Analytical Study of the Physicochemical Properties of Condemned Crankcase Oil and its Regenerated Form Obtained by a Combination of Acid Treatment and Multiple Beds Extraction Approach

Dr. Anietie E. Ekot

Department of Chemistry, Akwa Ibom State University, P.M.B. 1167 Akwa Ibom State, Nigeria
Email Address: anietieekot@gmail.com

ABSTRACT:
The physicochemical properties of condemned lube oil and its regenerated mineral base samples were determined to evaluate the environmental impact of the former on one hand, and to devise a recycling approach that would improve the quality of the latter on the other hand. The regenerated samples were obtained by a modified version of recycling technique involving a combination of acid treatment and multiple beds extraction. The properties of the condemned oil, regenerated samples and fresh oil were evaluated based on the standard parameters viz: specific gravity, viscosity, acid number, ash and moisture as well as metal concentration. The result showed that the condemned oil had the highest acid number of 5.41 mgKOH/g as against the maximum prescribed limit of 0.05 mgKOH/L. The heavy metals concentrations (mg/L) were: 2.177, 2.211, 0.092 and 1.522 for Cu (copper), Fe (iron), Pb (lead) and Zn (zinc) respectively. These values are above the EPA limits (in mg/L) of 1.00, 0.30 and 0.015 for Cu, Fe and Pb respectively; the only exception being the concentration Zn (1.52 mg/L) which is below the EPA limit of 5.0 mg/L. The above results revealed that the condemned oil is hazardous to the environment. Results based on the quality of basestock recovered showed the impurity difference between samples from acid treatment only and those from acid treatment followed by multiple beds extraction as: 0.011, 7cP, 0.07 mgKOH/g, 0.39% and 0.10% for specific gravity, viscosity, acid number, ash and moisture contents respectively. This indicates that the basestocks regenerated from the latter method are of better quality than those from the former.

Keywords: Condemned Lube oil, Environmental Concern, Regeneration Approach

1.0 Introduction:
Modern tribology has strongly underscored the need to reduce friction between two moving surfaces in contact through the use of fluids with high thermal and thermos-oxidative stabilities in order to protect the engine from tears and wears. Over the years crankcase mineral based oils which are marketed as SAE 40 monograde and SAE 20W50 multigrade have been in use under different names and trademarks for the afore-stated purpose (Ekot and Ofunne, 2001). However this rating by the Society of Automotive Engineers (SAE) is based majorly on only one of the physical properties of the lubricants namely, the viscosity. On the other hand the American Petroleum Institute (API) rating essentially measures the performance of the lube oil under normal operating conditions (Obiagwu, N., 2002). Whereas the viscosity of lubricants depends fundamentally on the hydrocarbon chain size present in the mineral basestock and increases with increase in the chain size, the lube oil’s performance characteristics depend essentially on the quality of additives incorporated in the mineral base oil obtained as one of the heavy distillates from the fractional distillation of crude oil (Austin, G., 1984). For lubricant to function optimally some amount of additives which may vary from a part per million to a large percentage must be
incorporated in the basestock. The quality of additive package is an important element in lube oil formulation (Denison and Michael, 1978).

1.1 Functions of additives commonly used in lube oil formulation
The chemical agents (additive package) used to optimize the performance characteristics of lube:
Viscosity improver reduces the influence of temperature changes on viscosity by absorbing heat of expansion on oil molecule thereby countering oil thinning with increasing temperature. Copolymers of unsaturated hydrocarbons are best candidates; anti wear agent reduces friction and wear by preventing metal to metal contact and zinc dithiophosphate (ZDDT) is good candidate for this job; anti-oxidant minimizes thermooxidative degradation of lubricant by retarding the activities of free radicals. Hindered phenol and aromatic amines fit in here; corrosion and rust inhibitor reverses rusting and corrosive tendency of metal by neutralizing any acidic species in the lube oil. Long chain fatty amines and phenolates of alkali or basic metals are used for this purpose (Bhatia, 2001)
Others are dispersant which as the name implies disperses insoluble contaminants by enhancing polar attraction to dispersant molecules thus reducing contaminant cluster and alkylsucinamides agood example of this agent; detergent maintains clean metal surface by neutralizing varnish and sludge forming particles. Phenolates of alkali earth metals are strong agents in this regard; antifoam inhibit foam formation by reducing surface tension between oil molecules exposed to moisture and for this silicone polymers are about the best examples; pour point depressant reduces the temperature at which liquid lubricants may solidify by providing colloidal medium that prevents the growth of wax crystals. Polymers of long chain acrylate and alkynaphthalenes are used as pour point depressing agents (Chawla, 2010):

