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Effects of Process Variables and a Comparative Study of Methods for Transfer Oil Production from Spent Engine Oil

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Authors' contributions

This work was carried out in collaboration between all authors. Author IJA wrote the first draft of the manuscript. Author JOO provided the initial topic which was eventually modified. Author MAO made useful suggestions that added value to the study, while author UGA designed and guided the study at every point to the production of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The influence of process variables on the production of transfer oil from spent engine oil (SEO) is presented in this paper. Various methods for SEO treatment are also highlighted. Process parameters like solvent type, solvent to oil ratio, extraction temperature, adsorbent to oil ratio, adsorption time (contact time), adsorption temperature and base oil to chemical additive ratio greatly influenced regeneration of base oil from SEO using solvent extraction-adsorption method which has also been established to be more advantageous over previous methods used in this process.

Keywords: Spent engine oil (SEO); regeneration; transfer oil; process parameters; methods of treatment of SEO.

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1. INTRODUCTION

The importance of environmental cleanliness to the general wellbeing of man and his environ cannot be overemphasized. This common factor has driven researchers to finding solution to environmental pollution; whether gaseous, liquid or solid [1-3]. The discharge of spent engine oil on the soil is an environmental pollution problem which must be handled with seriousness. It has been noted that there is a global increase in the use of vehicles leading to increase in the consumption of engine oil which is later discarded after use [4]. This cycle of events leads to the increase in the level of pollution by spent engine oil (SEO). The used oil contains a lot of contaminants like salt, broken down additives, varnish, gum, hydrocarbons, heavy metals, PCBs (polychlorinated biphenyls), halogen compounds etc [4-6] that are poisonous to aquatic life, human being and its environs. SEO may contain hazardous components like polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbons which have the ability to cause skin cancer [7] and fuel, which may reduce the flash point and make the material flammable [6]. Also, most heavy metals such as V, Pb, Cr, Cu, Si, Al, Mg, Zn, Ca, Ba, Mn, Ni and Fe which are not easily detected in unused lubricating oil have been noted in previous research [8-10] to give high content in used oil. According to Yong et al. [11], these heavy metals may be absorbed in the soil in the form of exchangeable cations and/or can also bound to organic matter in soils though it depends on the local environmental conditions and the type of constituent present in the soil–water system. Zenon et al. [12] noted that SEO is not safe ecologically but its technical and physical properties go alongside with the requirements of beneficial re-use and it allows the recovery of mineral base oil used to create new lubricants as a clean fuel. The sludge being a by-product from recycled used lubricating oils can be used for other purposes such as production of ink [13], modifier for bituminous materials for road, due to its richness in carbon, it can be used for the generation of carbon bar, it can be combustible which is capable of generating a net heating value of 4,000 kcal/kg [14,15] used in cement kilns for incineration. Considering these points, re-refining SEO (for environmental safety) is of a great interest due to several benefits accrue to it.

