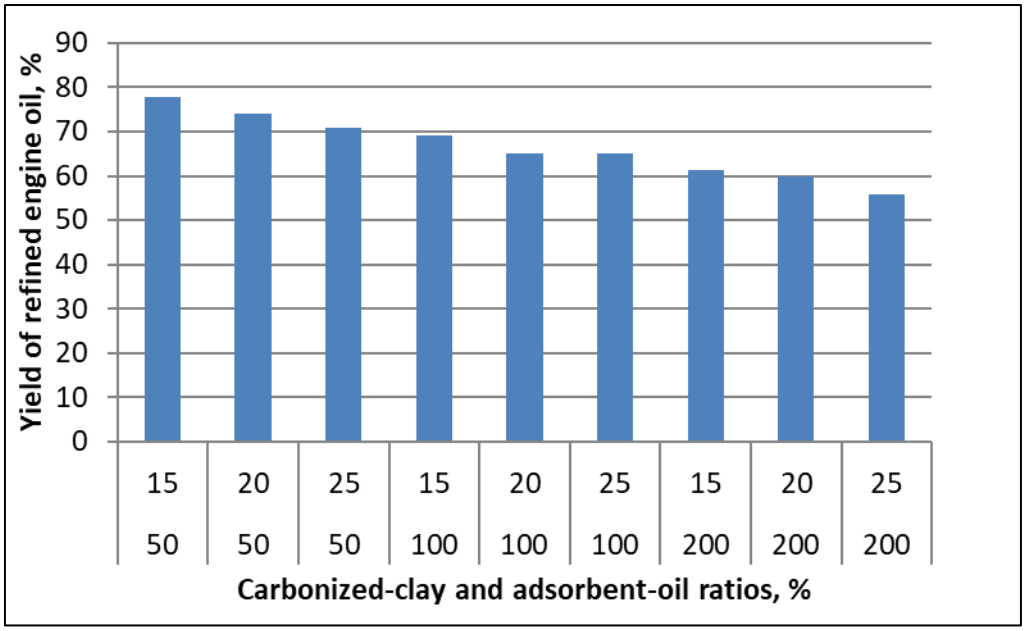


Figure 1 Graph of yield of refined engine oil versus carbonized-clay and adsorbent-oil ratios

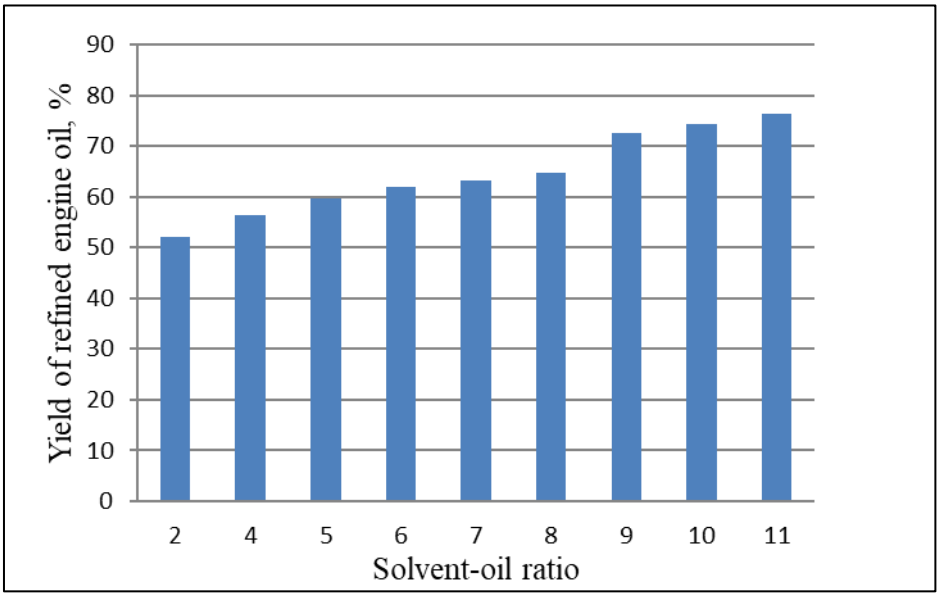


Figure 2 Graph of yield of refined engine oil versus solvent-oil ratio

3.2. Regression models for waste engine oil treatment

Results of the regression models from RSM method for adsorption and solvent extraction treatments of waste engine oil are presented as follows:

Adsorption treatment model:

$$Y = 60.9 + 0.45X_1 - 0.08X_2 - 0.004X_1^2 \quad (R^2 = 0.87) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Solvent Extraction model:

$$Y = 49.7 + 2.985X_3 \quad (R^2 = 0.97) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Table 7 Experimental and predicted yields of refined engine oil using solvent extraction treatment