1.2 Engine protecting characteristics of lubricating oil:
Mineral base oil containing the right chain size of hydrocarbons into which the best quality of additives have been incorporated in appropriate quantity becomes a lubricant for a particular engine type. In any case, a typical lubricating oil must be capable of protecting the lifespan of engines by continuously providing fluid film between moving surfaces in contact in order to reduce friction and wear between them; by serving as cleansing medium that carries away dirt and other debris that may damage the bearings as well as other parts operating in tight tolerance. Most importantly it must act as heat dissipating or cooling agent by ensuring that heat sensitive components are saved from the damages due to overheating.

1.3 Aging and contamination of lube oil:
Lube oils no matter best they are formulated get degraded over time and their performance characteristics depreciate due to aging occasioned by a combination of thermal and thermo-oxidative decomposition of hydrocarbons in the base oil and the additives. Depreciation of lube oil according to Demirbas et al. (2015) is a complex web of processes taking simultaneously such that even the best oil in the best engine, operating in an ideal environment with perfect maintenance practice will eventually degrade, wear out and becomes unfit for use. The thermochemical effect associated with the complex web of reactions generates contaminants such as unsaturated hydrocarbon fragments, organic acids, carboxylates, conjugated ketones and esters (Ekot and Ofunne, 2001). Contaminated oil also contains phenolic compounds, aldehyde, acidic compounds, additive, metals, varnish, gums and other asphaltic compounds originating from the overlay of bearing surfaces and degradation (Sadeek et al., 2014). Lubricating oil becomes unfit for further use due to accumulation of contaminants in the oil as well as chemical changes in the oil. These effects interfere with the basic properties responsible for effective performance of the oil during application. Awaja et al. (2006). At this point the need to replace the spent oil with a fresh one becomes imperative. The way and manner this waste product from the crankcase engine is disposed of has constituted a great deal of environmental nuisance across the length and breadth of the globe especially in the under-developed economies where waste management technology is still in its infancy. Dennis (2010), reported that lubricants deteriorate over time as the additives are chemically degraded and the oil becomes contaminated with various unwanted pollutants as a result of many physical and chemical interactions. Worst still, at certain critical temperatures the performance characteristics of engine oil are lost due to mechanochemical interactions between the oil molecules and antioxidants leading to the formation of volatile acid compounds and polymeric products deposited as sludge in valve trains (Jensen et al., 1981). The afore-stated phenomena are very common in all engines especially in the spark ignition internal combustion engines in which the crankcase oil is subjected to a vast array of hot spot temperatures ranging from 90°C at the connecting rod...
cylinder to about 430°C at the piston crown (Gruse, 1987). At this critical temperature the lubricating fluid or crankcase oil undergoes a combination of thermal and thermos-oxidative degradation resulting in the breakdown of additives such as anti-oxidants (e.g. hindered phenol) used to prevent deterioration associated with oxygen attack (Korceth et al., 1980); anti-wear agent such as zinc dithiophosphate (ZDDP) - a film forming compound that prevents metal to metal contact and many others including viscosity improvers which are long chain high molecular weight polymers that counteract the temperature effect on hydrocarbon matrix (Ekot et al., 2014). Under these conditions the oil completely loses its lubricity or tribological value. Consequently the performance characteristics of the oil fall and the oil eventually becomes unfit for normal engine operation. At this point the oil is spent or condemned and replacement in order to save the engine from metallic rattling known as engine knock becomes the best option.

