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European Journal of Advances in Engineering and Technology, 2017, 4 (5): 390-397

Research Article ISSN: 2394 - 658X

Development of a Processing Plant for Recycling of Spent Engine Oil

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ABSTRACT

The negative effect of indiscriminate disposal of the Spent Engine Oil (SEO) on the fertility of soil and the living of aquatic animals has been established. While SEO has been degraded by the environmental condition of the engine, recycling the oil to regains its invaluable properties and reuse will not only minimize the effects of indiscriminate disposal but will also minimize the servicing cost of engines. This paper discusses the development of a recycling plant for SEO. Laboratory experiments reveals that the viscosity of the recycled oil at 100^{O}c is 0.30mm^2/s compares to the fresh oil 0.4mm^2/s and spent engine oil 0.15mm^2/s. Also, the flash point of the recycled oil is 120^{O}C compares to fresh oil 110^{O}C and spent engine oil 100^{O}C. The metal content found in the recycled oil is 5.50ppm compares to the spent oil 22.50ppm.

Keywords: Spent engine oil, Viscosity, Flash point, metal content

INTRODUCTION

The function of oil in an engine includes lubrication of parts to minimize wear and tear by reducing friction, protection against rusting and corrosion and thus increases engines' life span, easy starting of the engine among others. In fact, Oil is the blood of an engine and just like the blood in human bodies, it does not only lubricate but carries away heat, dissolves contaminants, carries debris and provide a working medium for engines [1]. However, while the cost of engine oil justifies its irreplaceable functions, the disposal of used oil constitutes a great deals of environmental hazard to both terrestrial and aquatic living organism including human being, plants and animals. This used oil called Spent Engine Oil (SEO) is usually obtained after servicing and subsequently draining from automobile and generator engines and much of this oil is poured into the soil [2]. The disposal of SEO into gutters, water drains, open vacant plots and farms is a common practice in developing countries.

Extensive literature review show that several researchers have explored the effect of SEO spillage on soil as well as the influence on different farm produce on the affected soil. For an instance, the effect of spent oil pollution on the growth and performance of Zeamays at different stages of growth has been investigated [3]. The results from the study showed that generally Zeamays suffer greater inhibition of growth and performed poorly when it is exposed to spent oil pollution at tender stage of growth. Also the effect of different levels of spent engine oil application on soil properties, grain yield of maize and heavy metals uptake has also been studied [4]. Completely randomized design was used with nine treatment levels of spent engine oil at 0.0, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 1.0 L applied to 20 kg of soil. Maize was used as a test crop. The results reveal that grain yield of maize was significantly ($P < 0.05$) lower with spent engine oil application than control. It was concluded that contamination of soil with spent engine oil should be avoided in order to ensure sustainable soil productivity and risk of heavy metals toxicity of human beings. The study of effects of waste lubricating oil on the physical and chemical properties of soil and the possible remedies was also carried out [5]. The soil analysis showed that spent oil adversely altered the physical and chemical properties of the soil. It resulted in increase in bulk density from 1.10 to 1.15 g/cm^3, organic carbon (2.15 to 3.05), reduction in pH (6.5 to 6.0), capillarity (8.10 to 0.04 cm/h).

Therefore, with the adverse effects of indiscriminate disposal of SEO established, recycling of the oil to regenerate its used substance becomes inevitable. The choice of recycling method is determined by the nature of the spent oil, some require only purification from mechanical impurities while others require deep purification with the use of chemical and physiochemical methods. The physical methods involve removal of dirt, metal particles and combustible substances. These includes, centrifugation, settling, filtrations, distillation etc. Refining the spent engine oil will only bring back the base oil without additives [6]. The treatment of waste engine oils using four different acids (sulphuric acid, phosphoric acid, acetic acid and formic acid) followed by treatment with clay earth has been explored [7]. The effect of these treatments on the properties of the treated used was studied. The results showed that the formic acid-clay treatment improves the flash point of the used motor oil compares to the fresh oil. The sulphuric acid, acetic acid and formic acid followed by clay treatment improved the kinematic viscosity of the oil while the treatment with phosphoric acid clay has no improvement on the oil kinematic viscosity and flash point. However, no single treatment method yields a good result for all the tested properties. However, to the best of researchers' knowledge, literature is sparse in development of small scale processing plant for recycling SEO with some comparable properties to the fresh oil. This work solves the problem. The objective of this work is to develop a processing plant for recycling of SEO and evaluate the performance of the plant by comparing the properties of the recycled oil to that of the fresh oil using SAE 20W-50 as a case study.