Several methods have been used for the treatment of SEO and the level of contaminants removal depends on the type of method used which can permit the re-used of the treated oil [16]. However, not all of these methods are economically viable, mainly due to the high energy consumption along the recovery process, together with the treatment of the produced residue [17]. Acid treatments have been used for SEO treatment by different authors for de-asphalting and settling of acid sludge [10,14,18]. Udonne [19] reported that Acid/Clay treatment proves to be the best option among Distillation/Clay, Activated charcoal/Activated clay and Acid treatment methods with optimum yield of 80% (compare with that of crude oil which is 5 to 10%), 89.1 cSt compare with the 92.8cst for the fresh lube oil and other improved properties of the SEO. It was also observed that acid/clay treatment is a good method for heavy metal removal. Catalytic cracking (zoelite as catalyst) and acid/clay treatment was used by Rahman et al. [14], and Hani and Al-Wedyan [20] with oil recovery between 62% and 66%. The zeolite was used mainly for the removal of carbon particles. It has been reported that the clay was used to neutralize the acid of the treated oil and for removal of colour [20]. The method was used to produce brighter oil instead of quality oil. 70% concentration of sulphuric acid and activated carbon was the technical principle used by Ogbeide [16] and it was discovered that 25 L of SEO yield 10 L of lubricating oil after proper treatment and 50 L of SEO yield 20 L whereas 220 L of crude oil would be required to yield the same 10 L and 440 L of crude oil will be required to produce 20 L of lubricating oil. Also, acid treatment was used by Olutoye [13], but the excess acid in the sludge was neutralized and the sludge was further processed for the production of ink. Emam and Shoaib [10] showed that acid/clay treatment gave a better quality than solvent/clay treatment but the later gave a higher yield of 83%. A modified aluminium sulphate-sodium silicate-acid-base method employing a small quantity of acid and giving a high yield (approximately 60%) was proposed [21] to improve the conventional process of treating SEO that yields approximately 50% which is thought to be time consuming and environmentally perilous because of the acid sludge. Acid to oil ratio and adsorbent to oil ratio affected the regeneration of base oil from waste lubricating oil. The efficiency of the operation increases with increase in the ratios. Thus, desludging ratio of 20:1 and that of adsorption of 10:1 gave the best yield of 82.9% [22]. Bridjanian and Sattrin [23] reported that in this early century, the most common technologies used are sulphuric acid/bleaching earth and propane extraction/sulphuric acid/bleaching earth (clay) treatment methods which generate acid sludge (acid tar), filter cake from bleaching earth and waste water which contains high concentration of heavy metals or sulphuric acid (in the range of 17%w/w). They implied that using the first method, about 200 tons of environmentally harmful by-products is generated from each 1000 tons of used oil processed. Modern processes like vacuum distillation and hydro-treatment substitute sulphuric acid/bleaching earth and propane extraction/sulphuric acid/bleaching earth (clay) treatment methods; which gives a high viscosity index lube oil with a good and stable colour and oxidation resistance, yet having low or no discards. This method (that is vacuum distillation and hydro-treatment) has been used by several authors [10,23,24] which is similarly used in petroleum refining for the removal of H_2S, NH_3, H_2O and metals in two stages which are: mixing the used oil with solid catalysts (Co-Mo with Alumina) in the presence of hydrogen and removal of sulphur and nitrogen compounds in used lubricants by alumina and Ni-Mo catalyst in spherical or extruded shape [25].

