



EXPERIMENTAL INVESTIGATION AND SIMULATION OF A PROCESS FOR RE-REFINING OF USED LUBRICATING OIL USING ASPEN HYSYS.

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ABSTRACT

Used lubricating oil creates environmental pollution if not disposed of properly and there is a possibility that substances contained in it may enter the natural cycles through the food chain via water, soil, and air thereby posing a risk to human health and impeding the growth of plants and their ability to take up water because of the presence of hydrocarbons, heavy metals, polychlorinated biphenyls (PCBs), and other halogenated compounds. In this work, used lubricating oils were filtered, placed on a magnetic stirrer and stirred for about one hour and then allowed to stand for 24 hours. The transparent oily surface layer containing solvents and oil was transferred to a rotary evaporator to separate the solvents from the regenerating lubricating oil. Optimum Extraction of 74.7% was actualized after 12 minutes at an agitated stirrer speed of 1000 rpm, the temperature at 80°C. The simulation of the process using Aspen Hysys yielded an 80% oil recovery.

Keywords: *Additives, Lubricants, Refining, Simulation, Used oil.*

INTRODUCTION

Lubricating oils are made from base oil mixed with other chemicals (additives) to improve their properties. Engine oil lubricates moving engine parts, reduces friction, protects against wear, and removes contaminants. Moreover, it can act as a cleaning, anticorrosive and cooling agent. According to Usman et al., (2020), good lubricating oils possess the following characteristics: High boiling point, Low freezing point, High viscosity index, Thermal stability, Hydraulic Stability, Demulsibility, Corrosion prevention, High resistance to

oxidation. Typical lubricating oil contains ninety percent base oil, mostly petroleum fractions called mineral oils, and less than ten percent additives.

Additives are formulated for the improvement of the anti-friction chemical and physical properties of base oils and which lead to enhancing lubricant performance and extending equipment life. The combination of different additives and their quantities are determined by the lubricant type (Engine oils, Gear oils, Hydraulic oils, cutting fluids, compressor oils, etc.) and the specific operating conditions. The number of additives may reach 30% according to Shoaib, (2016) and they act as, Friction modifiers, Rust and corrosion inhibitors, Anti-oxidants, Pour point depressants, Viscosity index improvers, Anti-foaming and Anti-wear agents, Dispersants etc.

The chemical breakdown of these additives during use result in the build-up of halogenated hydrocarbons in the oil. Polycyclic aromatic hydrocarbons (PAHs) and other polycyclic compounds are generated and accumulate in the oil together with metals from the wear and tear of the engine being lubricated. Hence used lubricating oil if not properly disposed can create environmental pollution and subsequently enter the food chain either through water, air and the soil, and air posing risk to human health from impeding growth of plants because of their inability to take up water that has been polluted by hydrocarbons, heavy metals, polychlorinated biphenyls (PCBs), and other halogenated compounds (Nour et al., 2021). For example, in 1995 it was estimated that less than 45% of used oil was collected worldwide and the remaining 55% was either misused or improperly disposed of by end-users thereby increasing the problem of waste discharge into the environment (El-Fadel and Khoury, 2002)

Additionally, when used oil enters surface water, oil films will block sunlight, impair photosynthesis, and prevent the replenishment of dissolved oxygen, which leads to the death of aquatic plants and animals. When used oil is dumped down the drain and enters a sewage treatment plant, very small concentrations of oil in the wastewater (50 to 100 ppm) can foul sewage treatment processes. Hence, practicing good used oil recycling management is an important step for municipal solid waste reduction (Nour et al., 2021).

Used oil that is dumped onto soil can be washed into surface water by rain or snow, or it can seep through the soil into groundwater to contaminate our water

sources. Used oil in the soil can also evaporate into the air. The contaminants in used oil that enter the air through evaporation or improper burning can then settle, or be washed by rain or melting snow, into surface water or onto the soil. The only way to make sure that used oil will not contaminate either Water, soil, or air is to make sure that it is not released into the environment at all.

Used oil management system is not available in Nigeria and according to recent studies about 274,000 tons of used oil generated yearly from vehicles, is improperly disposed of (Joseph et al., 2016). It is therefore imperative to seek means of recycling and reusing spent oils.

One major parameter used in determining the quality of lubricants is The Viscosity Index, commonly designated VI. It is an arbitrary numbering scale that indicates the changes in oil viscosity with temperature changes. Viscosity index can be classified as follows (Rincón et al., 2005):

Low VI below 35

Medium VI - 35 to 80

High VI - 80 to 110

Very High VI - 110 10125

Super VI - 125 to 160

Super High VI above 160 to 200

General Treatment Methods for Used Oils

The following methods are used in treating used oils for the purpose of improving their quality for reuse:

- Acid/clay treatment
- Vacuum distillation clay treatment
- Vacuum distillation / catalytic hydrotreatment
- Solvent extraction and clay treatment

Acid/clay treatment

Most existing reclaiming plants for re-refining of oil use sulphuric acid to coagulate as an acid sludge the ash and polar components in used oil. This is followed by treatment with alkaline solutions to neutralize the acid, water washing, active clay decolorizing, stripping. and filtration yields a lube stock suited to reuse as low-grade motor oil or as a grease base. The poor yield of re-

refined oil and the environmental problems of disposal of acid sludge and clay make this reclaiming process a marginal operation at best.

Vacuum Distillation.

The basic steps in Vacuum Distillation are, pre-treatment of oil to remove impurities which can result in fouling and corrosion of the equipment followed by distillation, where water and light hydrocarbons are separated, then vacuum distillation using thin film or a conventional vacuum column (Oladimeji et al., 2018). Vacuum distillation is followed by hydro-treating of distillate with high pressure and temperature in the presence of a catalyst to remove chlorine, sulfur, nitrogen, and organic components. Hydro-treated oil is further fractionated under high vacuum into components of industrial, hydraulic, and motor oil. The resulting residue from the VD treatment can be used for road and roof bitumen production (Omolara et al., 2015).