Nomenclature

In developing the processing plant considered in this paper, the following notations are used:

r	Radius	**Ps**	Save working pressure (N/mm^2)
H	Height	δ_s	Save working Stress (N/mm^2)
R	Outside Radius	**T**	twisting moment or torque acting upon the shaft
τ	torsional shear stress	**J**	polar moment of inertial of the shaft about the axis of rotation
Sn	Schedule number	**r1**	distance from neutral axis to the outermost fibre
N	speed of the shaft in (rpm)	**P**	The power transmitted by the shaft

MATERIALS AND METHOD

This section discusses the design and assembly of all the component parts of the SEO recycling plant. The components of the plants include the closed heating vessels, double wall open vessels, settling tank, boiler, stirrer, gate valve, motor and stirrer and the discharge pipe. The stages of the designed were classified in the order of the components design.

Stage 1: The Closed Heating Vessel

The height and breadth of the vessel were measured out from Ø200 x 250 mm thickness mild steel sheet and the internal radius of the frustum of the cone was set at 11mm. A small medium vessel is fabricated and the capacity is calculated [8]:

Cylinder Capacity, $V_1 = \pi r^2 h = \pi \times 100^2 \times 250 = 7{,}855{,}000\ mm^3$ (1)

Capacity of discharge (Volume of frustum of a cone) $V_2 = \frac{\pi h}{3}(R^2 + Rr + r^2)$ (2)

$$= \frac{\pi \times 45}{3}(100^2 + 100 \times 11 + 11^2) = 528{,}777\ mm^3$$

Closed heating vessel capacity $= 7{,}855{,}000 + 52877 = 1.314 \times 10^6\ mm^3$

Fig 1. illustrates the closed heating vessel design.

Stage 2: Frame for Holding the Closed Heating Vessel

The height and breadth of the frame were measured with dimension of 400 x400 x1700mm with thickness of 40mm and top plate for holding the vessels with dimension of 400 x 400 x 3mm.

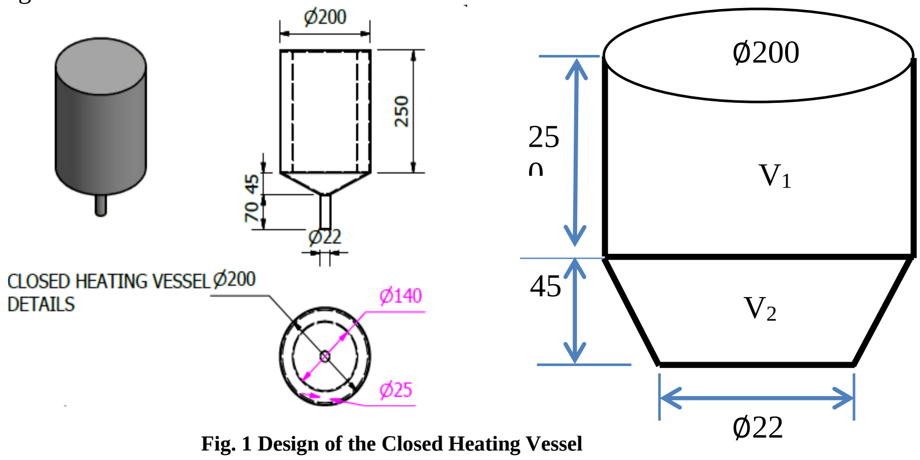

Fig. 1 Design of the Closed Heating Vessel

Stage 3: Double Wall Open Vessel
Two double wall open vessels cylindrical in shape, with the length of the vessels in mind, the height and breadth of the vessels were measured as Ø280 x 250 mm, the inner and outer diameters were Ø250 x Ø280.

