Optimisation of Base Oil Regeneration Using Response Surface Methodology From Spent Lubricating Oil Through Binary Solvent Extraction Process

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Abstract. Spent lubricating oil (SLO) is a high-pollutant material that requires responsible management. It may cause adverse effects to the environment when dumped into the ground or wastewater streams, resulting in soil and groundwater contamination. This research investigates the regeneration of spent lubricating oil using a binary solvent (hexane and methyl ethyl ketone). The laboratory experiment was based on a central composite design with two levels using response surface methodology. The SLO physicochemical properties gave the following undesired characteristics: low flash point (159°C), high specific gravity (0.9887), high kinematic viscosity at 40°C and 100°C (37.7 cSt and 11.4 cSt), high total acid number (3.9 mg KOH/g) and high colour index (11.0). The experimental run with a solvent-to-oil ratio of 3.99, mixing time of 30 min and agitation speed of 599 rpm was chosen as the optimum combination using statistical analysis. The optimum run yielded 77.20%, ash content 0.29%, and sludge removal percentage 11.25%. The adsorption process using kaolin achieved an 88.88% reduction in zinc ions concentration, while a 46.32% reduction was achieved for iron ions. However, a slight reduction in percentage yield (2.77%) was observed after the adsorption process. The regeneration process gave a yield of 75.06%. Physicochemical parameters of regenerated base oil; specific gravity (0.8699), kinematic viscosity at 40°C and 100°C (26.1 cSt and 7.3 cSt), flash point (192°C) conformed to ASTM standards while total acid number (0.96 mg KOH/g) and colour index (6) were slightly above the required values. The results showed that regenerated base oil has a comparable quality to virgin base oil (SN 150), indicating the process's effectiveness and the possibility of utilising the oil safely.

Keywords: spent lubricating oil; oil regeneration; kaolin.

INTRODUCTION

Spent lubricating oil is any synthetic or petroleum-based oil used for lubrication and has outlived its original use. After losing its original qualities, used oil can no longer be used. Physical pollutants cause this loss from the fuel, oxidation, air, and additives [1] and chemical reactions during use. Two solutions are provided locally for used oil management. It is either used directly or recycled.

Due to high levels of contaminants and negative effects on plants, aquatic and human lives, several ways have been developed to manage spent lubricating oil, including re-refining to regenerate base oil [2]. Regeneration is a form of solvent extraction that involves the use of a solvent to extract the lubricating oil from an oil-contaminated mixture selectively. Several materials have been employed to extract solvents, including new hydrocarbon solvents.

Recycling of waste oil is receiving a lot of attention. Authors [3] reported that recycling used lubricating oil deals with subjecting the oils to a series of processes that can eliminate most contaminants, including water, oxidation products, and additives, thereby allowing the initial

characteristics of the base oil to be re-established. Several methods have been proven feasible in the recycling of used lubricating oil. However, not all of them are economically feasible because of high energy consumption during recovery.

This study aims to develop a regression model collaborating the response (percentage yield and Percentage sludge removal) to the process variables (solvent to oil ratio, mixing time and agitation speed). This research aims to regenerate spent lubricating oil using binary solvent (hexane and methyl ethyl ketone) extraction technique and optimise the process variables affecting the base oil recovery yield and purity using Response Surface Methodology (RSM) through evaluation of physicochemical properties of the spent lubricating oil, regeneration and optimisation of process variables (solvent to oil ratio, mixing time, and agitation speed) using RSM for the extraction process, adsorption of degraded additives and heavy metals using kaolin and assessment of recovery capacity of the process by comparing the recovered base oil with virgin base oil.

METHODS AND MATERIALS

Spent lubricating oil was collected from a local service station in Kano, Nigeria. The samples were homogenised, transferred to a tank, and stored at room temperature for 7 days to allow large suspended particles to settle under gravity. Solvents used for the extraction were n-hexane and Methyl Ethyl Ketone. The adsorbent used was activated kaolin prepared in the lab of particle size 75μm.

After characterising the spent lubricating oil, the regeneration process was conducted to reduce or eliminate the various contaminants in the spent lubricating oil (SLO). The solvent extraction technique was selected to regenerate the spent lubricating oil in this research. The experimental procedure was based on the principles of the method described in the previous chapter. The first step in conducting this experiment was the pretreatment of the SLO, followed by heating to remove water and some light fuels. After cooling, the solvents and SLO were mixed to extract the base oil. After the extraction process, solvent recovery was carried out to enable separation of the solvents from the oil. The recovered solvent was further reused for the extraction process, as depicted in Figure 1.