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Solvent Extraction

Solvent Extraction process produces good quality base oils, lowers the rate of pollution and operates at a higher pressure requiring skilled operating systems and personnel. Several solvents have been used for solvent extraction which includes 2-propanol, 1-butanol, MEK, ethanol, Toluene, and acetone, research done with methyl ethyl ketone (MEK) has the highest performance due to its low oil percent losses and high sludge removal.

Extraction using a butane-1-ol solvent is projected to produce the highest sludge removal rate. A composite and single solvent consist of methyl ethyl ketone (MEK) and propan-2-ol while the composite consists of 75% MEK and 25% propan-2-ol. From the result, MEK gave the highest yield. It was also discovered that the solvent to oil ratio had a greater effect on the properties of the oil than temperature. Solvent Extraction and adsorption have been confirmed to be more effective processes for recycling waste lubricating oil. An examination conducted with blends of two or more solvents and activated alumina adsorbent gave higher solvent - oil ratios which was also in line with the findings of Razali et al., (2020), who in an experiment investigated the use of adsorbent materials which includes the almond shell, eggshell, walnut shell, and locally prepared acid-activated clay.

MATERIALS AND METHODS

Samples of used lubricating oil from bestselling products were collected from local service stations in Warri, Delta State, Nigeria. Other chemicals include, isopropanol, Butanol, Methylethylketone in addition to water.

The following were used in the experiments and analysis: Hydrometer, Viscometer, Flash point and Pour point measurement equipment, Rotary Evaporator, Gas Chromatography and Mass Spectrometry GC-MS, Fourier Transform Infrared (FT-IR) spectrometer.

Table 1: Table of Physical Properties Test

S/n	Test	Designation	Apparatus
1	Specific gravity	ASTM D-1298	Density bottle
2	Kinematic viscosity	ASTM D-445	Viscometer
3	Total Base Number	ASTM D 2896-11	Potentiometer Titrator
4	Flashpoint	ASTM D-92	Flash point tester
5	Total Acid Number	ASTM D664	Potentiometer Titrator

Methods

The samples of the used lubricating oil were collected after 2 months use in vehicles. and then transferred to appropriate flasks and kept from sunlight and at room temperature.

100 ml each of the oil was put into three different beakers and marked Sample A, B, and C. The following tests were conducted on them: flash point, pour point, specific gravity, and kinematic viscosity at 40 °C and 100 °C, using standard lubricating oil test methods.

The used oil was filtered before being treated.

100 ml of the used oil was mixed with a blend of 100 ml of isopropanol, 100 ml of 1-butanol, and 100 ml of methylethylketone respectively in a closed vessel. Each mixture was stirred for one hour and then allowed to stand for 24 h. The clear oily layer on the surface containing solvents and oil was transferred to a rotary evaporator to separate the solvents from the lubricating oil.

Gas Chromatography and Mass Spectrometry GC-MS

In solvent extraction, three (3) components are expected: the basic component, polar addition, and solvent. The polar addition here is Water while the basic

component is the used lubricating oil. The solvents were added in the following ratio shown in Table 2.

Table 2: Solvent to Oil Ratio

Number of Experiment	Basic component	Solvent addition	Polar addition	Solvent to Oil Ratio
1	Used oil A	Isopropanol	Water	1:1
2	Used oil B	Butanol	Water	1:1
3	Used oil C	Methylethylketone	Water	1:1

The resulting extract was analyzed using FTIR to determine its chemical composition as to standard lubricating oil standard.

Simulation Method

The Peng-Robinson (PR) property package was used in the simulation. The properties of used lubricating oils used in the computation are presented in Table 3.

Table 3: Properties of used lubricating oil

Properties	Values
Specific gravity	0.91
Base component	nC20
Volume % of Water	12.3

This set of data serves as the basis given to Aspen Hysys to estimate all other physicochemical properties of the hypothetical component. Hydrocarbons from C₁ to C₂₉ were included in the component list. The software also computed the product distribution of these components in the pyrolysis oil and non-condensable gas.

RESULTS AND DISCUSSION

A standard physical and chemical test was used to evaluate the nature and the extent of the contaminants in the used lubricating oils. Table 4 shows the tests involved in the analysis.

Table 4: Physical properties

S/N	Particular	Standard	Sample A	Sample B	Sample C
1	Kin. Viscosity @ 40C,cST	115.7	66.1	63	70.4
2	Kin. Viscosity @ 100C,cST	18.4	9	8.96	9.67
3	Viscosity index	178	111	118	117
4	Water content	0	0.1	0.1	0.1
5	Colour	-	L3.5	L3.5	L5
6	Flash point C	232	190	190	165
7	Total acid no. mg koh/gm	Base no >12.2	0.05	0.06	0.06
8	Solid contents	0	0.1	0.1	0

Physical Test Analysis

The viscosity of the used oil was found to be less than that of the unused fresh lubricating oil. This was probably due to oxidation, excessive dirt etc. The flash point of the used lubricating oil was observed to be lower than that of the fresh one. The lower flash point of used lubricating oil can be attributed to the dilution of the oil by the unburnt fuel. The lubricating oil losses its colour during use. The used oil was found to be acidic. The acidic nature of used lubricating oil is probably because of the reaction of the oil with oxygen and water which is promoted by the entry of metal particles and rise in temperature. Moreover, the lubricating oil loses its colour while in use which can easily be noted from the colour change.

Refined Lubricating Oil

The viscosity of re-refined oil samples was found to be less than the standard. The viscosity recovery was found to be almost 60% only. The flashpoint was found to be less than the quality. It was observed that the refined oil was acidic containing both solids and water.