Hollow cylinder capacity $= \frac{\pi \times h}{4}\,(R^2 - r^2)h$ (3)

$= \frac{\pi \times 248}{4} \times (137.5^2 - 112.5^2) = 1.217 \times 10^6\, mm^3$

Capacity of discharge (Volume of frustum of cone) $= \frac{\pi \times h}{3}(R^2 + Rr + r^2)$ (4)

$= \frac{\pi \times 46}{3}\left(137.5^2 + 137.5 \times 15 + 15^2\right) = 1.021 \times 10^6\ mm^3$

Double wall open vessel capacity $= 1.217 \times 10^6 + 1.021 \times 10^6 = 2.24 \times 10^6\, mm^3$

Fig. 2 illustrate the double wall open vessel design.

Stage 4: Settling Tank
The length and breadth of the tank were Ø225 x 170 mm. A circular plate of diameter 20mm was also rolled into a conical shape to form the base of the vessel, and then the vessel is welded with mesh to filter recycled oil. The capacity of the tank was calculated as follows:

Cylinder Capacity $= \pi\, r^2 h$ $= \pi \times 112.5^2 \times 170 = 6.76 \times 10^6\, mm^3$ (5)

Capacity of discharge (Volume of frustum of cone) $= \frac{\pi \times h}{3}(R^2 + Rr + r^2)$ (6)

$= \frac{\pi \times 33}{3}(112.5^2 + 112.5 \times 37.5 + 37.5^2 = 631.76 \times 10^6\, mm^3$

Settling tank capacity $= 6.76 \times 10^6 + 631.76 \times 10^6 = 7.39 \times 10^6\, mm^3$

Capacity of settling tank (Volume of frustum of cone) $= \frac{\pi \times h}{3}(R^2 + Rr + r^2)$ (7)

$= \frac{\pi \times 100}{3}\left(37.5^2 + 37.5 \times 22 + 22^2\right) = 284.31 \times 10^3 mm^3$

Capacity of discharge (Volume of frustum of cone) $= \frac{\pi \times h}{3}(R^2 + Rr + r^2)$ (8)

$= \frac{\pi \times 10}{3}\left(22^2 + 22 \times 10 + 10^2\right) = 8.42 \times 10^3\, mm^3$