1.4 Improper disposal of condemned oil and its environmental implication

While it is important that the spent oil be replaced with a fresh one to avert any unpleasant economic consequence the proper disposal or management of this non-biodegradable fluid, considering its impact in our ecosystem needs no over-emphasis. There is no gain saying that our ecosystem is already under serious threats of dislodgement of its natural equilibrium due to anthropogenic activities. According to Filho et al., (2010) disposal of spent oil in water bodies not only reduce water quality but are also harmful to marine fauna and flora. Watts and Teel (2014) in his work on sites characterization and data analysis noted that improper disposal of hazardous wastes and subsequent contamination of surface and ground waters has exposed the public and ecosystems to toxic substances that have detrimental consequences. The report described the cost of cleaning up the thousands of hazardous waste sites throughout the world as daunting. On a daily basis a large volume of condemned engine oil from myriad of sources is disposed as waste into the environment (Shakirullah et al., 2006). This waste contains traces of heavy metals which can contaminate soil and water bodies if present above the World Health Organization (WHO) limits in milligram per litre given as: Iron (0.05), Arsenic (0.01), Zinc (0.04), Copper (0.01); while no traces of Cadmium and Lead should be present (Ziegler and Pfaffin, 1983). This research work is part of the effort to reduce the volume of waste oil discharged into our environment considering the ever-increasing number of vehicles on our roads and the upsurge in demand for fresh products. This work apart from saving our environment from further pollution will go a long way in reducing the cost of the basestocks. The recovered base stock can be blended and appropriate additives incorporated to obtain lube oil with performance characteristics comparable to those of the original products. Once this is achieved the overall cost of the product will certainly drop as this will boost the supply with a consequent fall in the demand. Quite a number of works have been done in this area of research in the recent times. These include works by Aremu et al. (2015) on regeneration of spent oil by solvent extraction process; Katlyar, V. and Husain, S. (2010) who used 1-butanol as a solvent in the recycling of used oil. Other researchers in this field include: Ogbeide, (2009); Riyanto, B.R. and Wiyanti, D. (2018); Salah E.F. et al, (2017); Henry (2015) and Izza, H. et al. (2018). On the basis of their reports these workers have made tremendous efforts in refining the use of lubricating motor oil but the bulk of their works are concentrated on either the conventional solvent extraction or acid treatment methods, with little or no modifications. In any case some major in-roads have been made in this area of research by a couple workers. These include those of U Donna, (2011), on the use of acid and activated charcoal with Clay distillation method; Hamawand, (2013) known for the use of new washing agent in waste oil recycling, and Myung-Soo Kim et al, (2008) on the recovery of waste oil mixed with atmospheric residues as a feedstock in vacuum distillation. This work aimed at improving the quality of the regenerated oily organic acid in tandem with multiple beds extraction and dechlorization using Zinc Chloride activated beds of carbonized sawdust, coconut shell and coconut shaft.

2.0 Materials and Methods:

The samples used in this research work were sourced locally. All the samples were of the Society American Engineers (SAE) grades. The fresh sample of SAE-20W50 Multigrade, representing the mineral oil blend was obtained from retail outlet of Mobil Oil Nigeria (MON) plc in our state capital, Uyo. The condemned SAE- 20W50 Multigrade was sourced from the car servicing unit. Below are some typical characteristics of fully formulated mineral based Multigrade lube oil. The reagents used in this work were either sourced from our Chemicals Store or purchased from Standard Chemical Departments and the all conformed with analytical grades.

Table1: Some typical characteristics of multigrade mineral lube oil (Lenoil Brochure, 1990)
2.0 Experimental Procedure:

2.1 Preliminary purification/acid treatment:
The condemned sample was first filtered to get rid of solid particles present by reason of exposure. Thereafter 600ml of the sample was treated with 60ml acetic (ethanoic) acid and heated with stirring for 15minutes. Acid sludge was discarded after 24hrs and 200ml of the recovered oil was analyzed for its physicochemical properties based on the set parameters viz: specific gravity, dynamic viscosity, acid number, ash content, moisture content and heavy metal concentration. The remaining portion of the acid extract was preserved for multiple beds extraction/decolorization procedure and analysis.

2.2 Preparation of multiple filtration beds
A sufficient quantity of dry coconut shaft and sawdust were separately oven-dried and grind into powder while coconut shell was first burnt before grinding. 75g of each material was impregnated with 25g zinc chloride in separate beakers. The mixtures were gently stirred until homogeneous and transferred separately into three crucibles and heated in a furnace at a steady temperature of 600°C for 15 minutes to ensure complete carbonization. The activated materials were kept in a desiccator for 12hrs. Suction filtration apparatus was set up and filter paper of appropriate size was placed inside the Buchner funnel and the first bed was packed with carbonized coconut shaft. This was followed by carbonized sawdust and lastly carbonized coconut shell, with each bed interface separated by filter paper. The pre-treated oil sample was introduced into the suction funnel and filtered at initial flowrate of 21 drops per minute. This process lasted for 24hrs after which the extracted oil was analyzed for its physicochemical properties based on major parameters earlier stated for acid treatment samples.