Effect of Temperature

Temperature affects the solubility of waste oil impurities in organic solvents. Temperatures less than atmospheric were also not investigated because it was observed that at ambient temperature no oil was recovered, hence the lower limit was set to be 30°C.

The effect of temperature on the percent oil extraction yield was studied over the range of 30–80 °C to lube oil recovery ratio at the interval of 10%.

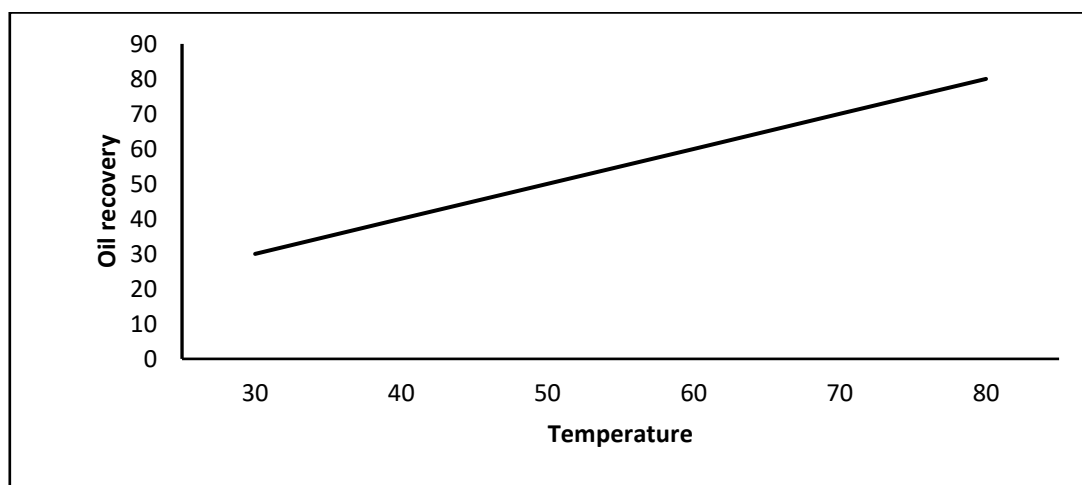


Fig 1: Effect of Extraction Temperature on the percentage yield of Extracted Oil

From Figure 1, the oil yield was found to be enhanced with the increase in temperature. This was thought to be due to the increase in the dissolution capacity of the solvent. When the mixture is preheated, the energy states of the molecules increase. When the intermolecular energy is excited, it results in more collisions between the molecules and as a result the rate of decomposition increases.

Similarly, the feed energy input for heat or temperature provides the required energy to break the intermolecular forces of attraction between the molecules.

Effect of Extraction time

Extraction was performed at various times starting from 2 to 18 minutes. Extraction time influences the separation of undesirable impurities from the lube oil extracted. It should be long enough to permit the solvent to dissolve the lube oil contained within the waste oil and also it should allow ejection by

permitting their aggregation to particle sizes large enough to break away the liquid phase by sedimentation as observed by (Usman et al., 2020). Extraction time is an important condition for the operation of extraction processes particularly in deciding the optimum residence time. Figure 2 shows that extraction increases with an increase in residence time. An increase in extraction time above 12 minutes did not show any improvement in extraction because after 12 minutes the extractable oil was exhausted.

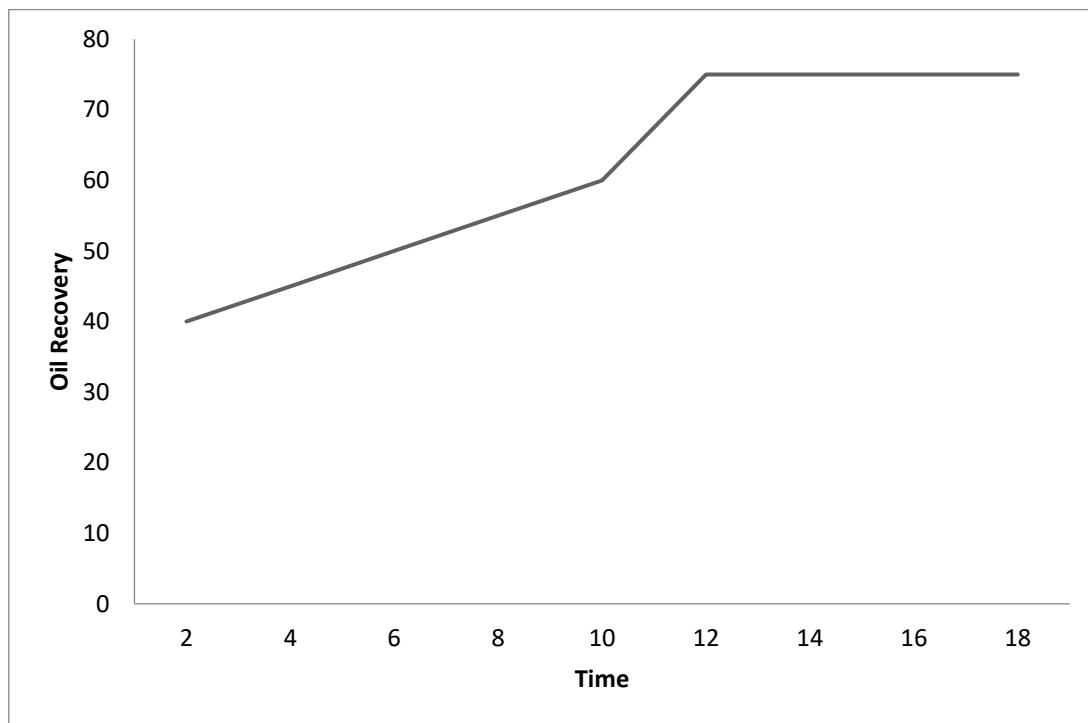


Fig 2: Effect of Extraction Time on the percentage yield of Extracted Oil

Effect of agitation speed

Extraction was performed at various agitation speeds starting from 200 to 1200 rpm. Agitation speed or mixing strength plays a crucial role in the decomposition of waste sludge because it increases molecular area and therefore the energy required in the breaking down of intermolecular bond (Joseph et al., 2016).