Fig. 3 shows the design Settling Tank

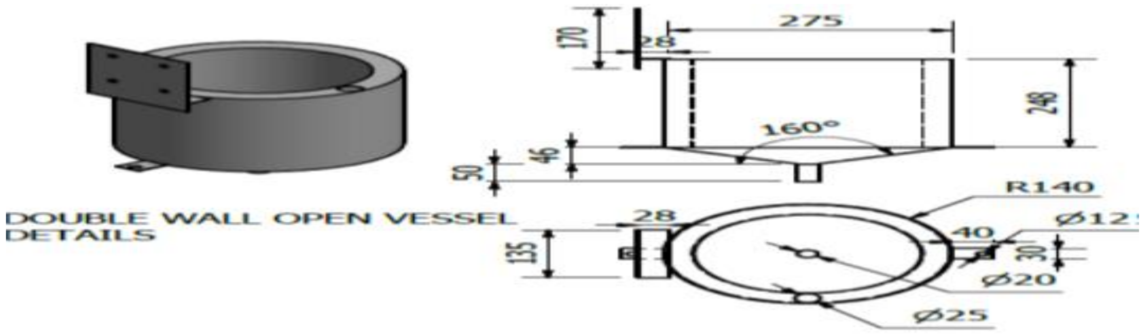

Fig. 2 The design of Double wall open vessel

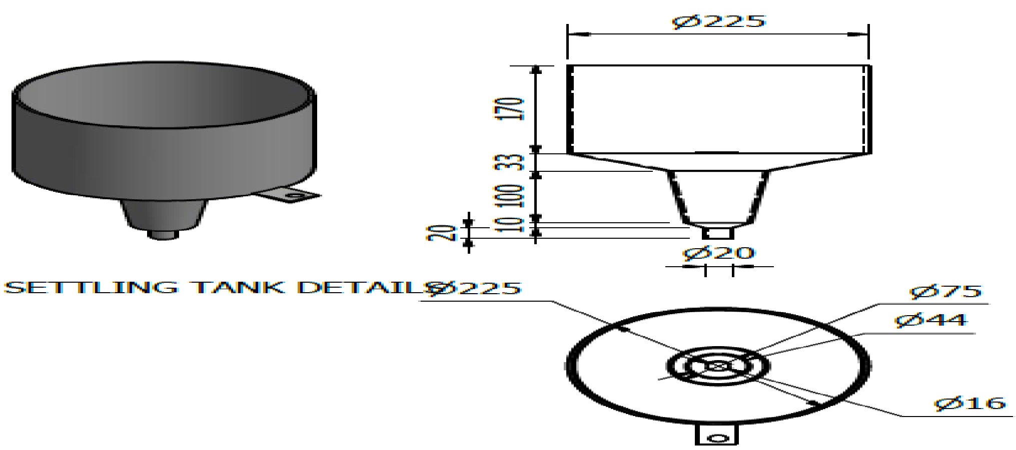

Fig. 3 The design Settling Tank

Stage 5: Boiler

The boiler is a closed vessel for generating steam. The height and breadth of the boiler were 300 x Ø320mm. The capacity of the boiler was calculated as follows,

Boiler capacity $= \frac{\pi}{4} \times d^2 \times h \quad = \frac{\pi}{4} \times 320^2 \times 300 = 2.4 \times 10^7 mm^3$

Fig. 4 illustrate the designed boiler.

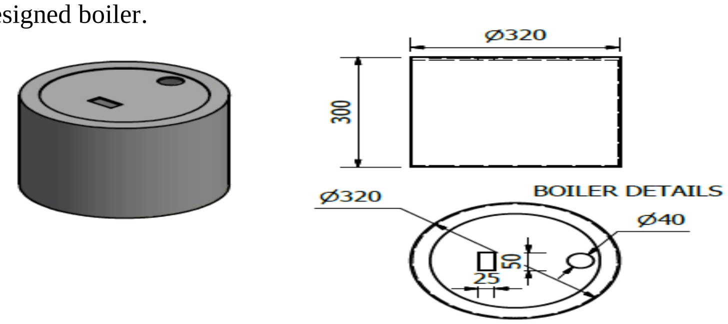

Fig. 4 The designed boiler

Stage 6: Stirrer and Motor

Steel rod dimensions 40 x 70 x 119 mm were welded to an electric motor for stirring the mixing oil. The electric motor was bolted to the machine frame. The diameter of the shaft is obtained by using torsion equation [9] when it is subjected to a twisting moment.

$$\frac{\tau}{r_1} = \frac{T}{j} \quad (9)$$

For a round solid shaft using equation

$$J = \frac{\pi}{32} \times d^4 = \frac{\pi}{32} \times 0.025^4 = 3.8 \times 10^{-8}\ m^4 \quad (10)$$

Using equation T $= \frac{\pi}{16} \times \tau \times d^3$ to determine the torque (T) as, taken $\tau = 56\ MN/m^2$

$$T = \frac{\pi}{16} \times 56 \times 10^6 \times 0.025^3 = 171.8\ Nm$$

The power transmitted by the shaft using equation:

$$P = \frac{2\pi NT}{60} = \frac{2 \times \pi \times 100 \times 171.8}{60} = 1.8\ kW \quad (11)$$

The power transmitted by the shaft is1. 8kW.The electric motor of power capacity ranges 3-4 kW was used. Fig. 5 illustrate the motor and stirrer designed.

Stage 7: Gate Valves

Four gate valves with dimension of Ø26 x 50 mm was installed at various opening point to discharge the recycled oil. Fig. 6 illustrate the gate valve used.