2.3 Determination of the physicochemical properties of the samples:
All analytical procedures for physical and chemical properties were carried out in accordance with the specifications of American Society for Testing and Materials (2019). The parameters used in analysis were: specific gravity or relative density, viscosity, acid number or neutralization number, ash content, moisture content and heavy metal content. The parameters were evaluated as described in ASTM (2019) version. However in the absence of a functional apparatus to determine the acid numbers in accordance with ASTM specification, acid-base titration was used, the difficulty of sourcing some of the reagents notwithstanding. By this classical method of analysis a known quantity (in grams) of each of the oil samples was dissolved in a known volume of toluene-methanol-water mixture and titrated with 0.1M KOH using 1-naphthol benzein as indicator. The number of milligrams of potassium hydroxide (KOH) required to neutralize 1gram of acidic oil was calculated from the titration data obtained on the basis endpoint (i.e. color transition from dark gray to dark green). In the same vein, the concentrations of heavy metals namely: Zinc (Zn), Copper (Cu), Lead (Pb) and Iron (Fe) were determined using Atomic Absorption spectrometer model SOLAAR. Oil samples were first digested using HCl at 90°C. The stock solution of each metal was prepared with 1g the metal at 1000 ppm concentrations. Thereafter the standard was prepared for each sample to be analyzed from the stock solution of the metal based on 2ppm, 4ppm, 6ppm, 8ppm, and 10 ppm. Each standard solution was aspirated into the flame and the absorbance recorded. A calibration curve was obtained by plotting the absorbance against the concentration of the standard solution and the concentration of the metal was determined by the extrapolation from the curve.
3.0 Result and Discussion:
The physicochemical analysis the oil samples was carried out based on the following parameters: specific gravity otherwise referred to as relative density, dynamic viscosity also known as absolute viscosity, acid number or neutralization number, ash content, moisture content and heavy metal content. The results obtained are discussed below:

3.1 Specific Gravity or Relative density:
Specific gravity samples was determined in accordance with the specification of ASTM D5002 (2019) using digital density analyzer in our laboratory. The specific gravity (which is inversely proportional the API gravity) of fresh lube oil (the standard) was first determined and the value was 0.902 whilst that of condemned oil was 0.971. The specific gravity of regenerated oil after acid treatment was 0.944 whilst the value after multiple-beds extraction was 0.913. These results indicate that the first phase of sludge removal by organic acid treatment actually left some finer particulate matter as contaminant behind thus as the oil sample was further subjected to multiple beds extraction the specific gravity finally dropped to 0.913; a value that nearly matches that of the fresh oil (fig.1) This a clear test of the effectiveness of the multiple beds extraction method.

![Specific Gravity values of the oil samples](image)

**Fig.1:** Specific Gravity values of the oil samples

3.2 Dynamic or Absolute viscosity
This parameter which measures the liquid internal resistance to flow is the single most important physical property of lube oil as the hydrodynamic conditions of lubrication of the rubbing parts and mechanical losses in an engine depends on this property. Viscosity is crude measure of lube oil’s molecular constitution from the standpoint of hydrocarbon chain size. The higher the intermolecular friction as is the case in longer molecular chains the higher the viscosity. In other words viscosity increases with length of hydrocarbon chain (Shashi Chawla, 2010). This temperature dependent parameter was determined at 30°C using digital density analyzer as described in ASTM D5004 (2019). From the figure below (fig.2) the viscosity of condemned oil dropped to 269cP compared with of fresh oil (326cP). The must be due to the thermochemical break down of the hitherto long chain hydrocarbon
molecules into short chain species which combine with other thermos-oxidative products to form sludge. In the presence of much sludge the lubricant can no longer generate a film of sufficient thickness to separate the surfaces under heavy loads. Thus removal of sludge is an essential in waste oil regeneration. At the first stage of sludge removal using organic acid the viscosity was 218cP while the viscosity value of 211Cp was recorded after multiple beds extraction process. This result indicates that the base oil obtained after second extraction is cleaner and can produce a better lube oil for reformulation.