The effect of agitator speed on oil extraction is shown in Figure 3. The range of 200-1200 rpm of extraction agitation speed was evaluated while other basic variables were kept constant.

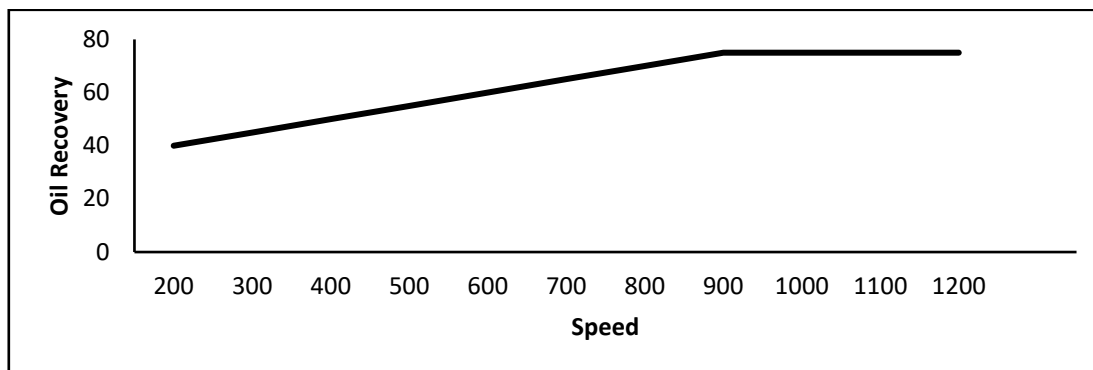


Fig 3: Effect of Agitation Speed on the percentage yield of Extracted Oil

The lube oil extraction yield increased from 48.84% to 74.66% with a rise in agitation speed.

However, for agitation speed more than 1000 rpm, no significant increase in the oil extraction yield was observed. The dependence of recovery on agitation shows that mass transfer plays a major role during extraction. The purpose of agitation is to break down the collated molecules to liberate oil molecules and also increase their active surface area to interact with the solvent. Optimum Extraction of 74.7% was achieved after 12 minutes at a stirrer speed of 1000 rpm, and a temperature of 80°C.

Fourier Transform Infrared (FT-IR) spectrometry Analysis

The unused lubricating oil was analysed along with the samples of used lubricating oil.

Figure 4 shows the FTIR spectra of unused motor oil. There is a notable degree of orderliness when compared to refined lubricating oil.

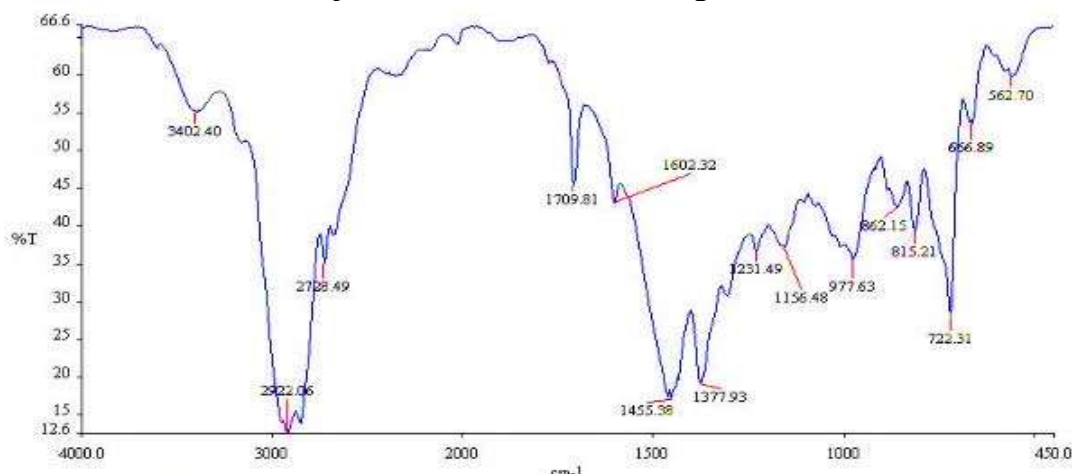


Fig 4: FTIR of unused lubricating oil.