Lately, extraction process followed by adsorption has become the most attractive and competitive method for the treatment of SEO. The solvent chosen must have high solubility parameters for the base oil recovery [4,26,27] and less soluble in additives and carbonaceous compounds [27]. Sterpu et al. [6] investigated the use of solvent extraction followed by vacuum distillation for the treatment of SEO. The solvent used are alcohol-ketone composite (25% 2-propanol, 50% 1-butanol, 25% butanone also known as methyl ethyl ketone (MEK) with an optimum yield of 92% using solvent to oil ratio of 4:1. The optimum was based on its high removal of ash content (about 49%). Emam and Shoaib [27] used MEK as the solvent for the oil recovery followed by clay treatment which gave 83%. The activities of three solvents (1-butanol, MEK and 2-propanol) based on variation of parameters like solvent to oil ratio and extraction temperature were studied by Durrani et al [28] and it was discovered that MEK gave the best performance and the result was based on lowest oil percentage losses and 1-butanol being highest in sludge removal both at 50ºC. Kamal and Khan [4] studied the solvency (for sludge formation) of the following solvent on used lubricating oil: 1-butanol, MEK, 1-hexanol and 2-butanol. 1-butanol gave the maximum sludge formation followed by MEK with a slight difference of 0.3%. MEK was preferred because of its low boiling point (for easy recovery) with 94% yield. Composite solvent (25% 2-propanol, 37% 1-butanol and 38% butanone) of solvent to oil ratio of 6:1 at vacuum pressure 600 mmHg and distillation temperature of 250°C was used by Durrani et al. [26] to treat used engine oil followed by clay (fuller's earth) which gave an optimum yield of 68% base oil. The performance was investigated on percentage sludge removal and percentage oil loss. Hamad et al. [18] used solvent extraction to treat used lubricating oils and the solvent used are liquified petroleum gas (LPG) condensate and stabilized condenser with overall yield of oils as 79%. Activated clay (fuller's earth) was used but the major challenge encountered with this method is the high temperature of the solvent for its recovery. An investigation was carried out on adsorption for the elimination of a potentially carcinogenic substances from waste lubricating oils such as polycyclic aromatic hydrocarbons (PAHs) by Moura et al. [17] with activated carbon as the most efficient adsorbent in the removal of PAHs and at the end of the process the technical principle proposed for the recovery of base oil from waste lube oil comprises of solvent extraction, adsorption and solvent distillation (recovery). They used the following solvents to study the solubility of base oil in the waste lubricating oils; n-pentane, n-hexane, toluene, ethanol, propan-2-ol, 1-butanol and tert-butanol. 1-butanol presented better efficiency as extraction agent of base oils followed by 2-propanol and ethanol. The adsorption isotherm indicated that activated carbon has a great potential for concentrated PAHs molecules on its surface. Waste lubricating oil was treated with a stabilized condensate (solvent) [29] with few drops of demulsifier followed by a fixed amount of different adsorbents to study their activity on the solvent treated waste oil. They reported that out of the following adsorbents; activated bentonite, bentonite, egg shale powder, date palm kernel powder, and acid activated date palm kernel, activated bentonite gave the best physical properties followed by the date palm kernel but the later with contact time of 4 h gave the best conditions for treating the waste oil. The whole process was carried out in ambient temperature.

These are the most common technical principles used for the treatment of SEO globally but each of them has different constraints environmentally or economically. The acid- clay treatment which is the conventional method generates acid sludge, acid water, and low yield [14]. The by-products from this process requires further treatment to avoid its environmental contamination by it thus making the process less cost-effectively feasible, but it has great effect on the quality of the produced base oil especially in the removal of heavy metals [10,19]. In the hydrogenation-distillation method, the challenge is at the hydrogenation stage whereby the nature of the heteroatom (S, O, N) can form gaseous compounds and stable ones that can remain in the solution and they are potentially pollutant depending on the level of contaminants/ deterioration of the oil, temperature and catalyst [30]. Solvent extraction is economically and ecologically viable [30,31] but the product is not commercially desirable because oxidation product remain solubilised in the oil. Due to these challenges, a lot of authors have worked on the use of adsorbent for the treatment of SEO which have appeared to improve the quality of the solvent treated product [4,26,29,30] with a reasonable yield. Thus solvent extraction-adsorption process appears to be the best method for SEO treatment.

The treatment of SEO regenerates base oil by removing contaminants which may include unused chemical additives [9,10].

1.1 Solvent Extraction Process

Extraction is the drawing or pulling out of something from something else. In terms of solvent extraction (liquid-liquid extraction) it is the separation of components of a liquid mixture by treatment with a solvent in which the desired component (solute) is soluble preferentially [32]. The mechanism of this process begins with vigorous agitation causing one phase to disperse in the other. Small droplet creates high interfacial area for interphase mass transfer, but care must be taken to ensure that the droplets are not so small that a diffuse layer appears in the region of the interface because this can remain in a semi-stable state over a long period of time and prevent effective separation from taking place [33]. A sequential approach is given below describing effective solvent extraction:

- As a result of vigorous agitation, the dispersal is in the form of droplets.
- More vigorous agitation gives rise to smaller droplets.
- The smaller the droplets the more surface area between the two solvents
- More surface area between the solvents leads to smaller linear distance travelled by the molecules to reach the other solvent and migrate into it.
- The shorter the distance travelled by the molecules, the more rapid the extraction process.