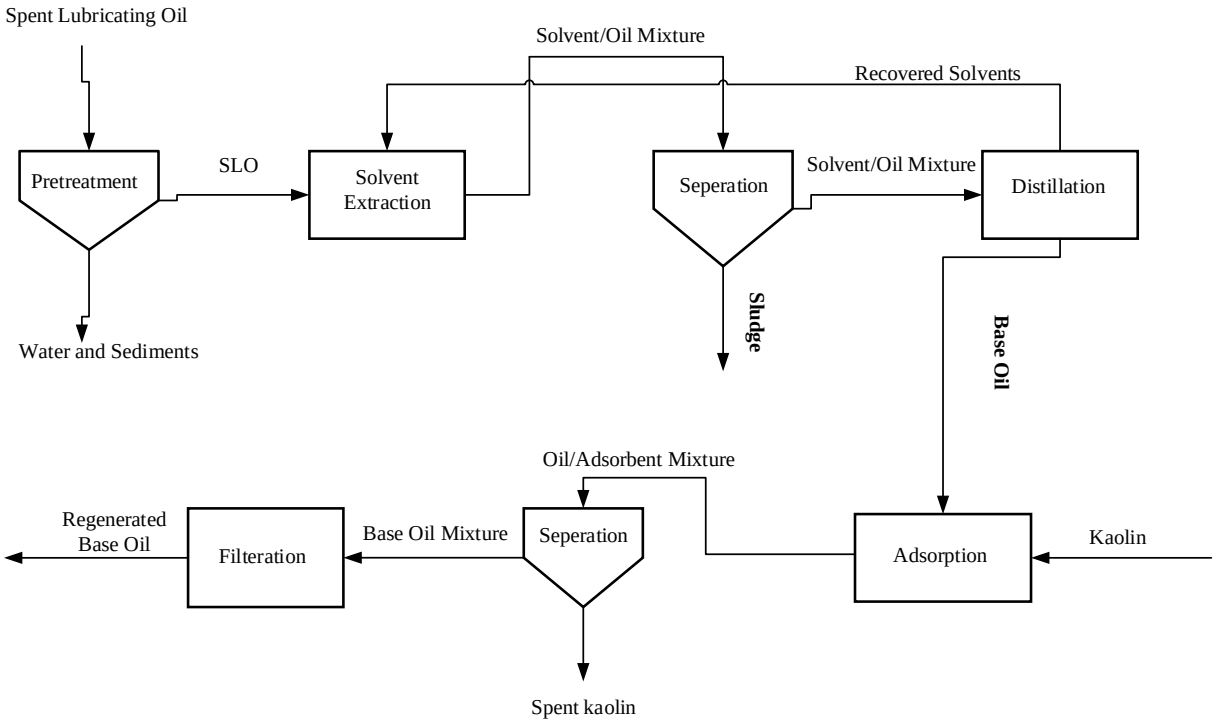

Figure 1 – Process Block Diagram for the Regeneration of Spent Lubricating Oil using Solvent Extraction / Adsorption Extraction process

The extraction process used two solvents, hexane and methyl ethyl ketone. The two solvents, hexane and methyl ethyl ketone were mixed in a ratio 2:3; 100 g of hexane was mixed with 150 g of methyl ethyl ketone. Fifty grams (50 g) of the SLO was weighed (W_{oil}) and poured into a 500 mL beaker. Different quantities of the binary solvents

were added to the oil sample in the beaker in varying ratios based on the experimental design of the central composite design of the response surface methodology.

The mixture was allowed to settle for 48 h in a separating funnel [3]. The sludge was collected from the separating funnel, weighed, and recorded (Wwet), after which it was washed with hexane to remove the remaining oil that might have been entrained. The sludge was put in an oven at 100 °C for 10 min to evaporate excess solvent, which was reported as dry sludge (W_{dry}) [4]. The weight of the dried sludge was weighed and recorded as well. The percentage sludge removal (PSR) was calculated using Eq. (1)

$$\% \text{ sludge removal (PSR)} = \frac{W_{dry}}{W_{oil}} \times 100 \qquad (1)$$