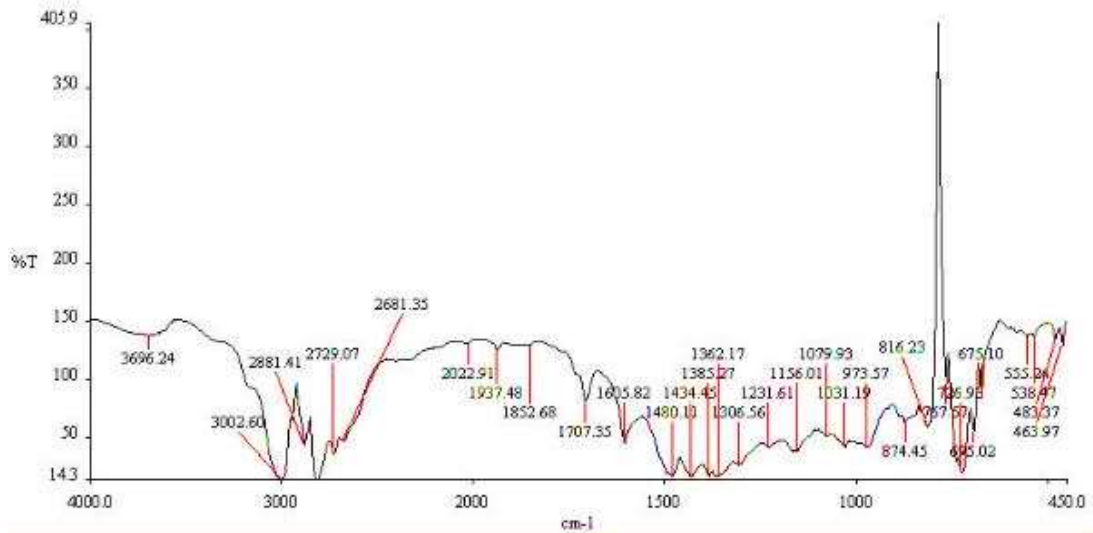


Fig 5: FTIR spectra of used Motor oil

Figure 5 represents spectra of used oil from a motor engine, the spectra show a great extent of disorderliness when compared with the unused oil. The spectra obtained, indicate a large number of unsaturated carbons along the wavelength of 1500 to 1000 cm⁻¹ which results from the high temperature and engine mechanism.

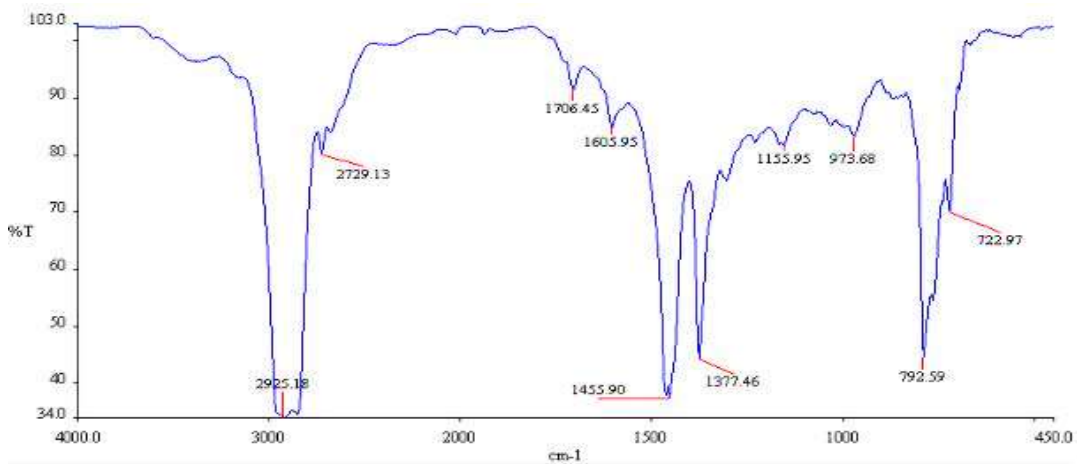


Fig 6: FTIR of refined used lubricating oil

The total ion chromatogram for an alkylbenzene refined lubricant is shown in Figure 6.

The spectra show that there is not much difference between refined used oil and fresh motor oil.

Table 5: FTIR Result Analysis (Beauchamp, 2020)

Peak Number	Functional group	Wavelength	Intensity
1	C-H	2905.18	Medium
2	C-H	2729.15	Medium
3	C=O	1706.45	Strong
4	Alkene	1605.95	Weak medium
5	C=C-C	1455.90	Strong
6	CN	1377.46	Weak
7	CN	1155.95	Medium
8	CH=CH ₂	973.68	Medium
9	Ortho-aromatic compounds	792.59	Strong
10	C-H	722.97	Weak-medium

GC-MS Analysis

Also, the possibility of synthetic lubricants has illustrated a necessity to spot different sources of the lubricant and also identify additives needed to enhance many of the properties of the lubricants. GC-MS is useful in both the identification of the bottom product and therefore the quantification of the components of the additive package.

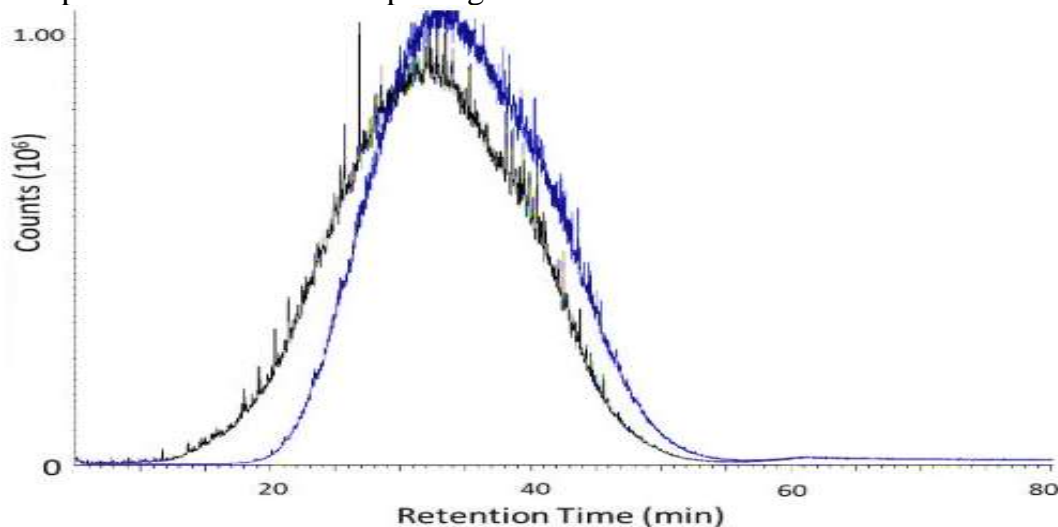


Fig 7: GC-MS of a refined lubricating oil

Typically, synthetic lubricants are categorized under the bottom product. Some base stock categories include alkylbenzenes, polyalphaolefins (PAO), polyethylene glycols, and polyol esters. Each of those categories of lubricants have characteristic features which permit them to be identified.