As reported by Richardson et al. [32], one of its important applications is in the separation of aromatics from paraffin and naphthenic compounds to improve the temperature-viscosity characteristics of lubricating oils. Thus the process is of great influence in the treatment of spent engine oil. The major impact of this technical principle is on the recuperation of the base oil and formation of sludge. This is subject to the type of solvent and other parameters used based on previous findings [4,17,26,31].

1.2 Adsorption Process

Adsorption has to do with adherence of molecules or particles on a solid surface by a weak bond though the binding can be reversible [34]. It is a physicochemical process. Compounds with colour and those that have taste or odour tend to bind stronger than any other. Thus, the process aids in the removal of colour and odour and some other impurities in used oils with activated clay [29]. Impurities accumulated in oils or used oil can be reduced by bleaching via adsorption process that makes use of clay [35], activated alumina, activated clay, carbon and silica gel [36]. According to Ajemba and Onukwuli [37], bleaching by adsorption involves the elimination of impurities like fatty acids, gums, trace metals, phosphatides followed by decolourization. The adsorbent to be used should have the ability to change the colour of the oil without altering the chemical properties of the oil [36] and with negligible loss of other materials. Many studies have been carried out on the use of adsorbents in form of activated carbon or activated clay for the treatment of SEO to regenerate lubricating base oil [4,14,16,19, 22,26,38] and their results showed a strong improvement in the quality of the oil that have either been acid-treated or solvent-treated. The activation of the adsorbent (physical or chemical treatment) such as acid, alkaline and ion-exchange treatment are often necessary for most adsorbent to modify their structure for higher activity. A good adsorbent must encompass carbonates compounds (carbonaceous material) and much of the substances volatilizes on heating, leaving behind a porous structure of carbon that usually contains some hydrogen (carbonization). This may then be activated to further open up the pores and increase total surface area [36] thus increasing the number of active sites. In clay activation, the mechanism involves the replacement of the structural cations (Al^{2+}, Mg^{2+}, Fe^{3+}) by protons H^{+} which leads to high capacity of adsorption (leaching of impurities) [34]. Activated carbons are distinguishable by their conditions of preparation, consequent characteristics [39] and the kind of precursor used for its production. It is of an importance that each adsorbate must be weakly adhered (physisorbed) to the active site of the adsorbent for easy recycling and the adsorbent must be inert to the base fluid and should not irreversibly react (chemisorbs) with the adsorbate(s) [40].

The produced lubricating base oil via the above described technical principles can be used for the production of transfer oil by "Blenders and Compounders" to enhance the performance of the base oil at required temperature (for viscosity control) for long-time usage. Transfer oil in this study refers to a low viscous hydraulic fluid which can be obtained by blending the regenerated base oil from SEO with chemical additives to enhance the efficiency of the lubricant. The foregone deliberation actually pointed out that there are various parameters which greatly influence the production of transfer oil. The present study was therefore aimed at reviewing these parameters and providing a new direction on the production of transfer oil from SEO using solvent extraction-adsorption method.

2. PROCESS VARIABLES AND THEIR EFFECTS IN SOLVENT EXTRACTION-ADSORPTION PROCESSES

In solvent extraction-adsorption process for the production of transfer oil through regeneration of spent engine oil, the following are the operating parameters that have major effects on the process: solvent type, solvent to oil ratio, extraction temperature, adsorbent to oil ratio, adsorption time (contact time), adsorption temperature and base oil to chemical additive ratio. The effects of these variables will be discussed accordingly.

2.1 Solvent Types

The kind of solvent used is of great influence especially in terms of its solubility (solvency) sludge formation and easy recovery. The efficiency of a polar solvent to flocculate contaminants (sludge) from SEO depends on the solubility parameters [26]. Components exhibits better solubility if their solubility parameters are very close and have to do with molecular weight. Thus, since oil is a mixture of high molecular weight components, it is necessary to use a solvent with a high molecular weight compounds that constitute the solvent [18]. This is one of the most important bases for solvent selection because from Reis and Jeronimo [41] investigation, it was observed that when low molecular weight hydrocarbons were used there was no segregation of the sludge even after many days settling by gravity. For solvent selection, some important factors must be placed into consideration: molecular weight, boiling point for easy recovery, availability and cost. Table 1 shows that the solvent with molecular weight closer to that of the treated oil gave better results especially in terms of flocculation.