Solvent Recovery Using Atmospheric Distillation. The oil-solvent mixture was heated on an electric heating mantle in simple distillation equipment at the boiling point of hexane (69 °C). At 69 °C, hexane vapours were condensed through the condenser and collected in a flask until no vapours were formed. The heating temperature was adjusted to 80 °C, the boiling point of methyl ethyl ketone; the vapours were also condensed and collected in a flask. The remaining oil in the distillation flask was weighed, and the percentage of the lubricant base oil extracted was calculated using Eq. (2).

$$\text{Oil yield, \%} = \frac{Oil\ extracted\ (g)}{spent\ lubricating\ oil\ feed\ (g)} \times 100 \quad (2)$$

Adsorption Process. One hundred millilitres (100 ml) of the extracted base oil was mixed with hexane in a ratio of 1:2 and then mixed with varying amounts of adsorbent (kaolin) from 0.5 g to 2.5 g. The mixture was stirred properly at a constant mixing time of 3 h in a batch adsorption process at ambient temperature. The oil and adsorbent mixture were allowed to sediment in a beaker for 24 hours, and the oil and solvent mixture was decanted into another beaker. The treated oil was filtered, and the solvent was recovered using a simple distillation process at 70 °C. The yield of the regenerated base oil after adsorption was computed using Eq. (2). The physicochemical properties of the regenerated base oil were further analysed.

Clay Preparation. Raw kaolin was obtained from a deposit in Alkaleri, Bauchi State. Five hundred grams (500 g) of the clay was weighed and crushed down from lumps to coarse powder using a wooden mortar and pestle. The coarse powder was soaked in five litres (5 l), sieved and dried [5]. The dried clay cake was milled and sieved to a size of 75 μm [6] and stored in polyethene bags for subsequent experiments. The beneficiated clay was calcined at 700 °C for two hours in a muffle furnace for processing into metakaolin [6]. The metakaolin was dealuminated using H_2SO_4 and then oven-dried at 120°C for four hours [7]. The dried dealuminated kaolin was ground and sieved to 75 μm.

Tests for both spent and regenerated base oil. The spent and regenerated base oil were tested for kinematic viscosity at 40 °C and 100 °C using a viscometer per ASTM D445, and the TAN (total acid number) was tested per ASTM D974. The pour point was determined per ASTM D97, and the Flashpoint was examined using the Pensky-Marten closed cup apparatus per ASTM D93. Ash content was determined using ASTM D482, while specific gravity was determined using a hydrometer per ASTM D1298.

Table 1 – 2- Level-3-Factor Experimental Design Plan

Name	Units	-1 Level	+1 Level
Solvent: Oil	Molar ratio	2	6
Agitation Speed	rpm	300	700
Mixing Time	minutes	15	35

RESULTS AND DISCUSSION

Characterisation of spent lubricating oil. The results of the characterisation of spent and regenerated lubricating oil are presented and discussed. The physicochemical properties of the SLO are listed in Table 2.

Table 2 – Physicochemical Properties of the Spent Lubricating Oil

Property	SLO	SN 150 Base	Test Method
Specific gravity @15 °C	0.9887	0.85-0.87	ASTM D1298
Flashpoint, °C	159	>180	ASTM D93
Colour	11.0	1.5-2.5	
Pour point, °C	-17	-12	ASTM D1500
Kinematic viscosity @40 °C, cSt	37.7	25-40	ASTM D97
Kinematic viscosity @100 °C, cSt	11.4	5-7	ASTM D445
TAN, mg KOH/g	3.9	<0.05	ASTM D445
			ASTM D974

From Table 2, it can be seen from the physicochemical analysis of the spent lubricating oil that there is a significant property alteration compared to virgin base oil due to significant deterioration during its service period. The lower flash point of 159 °C indicates light fuel contamination. A substantially low flash point of lubricating oil indicates that the oil has been contaminated with volatile hydrocarbons such as gasoline or oxidation products. An increase in specific gravity indicates the presence of solid matter and oxidised and condensed products rich in carbon. The increase in viscosity parameters can be attributed to oxidised and polymerised products dissolved and suspended in the oil. As shown in Table 6 above, the SLO's total acid number (TAN) is measured to be 3.9 mg KOH/g oil. This could be due to organic materials, heavy metal salts, and oxidation products that occur at high temperatures in the engine during use. The pour point value of -12 °C indicates degradation of additives in the lubricating oil as pour point depressants. A colour index value of 11.0 signifies the presence of a soot gel network as well as the deterioration of the oil.