One of the common classes of synthetic lubricant base stocks is the alkylbenzenes. These lubricants have been used in refrigeration systems and heavier alkylbenzenes have also been used in automotive applications (Johnson, 2017). The GC-MS spectra of those base stocks are characterized by series of peaks of equivalent relative molecular mass like different attachment points for the alkyl radical.

The peaks observed at 22–30 min retention time correspond to monoalkyl benzenes with C12–C14 alkyl groups attached. At longer retention times, dialkylbenzenes are observed with similar length alkyl groups. A second major class of synthetic lubricants is poly-alpha olefins. They are available in a wide range of viscosities for applications ranging from compressor lubricants through gear oils and greases, including automotive applications as observed by Yash (2015).

As observed in literature, the oligomeric mixture is firstly hydrogenated and distilled to give lubricants that are graded by their viscosity at 100°C. The GC-MS spectra of these appear as series of broad peaks which indicate different degrees of polymerization.

Simulation Result

The simulation of the process using Aspen Hysys to investigate the recycling of used lubricating oil by solvent extraction method using a ternary solvent consisting of isopropanol, 1-butanol, and methyl ethyl ketone (MEK) was carried out. Based on the experimental design, the water in the used lubricating oil was set to dry at the Dryer by heating the lubricating oil to about 110°C and entraining the water vapor with a purge gas stream of Nitrogen. The outlet stream was then sent to the Yield-shift and Gibbs reactors.

The yield shift reactor carries out the conversion of the used lubricating oil to conventional components while the Gibbs reactor does the calculation of the phase and chemical equilibria thereby predicting the product composition (via

minimization of Gibbs free energy) and kept at a temperature of 125°C. Also, the bottom stream is composed of elemental carbon which is the char material. The product from the reaction was sent to the condenser where separation of the pyrolyzed oil (i.e. the lubricating oil obtained at constant temperature in the absence of oxygen) from the non-condensable gases takes place. Further separation was carried out using the separation column denoted as V-100 where the purified lubricating oil is generated from and the overhead sent to the Mixer. Synthesis gas is obtained as the final overhead product of the condensation and separation process. The syngas is collected at the Mixer with the output stream which is denoted as total Syngas.

Analysis of Simulation Result

From the oil recovery efficiency and also the physicochemical properties of the oil obtained from the extraction process measured, the results showed that a ternary system consisting of 25% isopropanol/25% MEK/50% 1-butanol is the ideal mixture for effectively reducing the contaminants in used lube oil with a decent sludge separation before the fractionation. Also, a solvent-to-oil ratio of 3:1 and a temperature of 125 °C are the optimal parameters for the extraction when the aforementioned solvent mixture is employed. The whole refining process including the condensing unit for a plant of assumed capacity of 100 kg/h using Aspen Hysys is shown in Figure 8.

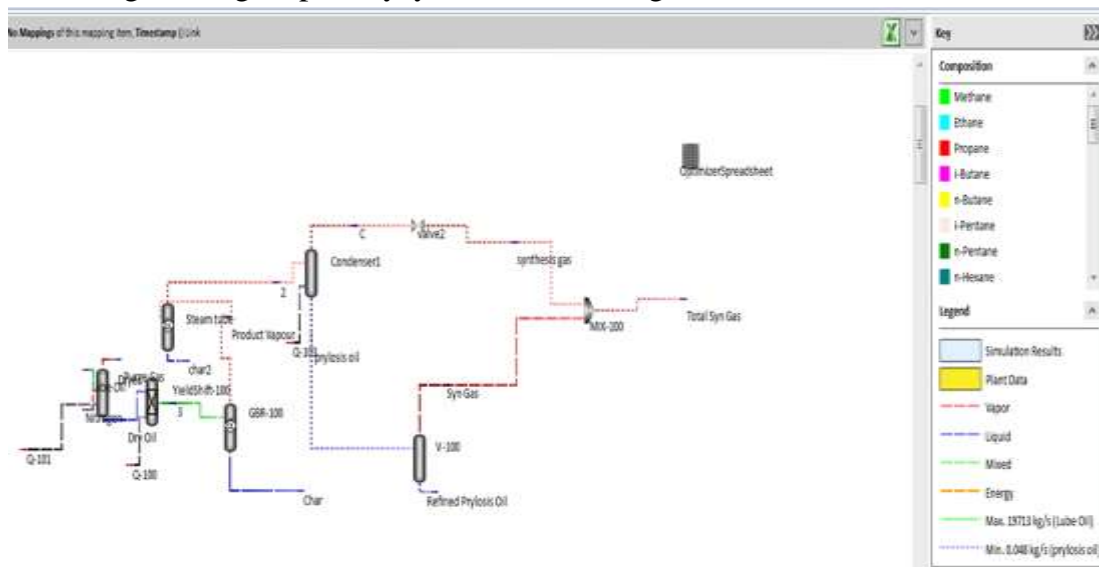


Fig 8: Simulation of Refining Process for Lubricating oil using Aspen Hysys.

The amount of char recovered is quite significant because the lubricating oil is made up of hydrocarbons. The summary of the streams are presented in Table 6.