2.2 Effects of Solvent to Oil Ratio in Treatment of SEO

Solvent to oil ratio has great influence on oil recovery especially in terms of the quality of the oil and percentage recovery. Durrani et al. [26] showed that solvent to oil ratio higher than 6:1 reduces the solvency power and does not improve the properties of the regenerated oil due to ash content present in the oil. Thus, the higher the solvent to oil ratio the greater the dissolution of some contaminants in the surfactant phase especially the ash forming materials which is not wanted [6,26]. The effectiveness in the ash content reduction increases and showed that the maximum ash reduction is achieved at the ratio of 4:1 (49% reduction) and declined from the ratio of 5:1 [6]. But it also indicates that increase in the amount of solvent used increased the oil recovery (it improves the solvency power). Kamal and Khan [4] showed that lower solvent to oil ratio can lead to the saturation of base oil in the extract phase which results to low oil recovery and at higher ratio, maximum oil recovery can be achieved with oil free sludge. In their study, sludge formation remained constant at solvent to oil ratio greater than 3:1 with increasing temperature. Solvent to oil ratio can also affect the percent oil losses in the sense that increase in the ratio leads to decrease in percentage oil losses. Katiyar and Husain [31] reported that MEK (Methyl Ethyl Ketone) gave the lowest percent oil losses followed by 1-butanol, 2-propanol and MIBK (Methyl isobutyl Ketone) respectively. Higher yield is attainable with increase in the ratio but its affects the quality of the oil because it decreases the settable matter concentration resulting in slower flocculation and decrease in the speed of the settling process. The kind of solvent or solvent composition and the quantity used, have great effect in used oil treatment. For instance, Abro et al. [43] carried out the comparative study of treatment of SEO by using composite solvent (butanol, propane and butanone), single solvent (propane) and acid treatment methods. Their best results based on the different properties analysed were obtained with the composite solvent followed by the acid treatment method. For instance, iron contamination decreased from 50 ppm to 13 ppm for composite solvent, for single solvent, it decreased to 30 ppm and acid treatment gave 15 ppm. The optimal ratio depends on the nature of the SEO thus optimization is required to know the optimum ratio for the regeneration of base oil from spent engine oil. In Table 2, it is observed that the quality of the treated oil improves up to a particular solvent to oil ratio and then, begins to decline.

Table 1. Influence of solvent type in SEO treatment

S/N	Types of solvent	Molecular weight (g/mol)	Influence in SEO treat	Yield (%)	Ref.
1	1-butanol	74.12	Best in sludge removal followed by MEK, MIBK and 2-propanl	Not indicated	Katiyar and Husain [31]
	2-propanol	60.1	Following MEK in low percent oil losses but the least in sludge removal	Not indicated	
	MEK	72.11	Best performance with lowest percent oil losses followed by 2-propanol,1-butanol and MIBK	Not indicated	
	MIBK	100.16	The least in terms of lowest percent oil losses	Not indicated	
2	MEK	72.11	Best performance with lowest percent oil losses followed by 2-propanol and 1-butanol	Not indicated	Durrani et al. [28]
	1-butanol	74.12	Best in sludge removal followed by 2-propanol and MEK	Not indicated	
	2-propanol	60.10	Following 1-butanol in percent sludge formation and MEK in percent oil losses	Not indicated	
3	1-butanol		1-butanol gave best performance in sludge removal followed by 2-propanol		Nimir et al. [42]
	2-propanol		Followed MEK in best performance for oil losses		
	MEK		Best performance with regards to oil losses		
4	1-butanol		In PAHs removal, 1-butanol gave the best performance followed by tert-butanol,2-propanol and ethanol	-	Moura et al. [17]
	Tert-butanol	74.12		-	
	2-propanol	60.10		-	
	Ethanol	46.04		-	
5	Liquefied petroleum gas condensate (LPG) with demulsifer		Stabilized condensate gave a better result in the purity of the used oil	Not indicated	Hamad et al. [18]
	Stabilized condensate with			79	