Run	Solvent-oil ratio	Experimental yield of refined engine oil, %	Predicted yield of refined engine oil, %
1	2	52.2	55.67
2	4	56.5	61.64
3	5	59.7	64.625
4	6	61.9	67.61
5	7	63.3	70.595
6	8	64.8	73.58
7	9	72.5	76.565
8	10	74.3	79.55
9	11	76.5	82.535

Table 8 Experimental and predicted yields of refined engine oil using adsorption treatment

Run	Carbon-clay ratio (%w/w)	Adsorbent-oil ratio (%w/v)	Experimental yield of refined engine oil (%)	Predicted yield of refined engine oil (%)
1	50	15	77.8	72.2
2	50	20	74.1	71.8
3	50	25	70.8	71.4
4	100	15	69	64.7
5	100	20	65.2	64.3
6	100	25	65.1	63.9
7	200	15	61.4	-10.3
8	200	20	60	-10.7
9	200	25	55.8	-11.1

4. Discussion

Results obtained from this study are discussed under the following sections.

4.1. Physicochemical properties of engine oil

Two grades of engine oil samples were analyzed for physicochemical properties in this study, namely, waste engine oil and refined engine oil. However, the refined engine oil was a product of the treatment undergone by the waste engine oil.

The following were the physicochemical properties considered for the analysis: specific gravity, viscosity, flash point, cloud point and pour point. Others are water content, ash content and heavy metal contents which are usual contaminants in waste engine oils in already published literature [6, 7, 8]. Apart from the physical inspection evidences of black coloration and petrol odor in waste engine oil sample, the results (Table 4) also showed further evidences of degradation and deformation due to the fact that its dynamic and kinematic viscosities had respectively dropped to 135 cP and 160 cSt when compared with the refined engine oil. There was also evidence of contamination in the waste engine oil sample, with some impurities such as water (1100 ppm), Cu (88.9 mg/l), Fe (322.8 mg/l) and Pb (12.4 mg/l).

The refined engine oil sample which had undergone treatment showed improved physicochemical properties. Their viscosities were enhanced to 185 cP and 211.2 cSt for dynamic and kinematic viscosities respectively. This increase would help to reduce friction between the piston rings and cylinder walls of an engine [9]. Also, the contamination level in the refined engine oil was highly reduced. Water and heavy metals contents dropped respectively: water (40 ppm), Cu (8.5 mg/l), Fe (58.6 mg/l) and Pb (8.8 mg/l).

4.2. Waste engine oil treatment

For this study, waste engine oil sample was subjected to three levels of treatments, namely preliminary, adsorption and solvent extraction treatments. The second and third treatments are considered significant because of its efficiency of treatment. The adsorption treatment method made use of carbonized-clay as adsorbent, and yielded refined engine oil samples based on different experimental runs as established by software. The optimal yield of the refined engine oil was obtained as 77.8 %, which was favored by carbon-clay ratio of 50% and adsorbent-oil ratio of 15 % (Table 5 and Figure 1). The implication of this finding is that adsorbent admixture of carbon-clay ratio of 1:2 is most favorable for waste engine oil adsorption treatment. Therefore, adsorbent admixture with carbon-clay ratio higher than 1:2 will not be very suitable for waste engine oil treatment.

In the same vein, solvent extraction method was used for waste engine oil treatment. Design expert software specified nine experimental runs, while the solvent-oil ratio of 11:1 was observed to yield optimally, 76.5 % of refined engine oil (Table 6 and Figure 2). This result implied that larger volume of solvent is more suitable for solvent extraction treatment for waste engine oil. In addition, the suitability of ethanol as test solvent for waste engine oil treatment is also validated.

4.3. Empirical model for waste engine oil treatment

The empirical (or regression) models developed for the adsorption and solvent extraction treatments for waste engine oil samples were tested for accuracy. To achieve the level of accuracy desired, yields of refined engine oil were predicted from developed empirical models for both cases (Table 7 and 8), while the predicted and experimental values of the yield of refined engine oil were compared for strength or degree of correlation. The results respectively showed R^2 for both adsorption and solvent extraction treatments as 0.87 and 0.97, indicating a strong degree of correlation between predicted and experimental values of yield of refined engine oil for both treatment methods.

5. Conclusion

The adsorption and solvent extraction methods showed evidence of effectiveness in the treatment of waste engine oils as indicated in the physicochemical property analysis results. However, the effectiveness of the carbonized-clay adsorbent was imparted positively by its moderate charcoal content of the admixture adsorbent. More importantly, the adsorbent to waste engine oil ratio was also moderate for higher adsorption capacity. Higher volume of ethanol solvent is seen to be effective for high yield of refined engine oil production. Empirical model expression of the quadratic format is suitable for adsorption treatment of waste engine oil, while that of linear format is suitable for solvent extraction treatment.

Compliance with ethical standards

Disclosure of conflict of interest

All authors declare no conflict of interest.

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