Step 8: Discharge Pipe

Pipes are specified by a schedule number (Sn) based on the thin cylinder formula. The schedule number is defined by, [10]. $S_n = (P_s \times 1000)/\delta_s$ (15)

To calculate the safe working pressure for 20mm diameter, schedule 40 pipe, mild steel and butt welded with safe working stress of 41.4N/mm is selected.

$$p_s = \frac{Sn \times \sigma s}{1000} = \frac{40 \times 41.4}{1000} = 1656 N/m^2$$

Fig. 7 illustrate the explored pipe. Table 1 summarizes the design procedure of the components.

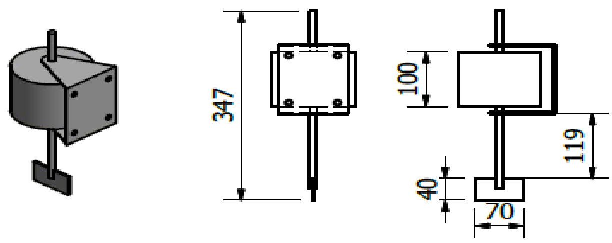

Fig. 5 The motor and stirrer designed

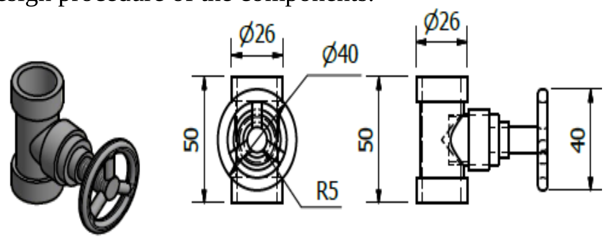

Fig. 6 The gate

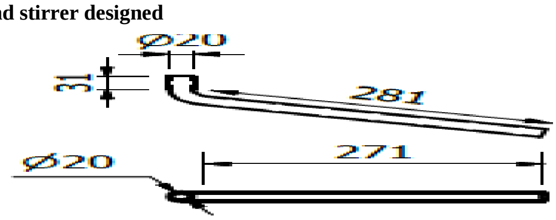

Fig. 7 The designed pipe

Table- 1 The Design of the Component of the Recycled Plant

S/n	Component	Design factor	Mathematical models used	Design value
1	Oil discharge pipe	Schedule number Safe pressure	$\frac{(schedule) \times \delta s}{1000}$ $\frac{Ps \times 1000}{\delta s}$	$\emptyset 40$ $1656 KN/m^2$
3	Closed heating vessel	Cylinder capacity discharge capacity	$V_1 = \pi r^2 h$ $V_2 = \frac{\pi h}{3}(R^2 + Rr + r^2)$	$1.31 \times 10^6 mm^3$
4	Double wall open vessel	Capacity	$\frac{\pi \times h}{4}(R^2 - r^2)h$	$2.24 \times 10^6 mm^3$
5	Settling tank	Cylinder and discharge capacity	$V_1 = \pi r^2 h$ $V_2 = \frac{\pi h}{3}(R^2 + Rr + r^2)$	$632 \times 10^5 mm^3$
6	Boiler	Capacity	$\frac{\pi}{4} d^2 h$	$2.4 \times 10^7 mm^3$
7	Stirrer shaft	Power	$\frac{2\pi NT}{60}$	1.8 Kw

Table- 2 Materials Selection

S/n	Component	Material	Reason for selection
1	Closed Heating Vessel, Double wall open vessel, Settling tank, Boiler and frame	Mild steel	High tensile strength and ability to withstand internal pressure
2	Oil discharge pipe	Stainless steel	High corrosion resistant and hardness.
8	Gate valve	Forged steel	High corrosion resistant and hardness
9	Heating element	Copper	High electrical conductivity
10	Electric motor	-	High efficient and 2HP
11	Stirrer	Mild steel	Strength to withstand impact load
12	Top plate	Mild steel	Strength to withstand impact load
14	Funnel	Mild steel	Ability to withstand internal pressure

Materials Selection

The selection of materials for the fabrication of the SEO recycling plant are shown in Table -2.