Physical analysis of extracted base oil. The result of the physical analysis of the extracted base oil conducted per the experimental runs generated by the software is listed in Table 3. From the analysis, it was observed that the maximum and minimum yield, PSR and ash content were 90.01, 59.67, 12.32, 4.75, 0.78 and 0.25% respectively.

Table 1 – Results from Physical Analysis of Extracted Base Oil

Factors				Responses		
Run	SOR, wt./wt. %	Mixing time, min	Agitation speed, rpm	Yield %	Ash content %	PSR %
1	2	22.5	500	61.52	0.69	6.93
2	4	22.5	500	75.82	0.35	12.01
3	4	22.5	300	71.5	0.4	8.93
4	4	22.5	500	75.27	0.36	11.61
5	4	22.5	500	74.99	0.37	11.27
6	4	22.5	500	75	0.39	11.00
7	4	22.5	500	75.03	0.36	12.32
8	6	30	300	82.37	0.29	6.51
9	4	22.5	500	75.12	0.35	12.50
10	4	22.5	700	77.86	0.31	10.10
11	2	15	300	59.67	0.78	4.75
12	4	15	500	73.75	0.4	11.21
13	6	30	700	90.55	0.25	5.92
14	6	15	300	81.93	0.29	6.48
15	2	30	700	65.73	0.52	6.31
16	4	30	500	76.14	0.32	11.47
17	6	15	700	90.01	0.3	5.75
18	2	15	700	64.31	0.71	6.02
19	2	30	300	60	0.61	5.66
20	6	22.5	500	86.22	0.29	6.89

Statistical Analysis. Model equations were developed to represent the three responses evaluated: yield, ash content and PSR as a function of solvent oil ratio (A), mixing time (B) and agitation speed(C). The coded equations are presented below:

$$\text{Yield} = +75.048 + 11.985A + 0.512B + \\ + 3.299C + 0.73625AC - 0.817A^2 \quad (3)$$

$$\text{Ash content} = + 0.361 - 0.189A - 0.049B - \\ - 0.028C + 0.03875AB + \\ + 0.01625AC + 0.112A^2 \quad (4)$$

$$\text{PSR} = +11.5564 + 0.188\,A + 0.177\,C - \\ - 0.405AC - 4.17688\,A^2 - 1.57187C^2 \quad (5)$$

Equations 3, 4 and 5 show the adequacy of the quadratic models, which were statistically significant with F-values of 96.72 for yield, 25.90 for PSR and 96.73 for ash content. The effects of the model terms on the responses are reviewed by their F-values.

Table 4 – Analysis of Variance (ANOVA) of the Developed Yield Quadratic Model

Source	Sum of squares	df	Mean square	F-value	p-value
Model	1555.53	5	311.11	1368.52	< 0.0001 Significant
A-SOR	1436.40	1	1436.40	6318.54	< 0.0001
B-Time	2.62	1	2.62	11.53	0.0043
C-Agitation speed	108.83	1	108.83	478.75	< 0.0001
AC	4.34	1	4.34	19.08	0.0006
A2	3.34	1	3.34	14.68	0.0018
Residual	3.18	14	0.2273		
Lack of Fit	2.67	9	0.2971	2.92	0.1252 Not significant
Pure Error	0.5085	5	0.1017		
Cor Total	1558.71	19			

Table 5 – Analysis of Variance (ANOVA) of the Developed PSR Quadratic Model

Source	Sum of squares	df	Mean square	F-value	p-value
Model	140.96	5	28.19	94.23	< 0.0001 Significant
A-SOR	0.3534	1	0.3534	1.18	0.2954
C-Agitation speed	0.3133	1	0.3133	1.05	0.3235
AC	1.31	1	1.31	4.39	0.0549
A^2	55.83	1	55.83	186.61	< 0.0001
C^2	7.91	1	7.91	26.43	0.0002
Residual	4.19	14	0.2992		
Lack of Fit	2.43	9	0.2698	0.7664	0.6573 Not significant
Pure Error	1.76	5	0.3520		
Cor Total	145.15	19			

Table 6 –Analysis of Variance (ANOVA) of the Developed Ash Content Quadratic Model