S/N	Types of solvent	Molecular weight (g/mol)	Influence in SEO treat	Yield (%)	Ref.
	demulsifier				
6	n-heptane		No sludge formation	-	Kamal and Khan [4]
	n-hexane		No sludge formation	-	
	MIBK		No sludge formation	-	
	MEK		Best due to 0.3% difference in sludge formation over 1-butanol, low cost and low boiling point.	97.6	
	1-butanol		1-batanol gave highest sludge removal followed by MEK,1-hexanol and 2-butanol	97.3	
	2-butanol		-	Not indicated	
	Benzene		-	-	
	1-hexanol		-	98.4	

Table 2. Solvent to oil ratio influence on regeneration of base oil from spent engine oil for the production of transfer oil

Type of SEO	Type of solvent	Ratio range tested	Optimal solvent to oil ratio based on quality	Ref.
Mixed SEO	25% 2-propanaol, 37% 1-butanol and 38% butanone	2:1-8:1	6:1	Durrani et al. [26]
Not specified	Liquefied petroleum gas condensate and stabilized condensate	1:4,1:2,1:1,2:1,3:1,4:1 and 5:1	4:1	Hamad et al. [18]
15W40	25% 2-propanaol,50% 1-butanol and 25% butanone	2:1-6:1	4:1	Sterpu et al. [6]

2.3 Influence of Extraction Temperature

Temperature has a great effect on the extraction process base on some studies that have been conducted. Mostly temperature, greater than 40ºC do not have any significant change in the process rather it may lead to poor quality oil. For instant, Katiyar and Husain [31] investigated on this effect and discovered that increase in temperature leads to decrease in percent sludge removal and reduces percent oil losses. This is because with increase in temperature there is always an increase in oil yield and at the same time an increase in solubility of sludge in solvent which results in poor quality oil and reduction in sludge formation [4]. It can also be observed from studies that increase in temperature up to 50°C reduces percent oil losses especially for MEK and increased percent sludge removal especially for 1-butanol. Thus, most treatments of SEO using solvent extraction [28] are best done at ambient temperature which is in line with the results of previous studies [4,6,18,26,29,31] considering the cost effectiveness of the process and good quantity base oil obtained.

2.4 Influence of Adsorbent to Oil Ratio in SEO Treatment

Adsorbent to oil ratio is an important variable to be considered in SEO treatment because the quantity of sorbent used with respect to that of oil has its own maximum adsorbency which mostly depend on some factors like the kind of adsorbent, the activation method/conditions of the adsorbent and the size of the adsorbent. For instance, from the works of Ajemba and Onukwuli [37] the optimum decolouration of activated Ukpor clay for a given set of activation condition may or may not coincide with its maximum value of the surface area attained under those conditions. This statement is in agreement with their work whereby Ukpor clay, activated with 5 M of H_2SO_4, gave the highest surface area of 239 m^2/g than that of 4 M which gave 226 m^2/g but the clay activated with 4 M of sulphuric acid gave the highest bleaching efficiency of 79.5% for the treatment of palm oil in the ratio of 1:25 (adsorbent/oil in g/g). A study carried out on Nteje activated clay showed that with adsorbent dosage varied from 0.5-4 g, the bleaching efficiency increased to an optimum value of 1g and there was no significant effect on the oil with increase in adsorbent dosage as a result of equilibrium attainment at 1 g of clay activated with 3 M HCl [43]. Durrani et al. [26] varied adsorbent to oil ratio of 3-4 wt%/vol% and they obtained their optimal value at 4 wt/vol% (Table 3). Oil to adsorbent ratio of 1:3, 1:5, and 1:10 which gave percentage yield of 63, 74.8 and 82.9, respectively was studied [22]. The results were simply attributed to the fact that the yield depended on the amount of clay used. High amount of clay and fine particles sizes of clay used can lead to high retention of the oil. Thus, the optimal yield should be determined by the quality of the oil. Snail shell was used as a precursor for activated carbon production with 85% H_3PO_4 by Kamalu et al. [36] and it was used to study the bleaching efficiency of palm kernel oil in which adsorbent dosage was varied (1, 2 and 3 g). It was observed that for 20 mL crude sample used, 2 g of the activated carbon gave the decolourisation with 99.24% colour reduction. 3 g gave no significant difference in colour reduction over 2 g. Thus variation of sorbent dosage is necessary for SEO treatment to determine the optimal dosage for the process.