Theory

This section discusses the working principle of the designed SEO recycling plant. Ten liters' of SEO, specification SAE 20W-50 obtained from Auto repair workshop was poured into a heating closed vessel made of steel and directly heated by heating element at the bottom. The oil is heated up to 170^0C with an intermediate holding for 20nminutes at 100^0C to let the water content evaporate. Above 100^0C, other volatile liquids like petrol or organic solvents were removed. At the temperature of 170^0C the oil is open into the first steel agitator. This open vessel is double walled to allow water to be passed through as cooling agent. The oil is cooled down to 30 ^{0}C and concentrated sulphuric acid is added at at a ratio of 1:10 to the amount of oil. The mixture is stirred steadily for two hours to let the acid reacts with the impurities forming sulphates. The oil-acid mixture is afterwards opened into cylindrical steel vessel with a conical shape at the lower end. There is a mesh between the cylindrical steel vessel and the conical shape to allow clear oil-acid mixture into the conical shape. The clear oil-acid mixture is subsequently open through valve into a second open steel agitator for heating via steam from a separate boiler. About 400g of Calcium oxide (CaO) was added to the oil-acid mixture in the agitator to neutralize the acid and form insoluble solid salt. The mixture was heated up to 170 ^{0}C, stirred, and filtered to separate the solid salt from oil. The clean oil is stored into a vessel. The amount of clean oil produced after this exercise was about seven litres.

The following properties of the recycled oil obtained were measured and compared to that of fresh oil and the SEO.

Flash Point

The flash point test gives an indication of the presence of volatile compounds in oil and is the temperature to which the oil must be heated under specific conditions to give off sufficient vapour to form a flammable mixture with air.

Specific gravity (Density)

The specific gravity of contaminated oil could be lower or higher than that of its fresh oil depending on the type of contamination. If the spent engine oil was contaminated due to fuel dilution and /or water originating from fuel combustion in the engine and accidental contamination by rain, its specific gravity will be lower than that of its fresh engine oil or the recycled one.

Contaminants in Spent Engine Oil

There are other various contaminants that could be presents in the spent engine oil apart from additive depletion and these include heavy metals, Sulphur etc.

Viscosity

A lubricating oil's viscosity is typically measured and defined in two ways, either based on its kinematic viscosity or its absolute (dynamic) viscosity. An oil's kinematic viscosity is defined as its resistance to flow and shear due to gravity. The absolute (dynamic) viscosity is the oil's resistance to flow and shear due to internal friction. Stating an oil's viscosity is meaningless unless the temperature at which the viscosity was measured is defined. Typically, the viscosity is reported at one of two temperatures, either 40°C (100°F) or 100°C (212°F). For most industrial oils, it is common to measure kinematic viscosity at 40°C because this is the basis for the ISO viscosity grading system (ISO 3448). Likewise, most engine oils are typically measured at 100°C because the SAE engine oil classification system (SAE J300) is referenced to the kinematic viscosity at 100°C. In this regard, the viscosity of the fresh engine oil, the spent engine oil and the recycled oil were measured and compared with respect to the two temperature.

RESULTS AND DISCUSSION

The same quantity of fresh engine oil, the spent engine oil and the recycled oil using the designed plants were subjected to various test to measure the degree of degradation in the spent oil and the recovery due to the recycling. The results are discussed in this section.