Table 6: Summary of stream composition

Unit	Lube Oil	Nitrogen	Purge Gas	Dry Oil	3	duct Vap	Char	2	C	ynthesis g	char2	pyrolysis oil	Syn Gas	Refined Pyrolysis Oil	nal Syn G
Comp Mole Frac (Methane)	0.03125	0	0.01998	7.3E-07	0.000005	0.026636	9.9E-05	0.117612	0.11895	0.117612	0.117612	0.000420953	0.11895	0.000420953	0.11895
Comp Mole Frac (Ethane)	0.03125	0	0.019979	2.1E-06	0.000209	0.008853	0.002026	0.008293	0.008387	0.008293	0.008293	5.60E-05	0.008387	5.60E-05	0.008387
Comp Mole Frac (Propane)	0.03125	0	0.019979	4.8E-06	0.000628	0.024778	0.006624	0.004905	0.004905	0.004905	0.004905	5.41E-05	0.004905	5.41E-05	0.004905
Comp Mole Frac (i-Butane)	0.03125	0	0.019977	9.2E-06	0.001046	0.021718	0.001043	0.014972	0.01514	0.014972	0.014972	0.000248231	0.01514	0.000248231	0.01514
Comp Mole Frac (n-Butane)	0.03125	0	0.019977	1.1E-05	0.00136	0.023174	0.001356	0.007713	0.007799	0.007713	0.007713	0.000143062	0.007799	0.000143062	0.007799
Comp Mole Frac (i-Pentane)	0.03125	0	0.019974	2.1E-05	0.002511	0.022236	0.002508	0.032048	0.032048	0.032048	0.032048	0.000898828	0.032404	0.000898828	0.032404
Comp Mole Frac (n-Pentane)	0.03125	0	0.019973	2.54E-05	0.00203	0.022205	0.002926	0.009457	0.005517	0.005517	0.005517	0.000164217	0.005517	0.000164217	0.005517
Comp Mole Frac (n-Hexane)	0.03125	0	0.019964	5.63E-05	0.003564	0.020353	0.005962	0.004777	0.004829	0.004777	0.004829	0.000232086	0.004829	0.000232086	0.004829
Comp Mole Frac (n-Heptane)	0.03125	0	0.019946	0.000122	0.011301	0.017751	0.011299	0.003998	0.00404	0.00404	0.003998	0.000308144	0.00404	0.000308144	0.00404
Comp Mole Frac (n-Octane)	0.03125	0	0.019906	0.000265	0.019148	0.013892	0.019149	0.003136	0.003167	0.003167	0.003167	0.00038087	0.003167	0.00038087	0.003167
Comp Mole Frac (n-Nonane)	0.03125	0	0.019823	0.000562	0.028042	0.00958	0.028046	0.002468	0.002491	0.002468	0.002468	0.000469426	0.002491	0.000469426	0.002491
Comp Mole Frac (n-Decane)	0.03125	0	0.01965	0.001182	0.035881	0.005769	0.035686	0.001933	0.001948	0.001933	0.001948	0.000574786	0.001948	0.000574786	0.001948
Comp Mole Frac (n-11)	0.03125	0	0.019291	0.002473	0.041122	0.03132	0.041128	0.00152	0.001529	0.00152	0.001529	0.000699025	0.001529	0.000699025	0.001529
Comp Mole Frac (n-12)	0.03125	0	0.018644	0.004794	0.044051	0.01681	0.044059	0.001175	0.001179	0.001175	0.001179	0.000825417	0.001179	0.000825417	0.001179
Comp Mole Frac (n-13)	0.03125	0	0.017206	0.009951	0.04583	0.000782	0.045838	0.00091	0.000909	0.000909	0.000909	0.0001002352	0.000909	0.0001002352	0.000909
Comp Mole Frac (n-14)	0.03125	0	0.014487	0.019707	0.046772	0.003941	0.04678	0.000719	0.000713	0.000713	0.000713	0.001278817	0.000713	0.001278817	0.000713
Comp Mole Frac (n-15)	0.03125	0	0.011766	0.029471	0.047086	0.000187	0.047094	0.000556	0.000546	0.000556	0.000546	0.001481446	0.000546	0.001481446	0.000546
Comp Mole Frac (n-16)	0.03125	0	0.008191	0.042296	0.047295	9.20E-05	0.047304	0.000417	0.000404	0.000417	0.000404	0.001555922	0.000404	0.001555922	0.000404
Comp Mole Frac (n-17)	0.03125	0	0.005362	0.052448	0.0474	4.92E-05	0.047408	0.000326	0.000309	0.000326	0.000309	0.001821652	0.000309	0.001821652	0.000309
Comp Mole Frac (n-18)	0.03125	0	0.003172	0.060304	0.0474	2.56E-05	0.047408	0.000249	0.000229	0.000249	0.000229	0.002032645	0.000229	0.002032645	0.000229
Comp Mole Frac (n-19)	0.03125	0	0.001862	0.065004	0.0474	1.42E-05	0.047408	0.000183	0.000161	0.000183	0.000161	0.002095005	0.000161	0.002095005	0.000161
Comp Mole Frac (n-20)	0.03125	0	0.000758	0.068968	0.0474	5.41E-06	0.047408	0.000142	0.000116	0.000142	0.000116	0.002426638	0.000116	0.002426638	0.000116
Comp Mole Frac (n-21)	0.03125	0	0.000395	0.070268	0.047504	2.80E-06	0.047513	0.000293	0.002192	0.002192	0.002192	0.067626667	0.002192	0.067626667	0.002192
Comp Mole Frac (n-22)	0.03125	0	0.000216	0.070912	0.047504	1.53E-06	0.047513	0.003073	0.002063	0.002063	0.002063	0.091542796	0.002063	0.091542796	0.002063
Comp Mole Frac (n-23)	0.03125	0	9.64E-05	0.07134	0.047504	6.85E-07	0.047513	0.00261	0.001473	0.001473	0.001473	0.102218414	0.001473	0.102218414	0.001473
Comp Mole Frac (n-24)	0.03125	0	4.68E-05	0.071518	0.047504	3.34E-07	0.047513	0.002305	0.001065	0.001065	0.001065	0.110941447	0.001065	0.110941447	0.001065
Comp Mole Frac (n-25)	0.03125	0	2.45E-05	0.071598	0.047504	1.77E-07	0.047513	0.002134	0.000798	0.000798	0.000798	0.119646481	0.000798	0.119646481	0.000798
Comp Mole Frac (n-26)	0.03125	0	1.14E-05	0.071645	0.047504	8.33E-08	0.047513	0.001806	0.000504	0.000504	0.000504	0.115951943	0.000504	0.115951943	0.000504
Comp Mole Frac (n-27)	0.03125	0	4.84E-06	0.071669	0.047504	3.55E-08	0.047513	0.00179	0.00035	0.00035	0.00035	0.127917586	0.00035	0.127917586	0.00035
Comp Mole Frac (n-28)	0.03125	0	2.88E-06	0.071676	0.047504	2.13E-08	0.047513	0.00158	0.000239	0.000239	0.000239	0.119030618	0.000239	0.119030618	0.000239
Comp Mole Frac (n-29)	0.03125	0	1.65E-06	0.07168	0.047504	1.24E-08	0.047513	0.001579	0.000181	0.000181	0.000181	0.124118443	0.000181	0.124118443	0.000181
Comp Mole Frac (Nitrogen)	0	1	0.639353	1.24E-05	0.00157	0.740568	0.001438	0.740568	0.749001	0.749001	0.749001	0.001753427	0.749001	0.001753427	0.749001
Comp Mole Frac (H2O)	0.03125	0	0.019979	1.55E-06	0.000209	0.02617	0.000205	0.02617	0.026467	0.026467	0.026467	0.000147889	0.026467	0.000147889	0.026467