Source	Sum of squares	df	Mean square	F-value	p-value
Model	0.4659	6	0.0777	257.84	< 0.0001 Significant
A-SOR	0.3572	1	0.3572	1186.14	< 0.0001
B-Time	0.0240	1	0.0240	79.73	< 0.0001
C-Agitation speed	0.0078	1	0.0078	26.03	0.0002
AB	0.0120	1	0.0120	39.89	< 0.0001
AC	0.0021	1	0.0021	7.01	0.0201
A^2	0.0627	1	0.0627	208.27	< 0.0001
Residual	0.0039	13	0.0003		

Source	Sum of squares	df	Mean square	F-value	p-value
Lack of Fit	0.0028	8	0.0003	1.53	0.3309 Not Significant
Pure Error	0.0011	5	0.0002		
Cor Total	0.4698	19			

Table 7 – R2 Statistics for the Regression Model

Response	R^2	Adj R^2	Pred R^2	Adq Pre	Std. Dev	Mean	C.V %	PRESS
Yield	0.9982	0.9965	0.9883	83.9673	0.5321	74.64	0.7128	18.18
Ash content	0.9917	0.9878	0.9721	51.8183	0.0174	0.4170	4.16	0.0131
PSR	0.9711	0.9608	0.9409	21.7591	0.5470	8.68	6.60	8.58

The 'Lack of Fit' values for yield, PSR and ash content, which are 0.1252, 0.3309 and 0.6573, respectively, were not significant, which is desirable.

The R^2 values for yield, PSR and ash content (0.9982, 0.9711 and 0.9917) are very close to unity, meaning that the regression models fit the experimental data well. The coefficient of variation, C.V for yield (0.7128), which is less than 1, indicates a relatively low variation, indicating high precision and good reliability of the experimental values.

Three Dimensional plots. From Figure 2, an increase in solvent-to-oil ratio from 2:1 to 6:1 led to an increase in yield (61.8686% to 85.5827%), which conforms with the results [8, 9]. However, an increase in mixing time could not favour the yield, as seen in Figure 2, because as mixing time increased from 15–30 mins, the yield increased from 61.8686% to 63.021%.

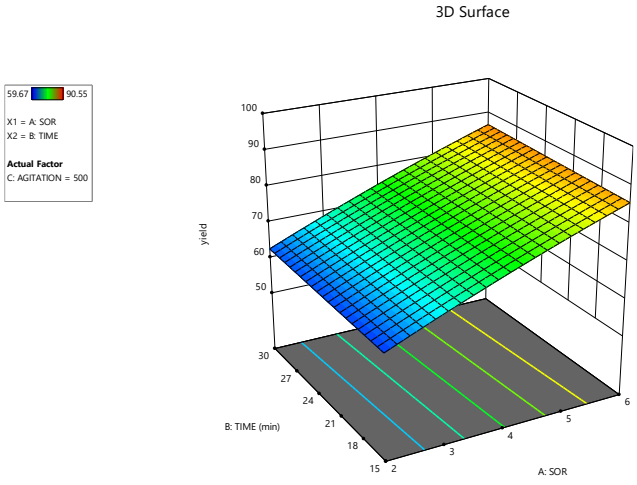

Figure 2 – Effect of Solvent to Oil Ratio and Mixing Time on Percentage Yield

The percentage yield increased rapidly with an increase in solvent-to-oil ratio compared to agitation speed. This shows that percentage yield increases with an increase in agitation speed, which conforms with the work [10]. Similarly, an increase in solvent-to-oil ratio increased the percentage yield, as established [8, 11].

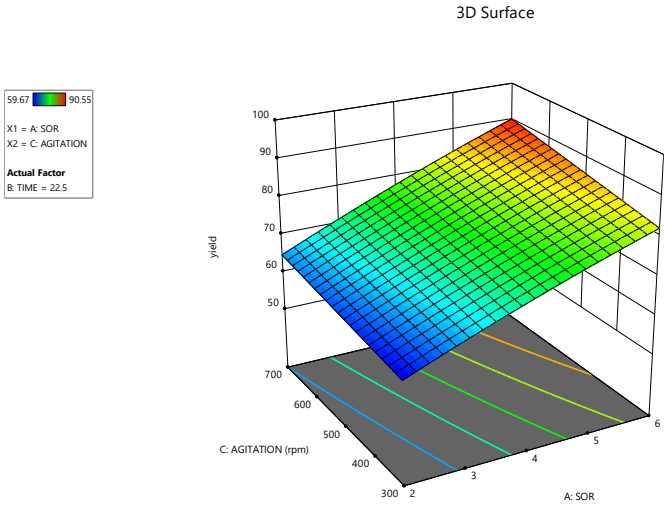

Figure 3 – Effect of Agitation Speed and Solvent to Oil Ratio on Yield

As the mixing time increased from 15 to 30 min with a corresponding increase in solvent-to-oil ratio from 2:1 to 6:1, a decrease in ash content from 0.728908% to 0.576041% was observed, which is contrary to the findings made [9], where they reported a significant increase in ash content as mixing time increased.