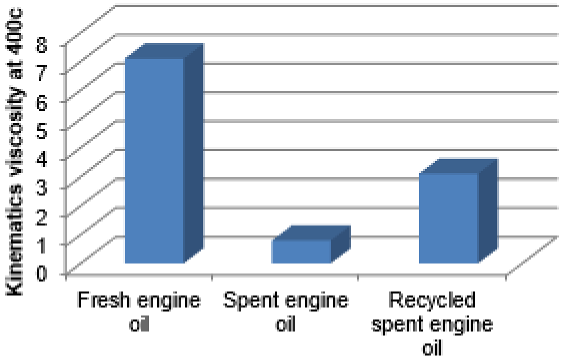

Fig. 8 Kinematics viscosity at 40^{0}C

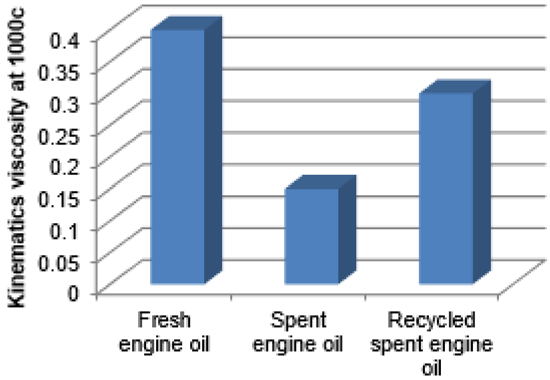

Fig. 9 Kinematics viscosity at 100^{0}C

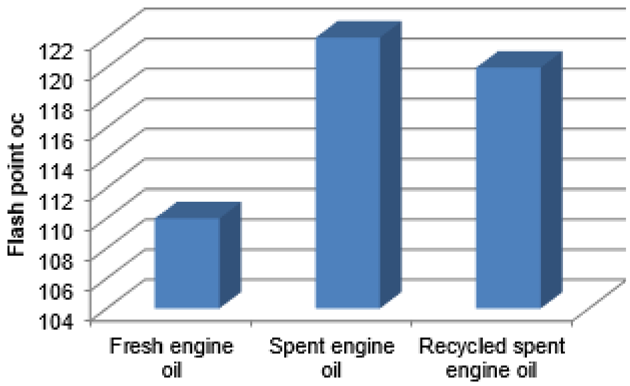

Fig. 10 Flash point (^{0}C) of the samples

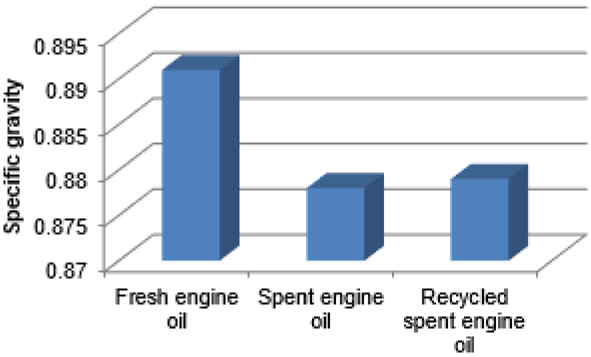

Fig. 11 The specific gravity of the samples

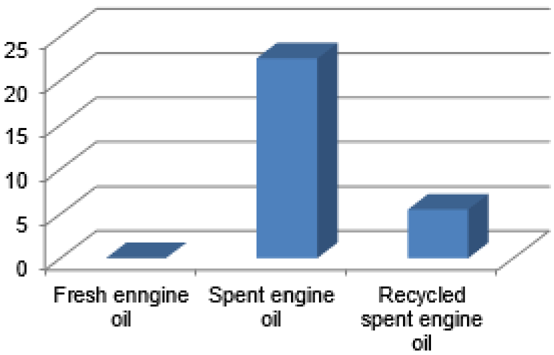

Fig. 12 Metal content (in ppm) of the samples

Kinematic Viscosity Test: The kinematic viscosity of the fresh engine oil, the spent engine oil and the recycled oil are determined at 40^{O}C and 100^{O}C using the capillary tube viscometer test method. The results obtained are illustrated in figure 8 and 9 for 40^{O}C and 100^{O}c respectively. The results of the viscosity test show that, though the spent engine oil has lost most of its viscosity due to contamination. The recycled oil has restored most of its viscosity.

Flash Point Test: The flash point of the three samples were determined in the laboratory using the *Cleveland* Open Cup Apparatus (manual). Fig. 10 shows the result obtained from the test. The flash points observed are 120^{0}C for recycled spent engine oil, 122^{0}C for spent engine oil and 110^{0}C for fresh engine oil. The increase in value of flash point for the spent engine oil could be as result of no presence of light ends of oil. In essence, after undergoing combustion and oxidation at high temperature of the combustion engine, the oil breaks down into component parts, which include some light ends.

Specific Gravity: The specific gravity of the three oils were determined using the hydrometer. The result is illustrated in fig.11. The specific gravity of contaminated oil is lower than that of its fresh oil and the recycled oil.