The proportion of methane in the gas (60%) is of great significant value. However, there are traces of C6 (≤ 2 mol%) and C7 (≤ 1 mol%) vapour that exist in the gas. The simulated lubricating oil (liquid fraction) showed a wide range of hydrocarbon components. However, a significant proportion is accounted for from C21 to C29 range of hydrocarbons. The material stream is presented in table 7 while the unit design properties are shown in Table 8.

Table 9 shows the Gibbs Reactor parameters while Table 10 shows the Mixer parameters.

Table 7: Summary of Material Streams

	Unit	Lube Oil	Nitrogen	Purge Gas	Dry Oil	3	duct Vap	Char	2	C	ynthesis ga	char2	pyrolosis oil	Syn Gas	efined Pyrolosis Oi	Total Syn Gas
Vapour Fraction		0.103493	1	1	0	0.000178	1	0	1	1	1	0	0	1	0	1
Temperature	C	24.85	24.85	109.85	109.85	109.85	109.85	109.85	125.4725	229.9632	229.8822	125.4725	229.9632	229.9632	229.9631934	229.8822214
Pressure	kPa	101.325	1	1	1	101.325	101.325	101.325	101.325	101.325	51.325	101.325	101.325	101.325	101.3249966	51.32499658
Molar Flow	kgmole/h	100	100	156.4072	43.59283	66.80568	0.011885	66.7938	0.011885	0.011751	0.011751	0	0.000134	0	0.000134122	0.011751229
Mass Flow	kg/h	19713.02	2801.3	8799.22	13715.1	17760.45	0.444068	17760	0.444062	0.39654	0.39654	0	0.047522	0	0.047521991	0.39654048
Liquid Volume Flow	m3/h	25.86249	3.473946	12.13288	17.20356	22.57592	0.000627	22.57529	0.000628	0.000569	0.000569	0	5.91E-05	0	5.91E-05	0.00056918
Heat Flow	kJ/h	-4E+07	-444.768	-1.1E+07	-2.4E+07	-3.1E+07	-424.06	-3.1E+07	-424.06	-293.057	-293.057	0	-66.0031	0	-66.0030684	-293.0565155

Table 8: Equipment Design Condenser and Dryer

Vertical vessel			
Name	DVT CYLINDER V-100	DVT CYLINDER Condenser1	DVT CYLINDER Dryer
User tag number	V-100	Condenser1	Dryer
Remarks 1	Equipment mapped from 'V-100' Equipment mapped from 'Condenser' Equipment mapped from 'Dryer'		
Liquid volume [m3]	2.401932948	2.401932948	29.42367848
Vessel diameter [m]	0.9144	0.9144	3.2004
Vessel tangent to tangent height [m]	3.6576	3.6576	3.6576
Design gauge pressure [kPag]	103.425	103.425	103.425
Design temperature [C]	257.7409706	257.7409706	137.6277778
Operating temperature [C]	229.9631928	229.9631928	109.85

Table 9: Gibbs Reactor Parameters

	Unit	GBR-100	Steam tube
Separator Type		Separator	Separator
Vessel Temperature	C	109.85	125.4725
Vessel Pressure	kPa	101.325	101.325
Vapour Molar Flow	kgmole/h	0.011885	0.011885
Liquid Molar Flow	kgmole/h	66.7938	0
Heat Flow	kJ/h	0	0

Table 10: Mixer Parameters

	<i>Unit</i>	MIX-100
Product Molar Flow	<i>kgmole/h</i>	0.011751
Product Mass Flow	<i>kg/h</i>	0.39654
Product Volume Flow	<i>m3/h</i>	0.000569
Product Temperature	<i>C</i>	229.8822
Product Pressure	<i>kPa</i>	51.325
Equalize Pressures		No

CONCLUSION

The experiments conducted on the used lubricating oils yielded very promising results as also corroborated with the GC-MS and FTIR investigation and analysis. At standard temperature and pressure and with a feed rate of 100 kgmole/hr, the simulation using Aspen Hysys achieved an 80% oil recovery. This shows that the refining of used lubricating oil can give a very good product recovery following a viable recycling procedure. The product composition from the simulation aligns with experimental results. The simulated used oil gives a wide range of hydrocarbon components. However, a significant proportion is made up of constituents between C21 and C29 hydrocarbons which is an acceptable range of carbon composition for used oil.

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