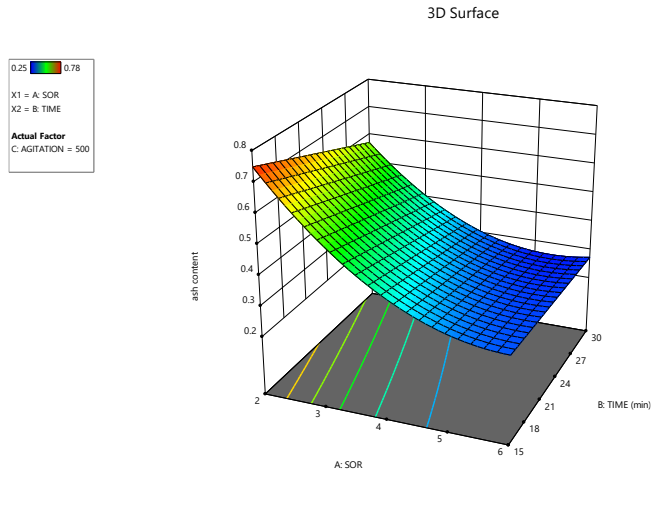

Figure 4 – Effect of Solvent to Oil Ratio and Mixing Time on Ash Content

The interactive effect of solvent-to-oil ratio and agitation speed on ash content at a constant mixing time of 22.5 min is shown in Figure 5. The percentage of ash content was observed to rapidly decrease from 0.7% to 0.295421%, with an increase in the solvent-to-oil ratio from 2:1 to 6:1, which is desirable.

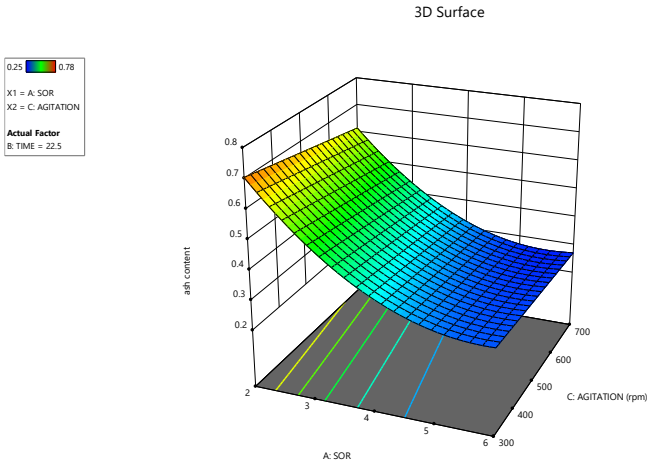

Figure 5 – Effect of Solvent to Oil Ratio and Agitation Speed on Ash Content

As observed from the plot in Figure 6, an increase in solvent-to-oil ratio increases the percentage of sludge removal, which conforms to the findings [12]. However, beyond a solvent-to-oil ratio of 4:1, a retreating effect was visible, which implies that as the solvent-to-oil ratio exceeds 4:1, some portion of the coagulated contaminants dissolve back into the extract phase, as also established [9].

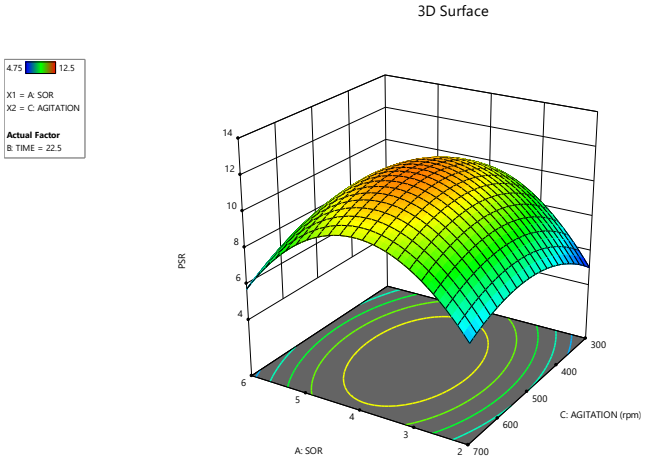

Figure 6 – Effect of Agitation Speed and Solvent to Oil Ratio on Percentage Sludge Removal

Figure 7 shows the mixing time and solvent-to-oil ratio interaction on percentage sludge removal. As the mixing time increased from 15–30 min at any given solvent-to-oil ratio, there was little or no increment in the percentage of sludge removal.