Metal Content

The engine block is made of aluminum, iron and lead, hence during combustion of fuel in the engine chamber, the wear of these metals in parts per million (ppm) are found in the spent oil and has been filter during the recycling process. These is determined using the spectrometer test. The result is illustrated in Fig. 11.

PROJECT COST

The table 3 encompasses the project cost of the recycling plant which includes the fabrication cost of all the components, the electrification and installation charges as well as the laboratory testing charges.

Table-3 Project Cost for the Development and Testing of the Recycled Spent Engine Oil

S/No	Component	Specification	Quantity	Unit cost (₦)	Total cost (₦)
1	Thermometer	10 ℃ – 180 ℃	1	5,000	5,000
2	Funnel	130 x 147mm	2	500	1,000
3	Closed heating vessel	200 x 250mm	1	5,000	5,000
4	Top plate	400 x 400 x 3mm	1	3,000	3,000
5	Frame	1700 x 400x 400mm	1	5,000	5,000
6	Motor and stirrer	3kw, 347 x 70mm	2	20,000	40,000
7	Double wall open vessel	280 x 250mm	2	6,000	16,000
8	Settling tank	225 x 170mm	1	5,000	5,000
9	Boiler pipe	44 x 165mm	1	2,000	2,000
10	Boiler	320 x 300mm	1	10,000	10,000
11	Oil discharge pipe	20 x 271mm	1	4,000	4,000
12	Gate valve	26 x 50mm	4	1,000	4,000
13	Heating element	-	1	2,000	2,000
14	Bolt and Nut	12mm	16	100	1,600
	Gross- cost				**103,600**
15	Electrification and testing	-	1	10,360	10,360
16	Laboratory testing	-	1	5,180	5,180
17	Miscellaneous	-	-	31,000	31,000
	Total cost				**₦150,140**

CONCLUSIONS

The recycled oil can be reused in the engine as the properties like viscosity, flash points as well as the metal contents of the recycled oil is comparable to that of the fresh oil. Finally, the need for reclamation of good engine oil from spent engine oil should be paramount especially in the developing countries because of its benefits, which include environmental pollution control and management and cost savings for end users.

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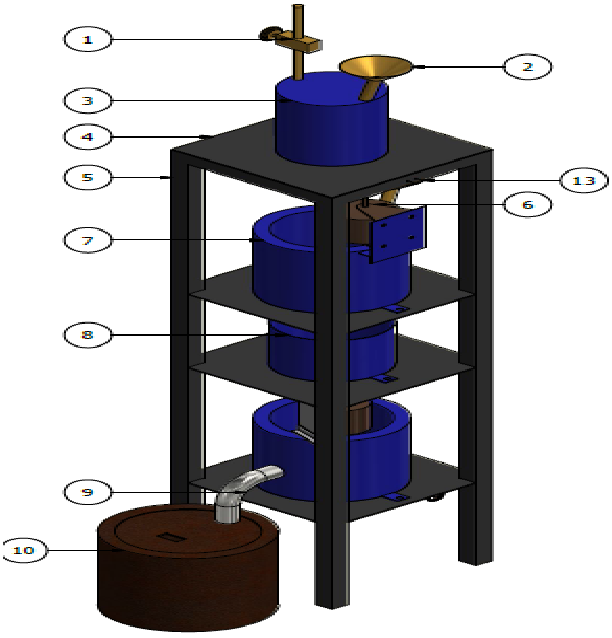
APPENDIX



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	THERMOMETER	Ø17 X 300
2	2	FUNNEL	Ø130 X 147
3	1	CLOSED HEATING VESSEL	Ø200 X 250
4	1	TOP PLATE	400 X 400 X 3
5	1	FRAME	1700 X 400 X 400
6	2	MOTOR AND STIRRER	347 X 70
7	2	DOUBLE WALL OPEN VESSEL	Ø280 X 250
8	1	SETTLING TANK	Ø225 X 170
9	1	BOILER PIPE	Ø44 X 165
10	1	BOILER	Ø320 X 300
11	1	OIL DISCHARGE PIPE	Ø20 X 271
12	4	GATE VALVE	Ø26 X 50
13	1	HEATING ELEMENT	Ø120

Processing Plant