2.5 Influence of Adsorption Temperature

Metal uptake and efficiency in its removal is always dependent on temperature. Therefore, increase in temperature could enhance the uptake in adsorption process which results to increase in average kinetic energy of the metal ions or colour pigment in solutions containing the adsorbent. This effect increases the number of metal ions or colour pigment adhering with the adsorbent surface by increasing the rate at which they hit the binding sites at the surface of the adsorbent thus increasing the adsorption capacities [44,48]. Increase in temperature can also retard the rate at which metal ions hit the active sites of the adsorbents. Oladunni et al. [48] observed that with increase in temperature from 30 to 60°C, there was no significant influence in the adsorption of cadmium ions using 1 M phosphoric acid activated locust bean husk as an adsorbent. Also Olayinka et al. [49] reported that there was no significant positive effect on adsorption capacity on chromium and nickel with increase in temperature using both modified and unmodified coconut husk except for nickel ions that showed an improvement at 50°C with HCl modified coconut husk and unmodified coconut husk after which it retarded at temperature above 50°C. Their study was carried out at temperature range of 40-60°C. Earlier study on the removal of heavy metals from spent engine oil using chitosan [47] observed that in the interactive effect study, heavy metals removals greatly depend on temperature and the

Table 3. Comparison of absorbent to oil ratio from past studies

Adsorbent type	Precursor	Activation method/ condition	Adsorbent/ oil ratio	Optimal ratio	Optimal quality			Reference
					Pour point (°C)	Ash content (wt %)	Sulphur content	
Fuller's earth (clay)	Clay	-	3-4 wt%/vol	4 wt%/ vol%	-14	0.021	-	Durrani et al. [26]
Natural clay	-	-	20%wt/wt	-	-6	0.17	0.81%	Emam and Shoaib [27]
SM-400 Activated clay	-	Commercial	1-3wt%/vol	3 wt%/ vol	2	-	-	Shivankar [45]
C3445 Activated carbon	-	Commercial	0-10% wt	5% wt	-	-	38.78%	Al-Zubaidy et al. [46]
Activated carbon	Date palm kernel	Thermal/ carbonized	0-10% wt	6% wt	-	-	34.15%	Al-Zubaidy et al. [46]
Chitosan	Chitosan	-	0.5 g and 2.5 g	0.5 g	-	-	-	Jumil et al. [47]

chitosan dosage. The temperatures that were studied are 30°C and 70°C. From the works of Ajemba and Onukwuli [44], temperature had great effect on bleaching efficiency of palm oil using acid activated Nteje clay. They observed that bleaching efficiency was not favoured by low temperature. But as temperature increased from 30°C to 120°C, there was an increase in bleaching efficiency especially at 120°C with optimum time of 60 min. According to Kamalu et al. [36] findings, with temperature of 100-200°C, 200°C gave the best bleaching efficiency of 99.24% on palm oil with 2 g of activated snail shell which did not give a significant difference at 180°C that gave 99.23% for 30 min. Aziz et al. [38] worked on automobile used oil with temperature of 150-450°C to determine the bleaching capacity of local clays and from their observations, 400°C gave the optimum temperature with optimum contact time of 4 h using bleaching efficiency to determine the optimum condition. With these effects, there is need to determine the optimum temperature for an adsorption process based on the nature of the oil and its contaminants, nature of the adsorbent, contact time, adsorbent dosage and the size of the adsorbent.