![Viscosity readings of oil samples](image)

**FIG. 2:** Viscosity readings of oil samples

3.3 Acid Number:

The acid number otherwise referred to as neutralization number one of the crucial chemical properties of lube oil it portrays the amount of alkali required to neutralize a unit mass of the acid contaminated oil. Acid number is highest (5.41mmKOH/g) in condemned oil because of the presence of oxidation products which may include peroxides, carboxylic acid and carbonyl compounds. The concentration of these compounds usually increases as the lube oil ages and this explains why acid number of the fresh oil is only 2.11mmKOH/g. The difference in the acid values between the two oil samples is a graphic picture of the extent to which the condemned oil would impact the environment if not properly handled or managed. Another aspect of the below figure worthy of note is the marked difference between the acid values oil regenerated after acid treatment oil regenerated after multiple beds extraction. Whereas the former had acid number of 3.39mmKOH/g the latter had 3.32mmKOH/g depicting the effectiveness of the multiple beds extraction as an additional processing step for a cleaner base oil recovery.
3.4 Ash Content
Ash content otherwise referred to as carbon residue in lubricant is a measure of the quantity of carbonaceous deposit formed as a result of molecular decomposition that occurs when lube oil is subjected to high temperature under normal operating conditions. Under such temperature regimes long chain hydrocarbons undergo cracking leading to the formation carbon residue which on analysis is isolated as ash. Fig.4 below x-rays the ash contents in the oil samples analyzed. The condemned oil had the highest ash content value of 4.97% followed closely by oil sample recovered after acid treatment with a value of 4.30%. However the oil sample regenerated after multiple beds extraction recorded the ash content of 2.91% indicating that the multiple beds extraction as a final stage in base oil recovery has the potential to provide high quality mineral basestocks to supplement the refinery supply. Meanwhile the ash content of the fresh oil (0.09%) is almost negligible compared with values for the condemned oil and regenerated oil after acid treatment.
3.5 Moisture content:
This parameter measures the amount of water in percentage (%) or part per million (ppm) which is present in the crankcase oil at any point in time. It can be present in form of emulsion, solution or free water. In any case water in oil is deleterious to lubricating systems due its polar nature. As a universal solvent it reacts chemically with metal surfaces initiating oxidation process known as corrosion or rusting. Moisture also attacks metals in additive molecules rendering them ineffective and incapable of performing their elastohydrodynamic functions. The results on the moisture content of the oil samples are given below (Fig.5).The condemned oil recorded the highest value of 570ppm or 0.057% depicting the extent to which the lube oil was exposed to water infiltration while in service. In contrast the fresh oil recorded the lowest moisture content of 40ppm or 0.004% which is far below the maximum allowable limit of 2000ppm or 0.2 % SAE (2014). Meanwhile the moisture content of oil regenerated after acid treatment is 292ppm or 0.0292% and that of the sample measured after further extraction with multiple beds is 271ppm or 0.0271%.This further proves that the multiple beds extraction may well serve as an efficient final step in waste oil regeneration.
3.6 Metal Content:
The presence of metals in lubricants may be due to a vast array of factors. But the most likely source of metals in lube oil is wearing out of components (Diphare, et al., 2013). Appearance of metals such as Iron(Fe), Copper(Cu) and Lead (Pb) in lubricating oil may well indicate wears in engines or any wetted component. While the presence of Zinc (Zn) and traces Group II elements originate from the breakdown of additives (AL-GHOUTI et al., 2009). The figure below shows the distribution of four heavy metals in the four oil samples analyzed. The results indicate that all metals are present in the highest concentration in the condemned oil while their concentrations are lowest in the fresh oil and even below the DPR limit. The total absence of lead in the fresh oil is an indication of its contaminant-free state. In the converse the high concentration of metal contaminants in condemned oil portends the level of hazards it might cause if discharged into the environment. Between the regenerated samples, the base oil recovered after multiple beds extraction is still ahead of its counterpart regenerated after acid treatment in terms of degree of purity. This is another plus for multiple beds extraction recycling stage.
Table 2: Summary of Physicochemical Properties of oil samples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Condemned Oil</th>
<th>ORAAT</th>
<th>ORAMBE</th>
<th>Fresh Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity [a]</td>
<td>0.971</td>
<td>0.944</td>
<td>0.913</td>
<td>0.902</td>
</tr>
<tr>
<td>Dynamic Viscosity(cP) [b]</td>
<td>269</td>
<td>218</td>
<td>211</td>
<td>326</td>
</tr>
<tr>
<td>Kinematic Viscosity(cSt) [b]/[a]</td>
<td>277.03</td>
<td>230.93</td>
<td>231.11</td>
<td>361.42</td>
</tr>
<tr>
<td>Acid Number (mgKOH/g)</td>
<td>5.41</td>
<td>3.39</td>
<td>3.32</td>
<td>2.11</td>
</tr>
<tr>
<td>Ash Content(%)</td>
<td>4.97</td>
<td>4.30</td>
<td>2.91</td>
<td>0.09</td>
</tr>
<tr>
<td>Moisture Content (ppm)</td>
<td>570</td>
<td>292</td>
<td>271</td>
<td>40</td>
</tr>
</tbody>
</table>