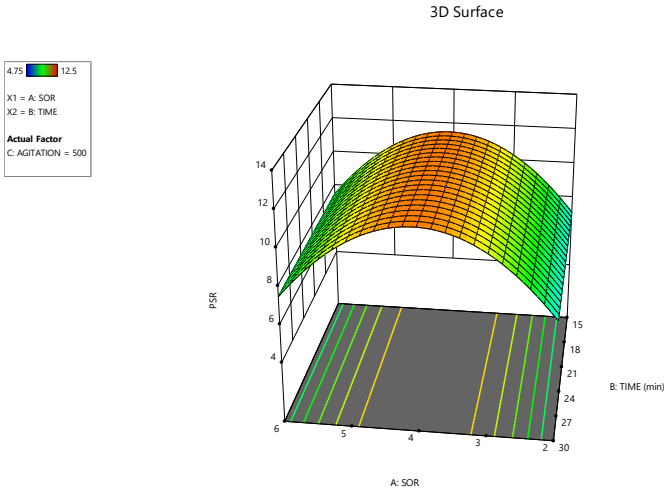

Figure 7 – Effect of Mixing Time and Solvent to Oil Ratio on Percentage Sludge Removal

Numerical Optimisation. Since the optimum condition of one response differs, optimising the design criteria favorable for the desired responses is crucial.

Table 8 – Numerical Optimisation Constraints for the Extracted Base Oil

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: SOR	minimise	2	6	1	1	5
B:Time	is in range	15	30	1	1	3
C:Agitation speed	is in range	300	700	1	1	3
Yield	maximise	59.67	90.55	1	1	5
Ash content	minimise	0.25	0.78	1	1	5
PSR	maximise	4.75	12.5	1	1	5

Table 9 – Solutions for 16 Combinations of Factor Levels

Number	SOR	Time	Agitation speed	Yield	Ash content	PSR	Desirability	
1	3.999	30.000	599.999	77.202	0.298	11.252	0.682	Selected
2	3.982	30.000	598.798	77.076	0.299	11.260	0.682	
3	4.005	30.000	596.526	77.181	0.298	11.276	0.682	
4	4.012	29.945	599.989	77.282	0.297	11.252	0.682	
5	4.007	30.000	593.727	77.149	0.298	11.294	0.682	
6	3.995	29.917	599.971	77.171	0.299	11.252	0.682	
7	4.019	30.000	590.462	77.166	0.298	11.315	0.682	
8	3.916	30.000	599.995	76.688	0.304	11.245	0.682	
9	3.973	30.000	588.654	76.855	0.302	11.325	0.682	
10	4.048	30.000	587.341	77.297	0.296	11.332	0.682	
11	4.071	30.000	585.402	77.405	0.295	11.341	0.681	
12	4.043	30.000	576.616	77.087	0.298	11.392	0.681	
13	4.012	30.000	571.185	76.811	0.301	11.420	0.681	
14	4.201	30.000	599.998	78.445	0.285	11.208	0.679	
15	4.002	30.000	557.500	76.518	0.304	11.477	0.679	
16	4.288	30.000	579.746	78.625	0.282	11.294	0.676	

The optimal condition for the extraction process was established by solving the regression equation using Design Expert Software. The optimum conditions obtained from this study were SOR (solvent: used oil) of 3.98, mixing time of 30 min and agitation speed of 612.15 rpm. At these conditions, the responses obtained were 77.53% for yield, 0.30% for ash content and 11.16% for percentage sludge removal with a desirability of 0.685.

The suitability of the model equations for predicting the optimum response values was validated using the optimal conditions suggested by CCD. From the results obtained in Table 10, the experimental values were close to the predicted values, confirming the predicted models' validity and adequacy. Under optimum conditions with a solvent-to-oil ratio of 3.99871, mixing time of 29.999 min and agitation speed of 599.999 rpm, the standard deviation values for yield, ash content, and PSR were 0.4767, 0.0173 and 0.5469, respectively, indicating the closeness to the mean of the predicted values.

Table 11 shows that the colour index value of SLO was very high due to the presence of oxidation products, burnt additives and other impurities.

Table 10 – Validation Result

Response	Predicted Mean	Predicted Median	Std Dev	n	SE Pred	95% PI low	Data Mean	95% PI high
Yield	77.2015	77.2015	0.476793	3	0.356267	76.4374	78.08	77.9656
Ash content	0.298092	0.298092	0.0173538	3	0.012967	0.270079	0.306667	0.326106
PSR	11.2519	11.2519	0.546969	3	0.370615	10.457	10.8133	12.0468

Table 11 – Comparative Properties of Virgin Base Oil, Spent Oil and Regenerated Base Oil

Property	Test Method	SN 150 Base Oil	Spent Lubricating Oil	Regenerated Base Oil
Colour	ASTM D1500	1.5-2.5	11.0	6
TAN, mg KOH/g	ASTM D974	<0.05	3.9	0.96
Kinematic viscosity @40°C, cSt	ASTM D445	25-40	37.7	26.1
Kinematic viscosity @100°C, cSt	ASTM D445	5-7	11.4	7.3
Flashpoint, °C	ASTM D93	>180	159	192
Pour point, °C	ASTM D97	-12	-17	-13
Specific gravity @15°C	ASTM D1298	0.85-0.87	0.9887	0.8699

After regeneration, a significant improvement was observed as the index value decreased from 11.0 to 6.0. This confirms that many impurities and burnt additives have been removed. However, the colour index value is not within the range of (1.0-3.0) [13] as specified for base oil.

The specific gravity values for the SLO and regenerated base oil were found to be 0.9887 and 0.8699, respectively. The decrease in specific gravity value shows that the regeneration process removed lower carbon chains, lacquer, and other impurities that caused higher specific gravity of the SLO, which conforms to findings made by [14]. The obtained specific gravity for the regenerated base oil (0.8699) is within the standard range (0.85-0.87) specified for light base oil.

The result of the kinematic viscosity test showed that the regeneration process had recovered most of the viscosity of the oil lost due to contamination during usage. The viscosity test indicates the presence of contaminants in the SLO. The presence of oxidised and polymerised products dissolved in the oil may cause an increase in the viscosity of the oil, while a decrease in the viscosity of lubricating oil could indicate fuel contamination. The kinematic viscosity of the SLO and regenerated base oil were found to be (37.7 cSt and 26.1 cSt) at 40°C and (11.4 cSt and 7.3 cSt) at 100°C, respectively. This signifies that oxidised and polymerised products were successfully reduced significantly.

Total acid number (TAN) is the weight (in milligrams) of potassium hydroxide (KOH) required to neutralise one gram of acidic materials in the oil that will react with KOH under specific test conditions. The usual major components of such materials are organic acids and soaps of heavy metals [15]. At elevated temperatures within the engine block, oxidation occurs, forming organic acids. As shown in Table 15, the TAN of the SLO and the regenerated base oil were measured to be 3.9 mg KOH/g and 0.96 mg KOH/g of oil, respectively, which indicates a significant reduction in the amount of resins, heavy metals salts and materials.

The analysis showed that the flash point was greatly improved from 159°C to 192°C. The flash point of base oil SN 150 is usually >180°C, which shows that the regeneration process eliminated the light ends in the oil. The pour point of an engine oil is the lowest temperature at which the oil will flow. Most engine base oils contain waxes and paraffins that solidify at cold temperatures [15]. The result obtained for the SLO pour point was high because of the degradation of additives in the lubricating oil. After regeneration, the pour point decreased from -17°C to -13°C, which is very close to the standard value of -12°C.

CONCLUSIONS

The study presents the utilisation of solvent extraction-adsorption technology to regenerate spent lubricating oil. This paper studied the performance of Hexane and Methyl Ethyl Ketone as solvent followed by adsorption using activated charcoal. Investigation and comparison of the properties of the regenerated base oil with SN-150 base oil specifications indicate that kinematic viscosity @40°C, kinematic viscosity @100°C, flash point and specific gravity of regenerated base oil conformed with the SN-150 standard. Adding activated kaolin (2.5 g) significantly reduced heavy metal ion concentration.

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