2.6 Influence of Adsorption/Contact Time

There is need to study the optimum contact time for an adsorption process because from most studies reported, it was observed that there is always an optimum time at which the adsorbent attains its equilibrium and after that, increase in the adsorbent dosage or the contact time will be insignificant. Also in some cases, it can retard the adsorption process. These effects are in consonance with previous studies [22,29,36, 38,44,48,49].

2.7 Influence of Base Oil to Chemical Additives Ratio

Engine oil originally contains base oil and chemical additive. Engine oil is basically condemned in a car engine as a result of degradation of its chemical additives due to its usage not the base oil. Thus, treatments of SEO lead to regeneration of base oil only and leaching of the condemned additives and other impurities.

Base oils are normally of mineral (petroleum) or synthetic origin, although vegetable oils may be used for specialized application [50]. The performance of an additive is always influence by the kind of base oil and their blends most match the requirements of the machinery and operating conditions to which they can be subjected [51]. Lately, all types of lubricating oil contain at least one chemical additive, and some contain chemical additives of several different types with their respective functions. The amount of additive used varies from a few hundredths of a percent to 30% or more and this amount varies depending on the kind of additives in use and the end use of the lubricant [51]. For instance, for premium ashless anti-wear hydraulic fluids, TE-5064 is always recommended at 0.9%wt-1.0%wt with maximum handling temperature of 60°C [52]. Also for anti-friction hydraulic oil, V3268 is used as an additive which can also be used in some kind of hydraulic oil and the percentage recommendation for high level hydraulic oil is 0.85% with highest blending temperature of 66°C [53]. For HitEC 317 industrial gear oil additive package, 1.3% wt - 2.0% wt is always recommended for conventional mineral oils with maximum handling temperature of 60°C [54]. The additive dosage may be effective at low dosages and the effectiveness can decrease as the dosage increases. Thus, the additive may need to attain a specific dosage before it becomes active. That means, it performance increases till a specific dosage and then begins to decline. Thus optimization of the blending process variables like base oil to additive ratio and blending temperature is necessary to determine the ideal treatment rate for the production of a lubricant which may be different for different systems [55].

3. CONCLUSION

Different process parameters influence the regeneration of base oil from spent engine oil for the production of transfer oil (low viscous hydraulics). The effects of the parameters depend on the nature of the oil and the level of contaminants. Thus, variation of the parameters helps to determine the best parameters for the SEO treatment to regenerate base oil. Some solvents are more effective at high temperature while most of them are not. But considering cost effectiveness, it is preferable to work with ambient temperature. Also the dosage of chemical additives in addition with the produced base oil is highly influential because the chemical additive only becomes active at a particular dosage. The nature of an adsorbent greatly affects the treatment of SEO along side with its dosage to oil ratio, adsorption temperature and the contact time. Several methods have been used for SEO treatment but lately, solvent extraction-adsorption method is mostly adopted because of it advantages over other methods; such as no generation of acid sludge, solvent recovery, ease of regeneration of spent adsorbent, high yield of base oil and the compatibility of the regenerated base with standards or commercial products; thus it is cost effective. The paper also revealed that composite solvent gives better results in terms of both quality and quantity of the base oil regenerated than single solvents as a result of the interaction between the solvents. Acid/clay treatment method which is the conventional method gives good quality base oil but produces lots of acid sludge which requires further treatment; it is therefore less cost effective and environmentally unfriendly. Solvent extraction-adsorption process is recommended for further studies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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