Legend: - ORAAT: Oil regenerated after acid treatment  
ORAMBE: Oil regenerated after multiple beds extraction

### Table 3: Summary of Heavy Metals Concentrations in the oil samples

<table>
<thead>
<tr>
<th>OIL SAMPLES</th>
<th>COPPER</th>
<th>IRON</th>
<th>LEAD</th>
<th>ZINC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>2.177</td>
<td>2.211</td>
<td>0.092</td>
<td>1.522</td>
</tr>
<tr>
<td>ORAAT</td>
<td>0.559</td>
<td>0.661</td>
<td>0.075</td>
<td>0.511</td>
</tr>
<tr>
<td>ORAMBE</td>
<td>0.301</td>
<td>0.425</td>
<td>0.041</td>
<td>0.319</td>
</tr>
<tr>
<td>FO</td>
<td>0.15</td>
<td>0.034</td>
<td>0</td>
<td>0.203</td>
</tr>
<tr>
<td>DPRL</td>
<td>1.50</td>
<td>1.00</td>
<td>0.05</td>
<td>1.00</td>
</tr>
<tr>
<td>WHOL</td>
<td>&gt;1ppm</td>
<td>&gt;1ppm</td>
<td>&gt;1ppm</td>
<td>&gt;1ppm</td>
</tr>
</tbody>
</table>

Legend: - CO: Condemned oil  
FO: Fresh oil  
DPRL: DPR limit  
WHOL: WHO limit

### 4.0 Conclusion:

The results from this study indicate the physicochemical properties of oil samples varied from very high to very low depending on the degree of depreciation of their performance characteristics occasioned by thermal and thermo-oxidative degradation of the hydrocarbon molecules and additive components of lube oil under the engine operating conditions. In the light of the above the condemned oil recorded the highest concentrations for all the metals analyzed having the following values: 2.177, 2.211, 0.092 and 1.522 (mg/L) for Copper, Iron, Lead and Zinc respectively (Table 3). The high metal content in this sample is direct reflection on its highest value of specific gravity of 0.971 (Table 2). These values are above the WHO and DPR limits combined; which fall within the range of 0.05 ≤ X ≤ 1 ppm, where X is any toxic metal under study. The presence of metals at the above concentrations especially lead (0.092 mg/L) in waste oil raises a serious environmental concern considering its indiscriminate disposal. Another property of condemned oil highlighted by this study as an environmental hazard is the high acid number of 5.41 mgKOH/g. Based on the above results the need to mitigate indiscriminate disposal through recycling should not be overemphasized.

On the other hand results based on the use of multiple beds extraction in tandem with acid treatment in condemned oil refining revealed that the base stock samples regenerated by this technique are of better quality than the samples recovered by the use of acid treatment in isolation. For instance heavy metal concentrations in the regenerated base stock samples obtained by the former method are: 0.301, 0.425, 0.041 and 0.319 (mg/L) for Copper, Iron, Lead and Zinc respectively (Table 3); whilst the values from the base stock samples from the latter method (acid treatment only) are (higher): 0.559, 0.661, 0.075 and 0.511 (mg/L) for Copper, Iron, Lead and Zinc respectively (Table 3). Results obtained from all the parameters using the two methods followed the above trend; thus suggesting that the multiple beds extraction technique if deployed in the last stage of condemned oil regeneration may well serve as an innovative approach capable of improving the quality of the mineral base stocks recovered from acid treatment methods as well as those from other conventional techniques.
References:


