

An Experimental Study on Producing a Sustainable Diesel-like Fuel from Waste Engine Oil

E. H. B. Hani^{*1}, F. Alkhatib¹, A. Sedaghat¹, A. Alkhazzam¹, F. Al-Dousari¹ and O. Al-Saad¹

1. Mechanical Engineering Department, School of Engineering, Australian College of Kuwait, Kuwait

Receive Date 10 December 2019; Revised 21 January 2020; Accepted Date 07 February 2020

*Corresponding author: e.hani@ack.edu.kw (E.H.B. Hani)

Abstract

The used engine oil is one of the most environmental pollutants that is produced in large quantities. Methods of recycling and reuse of the oil are important for a sustainable environment. In this work, a new experimental method is proposed for producing a diesel-like fuel from the waste engine oil. This paper proposes new physical and chemical treatment methods to produce a diesel-like fuel from the used engine oil. The produced oil is chemically analyzed to characterize the produced engine oil fuel for application in a diesel engine, to calculate the power produced, to measure the gaseous emissions, and to compare it with the standard diesel fuel. The diesel-like fuel properties including the viscosity, flash point, pour point, energy content, and gaseous emissions are investigated. The diesel-like fuel produced proves to emit less gaseous pollutants such as NO_x than the diesel fuel. The diesel-like fuel is tested in a diesel engine, providing an efficiency of 22.4%. The proposed experimental approach proves to be sustainable for producing diesel-like fuel from waste engine oils and protects the environment from the abundant amount of the waste engine oil.

Keywords: Air pollution, Engine oil, Environmental management, Fuel, Waste.

1. Introduction

The high rates of fossil fuel demand and consumption have led to an increase in its cost and a rapid depletion of its resources globally. It is estimated that crude oil will approximately last for 80 more years, coal for 230 years, and gaseous fuels for roughly 150 years [1]; these resources are concentrated in certain regions of the world [2, 3]. The combustion process of fossil fuels has resulted in negative effects on living organisms, and has polluted the atmospheric air, and underground and surface waters when it is transferred into soil or water.

These facts have encouraged the researchers to consider the possibility of using alternative sources of fuel that are cheaper and have less environmental impact while conserving the existing resources [4-8]. The majority of research works and scientists all over the globe are focusing on investigating the alternative sources of energy such as renewable energy sources mainly solar, wind, and conversion of waste into fuel for the future [9-14].

Wastes can be obtained from different resources such as trees, waste oils, tires, and plastics [15]. It has numerous negative impacts on the living organisms and the environment when used directly.

Engine oils steadily lose their lubricant property and are polluted with dust and metal particles from motor pieces because of the extreme conditions encountered in the engine. When physically and chemically treated, these contaminations should be highly reduced. The reproduced oil can be reused as lubricating oil, reconditioned as fuel or produced into diesel-like fuel. Diesel-like fuel produced from waste oils such as industrial and engine waste oils, wood pyrolysis oils, vegetable oils, and waste fat oils is an important source of making alternative fuels. Industrial and engine waste oils [16], fresh and waste fat oils, wood pyrolysis oils [17], and vegetable oils [18] have been proposed as pyrolysis raw materials to produce gasoline and diesel-like fuels. Large amounts of used engine lubricating oils are produced globally every year [19].

About 40 million metric tons per annum of engine oils are produced globally, and around 60% of the production becomes waste [20]. The majorities are petroleum-based oils, and the use rate is about 97% of the total lubricant oil production [21]. Global oil consumption is in millions annually. Having said that, waste engine oil can provide an alternative source of energy that can be used to replace diesel. Studies on testing converted oil blends (converted

oil and diesel fuel) have shown that the property of converted oil is comparable to that of diesel [22]. Engine oils has inorganic matters such as copper (Cu), lead (Pb), and halogens (Cl, F, and Br) in the structure of these oils. Studies have also shown that it would be unsuitable to use such blend as an energy source without being processed [20, 22-27]. Matters such as nitrogen, chlorine, bromine, and sulfur are the most important elements that make it difficult to recycle into diesel-like fuel [20]. The sulfur in waste oils settles reacting with metal oxide dusts such as ferrous oxide (Fe_2O_3), copper oxide (CuO), and zinc oxide (ZnO) at certain temperatures, so sulfur can be decomposed from the oil [24, 26].

Some studies linking utilization of fuel obtained from waste oils by settling down the plastics and waste engine oil thermally in 300–385 °C have shown a reduction in the amount of SO_2 and NO_x in the exhaust emissions [26]. The thermal and catalytic treatments of waste lubricant oil have been carried out with silica–alumina, silica, and alumina-supported iron oxide catalysts at 400 °C and atmospheric pressure [20]. They have reduced the sulfur content from 1640 ppm to 90 ppm via adding the Fe/SiO₂ catalyst. A review has been carried out on the recycling of waste engine oil and lubricating oil [27], where the physical and thermal properties and exhaust emission and engine performance parameters of the fuel obtained after the recycling process have been examined. For example, the heat content of the processed waste engine oil has a high-energy capacity (43.07 MJ/kg) [20], which is close to petroleum (42.00 MJ/kg) and petro-diesel (43.00 MJ/kg), slightly lower than that of gasoline (46 MJ/kg) but higher than coal (32.00–37.00 MJ/kg).

The problem of gas emissions is very important when dealing with engine oil wastes. Generally speaking, waste incineration can produce very toxic gas emissions [28]. The waste engine oil has also some heavy metals and other substances that have been introduced to the oil by contacting the engine, and by adding chemicals for preparation, these substances can lead to toxic gas emissions [28, 29].

The large amount of UEO treated as wastes has a significant impact on both the economic and environmental aspects. These cost millions of dollars to manufacture and represent a high pollutant material when disposed of. If discharged into the land and water or even burnt as a low-grade fuel, this may cause serious pollution problems because they release harmful metals and other pollutants into the environment. Spilled oil and fuels [30, 31] tend to accumulate in the

environment, causing soil and water pollution. Oil decomposes very slowly. It reduces the oxygen supply to the microorganisms that break the oil down into non-hazardous compounds. Again, the new development of the renewable energy sources should be considered to minimize the pollution problems [32-36].

Toxic gases and harmful metallic dust particles are produced by ordinary combustion of used oil [37, 38]. A high concentration of the metal ions lead, zinc, chromium, and copper in used oil can be toxic to ecological systems and to the human health if they are emitted from the exhaust stack of uncontrolled burners and furnaces. Certain compounds in used oil like poly-aromatic hydrocarbons (PAHs) can be very dangerous to the human health; some are carcinogenic and mutagenic. The PAH content of engine oil increases with operating time, because the PAH formed during combustion in petrol engines accumulates in the oil. In addition, other contaminants accumulate in oil during the use of fuel, anti-freeze/coolant, water, wear metals, metal oxides, and combustion products.

UEO is a valuable resource. If it is disposed of at a used oil collection facility, it can be recovered and reused without posing a threat to the humans or the environment. No other substance should ever be allowed to mix with used oil. Contamination by water or other chemicals may mean that used oil cannot be recycled. In Kuwait, it is roughly estimated to have 131072 L/month of UEO generated from Kuwaiti local market, which is a large quantity.

Thus in this work, we aimed to treat the used engine oils collected from car service stations in Kuwait. The treatment included the physical and chemical treatments. The final product would be used as fuel, which is diesel-like in properties, thus a characterization of the final product would be performed. Finally, a diesel-like fuel was used in a diesel engine. The produced fuel would be compared with a sample from the Kuwait National Oil Company (KNPC) diesel product in terms of energy output and emissions. It should be mentioned here that different chemical treatment methods would be applied to select the best method of treatment.

2. Materials and Methods

Field visits to car service stations to collect samples of used engine oil (UEO) and to get an idea about the quantities of UEO generated are important to sustain the production of the fuel from the wastes on a larger scale. The samples were kept in an underground tank for two days to deposit

impurities and residuals at the bottom. After that, a pipe sucks out the filtered waste engine oil into the refinery, where UEO is chemically treated. After the physical treatment, the processes of producing the diesel-like fuel will be as what follows.

2.1. Chemical Treatment

The following chemicals are used in the chemical treatment stage:

1. Acidic treatment, methanol and sulfuric acid ($CH_3OH + H_2SO_4$);
2. Basic treatment, sodium hydroxide (NaOH);
3. Clay treatment (bleaching power as an activated clay);
4. The acids that were used for treatment were sulfuric acid (97.99%), phosphoric acid (less than 85%), acetic acid (99%), and formic acid (85%). Industrially produced bleaching earth was used for bleaching, and potassium hydroxide (92%) for neutralization.
5. Isopropanol and methanol were used to improve ignition.
6. Vanadium oxide (V_2O_5) as a catalyst.

300 mL of UEO was measured in a 500-mL beaker. Then 30 mL of the acids (sulfuric acid, acetic acid, phosphoric acid, and formic acid) was measured in a separate 50-mL beaker. The regulated hot plate was switched on and the measured quantity of UEO was placed on top. The temperature of UEO was maintained at 40-45°C. At this temperature, sulfuric acid, acetic acid, phosphoric acid, and formic acid, and UEO were added and mixed simultaneously with stirring of the mixture for 10 min.

2.2. Sedimentation/Decantation

At the end of the acid treatment step, the acidic oil was allowed to settle for 24 h to form a sediment at the bottom of the beaker. After this period, the acidic oil was properly sedimented and transferred into another 500-mL beaker using filter papers, while the residue (acidic sludge) at the bottom of the beaker was discarded.

2.3. Clay Activation

200 g of clay (after dirt, sand, and stone removed) was made into slurry with distilled water of about 80 cm³. 50-60 cm³ of acid in 0.35-mol/cm³ concentrations was added to the slurry made. The slurry was transported into an aluminum pan and left for 1 h at a temperature between 90-1000°C. After the time duration, the mixture was washed with distilled water in order to remove any excess acid. The pH of the washing water was monitored until it was found to be neutral. The washed clay mixture was dried in an oven for 1 h and grounded into a powdery form.

2.4. Bleaching

The acidic oil in the beaker was then subjected to bleaching. The oil was placed on a regulated hot plate, and the temperature was maintained at 110°C. 10 wt% of activated bleaching earth was introduced into the oil, and the mixture was continuously stirred for 15 min. At the end of the bleaching step, the bleached oil was neutralized.

2.5. Neutralization

The bleached oil was neutralized to adjust the pH of the oil to neutrality. At this step, 4 wt% of the oil of hydrated lime was introduced into the bleached oil by considering the pH of the bleached oil at a given point in time. The bleached oil was neutralized with a continuous manual stirring for 10 min. At the end of the bleaching and neutralization steps, the oil was allowed to sediment in the beaker for 24 h and was decanted into the beaker, while the residue at the bottom of beaker was discarded.

2.6. Sedimentation/Decantation

During this stage, the oil was allowed to sediment into the beaker for 24 h and was decanted into another beaker, while the residue at the bottom of the beaker was discarded.

2.7. Filtration

The sedimented oil was finally filtered. The filtrate was collected in a filtration flask and it was observed to be clear, while the residue was discarded.

After this stage, the diesel-like fuel (DLF) is ready to be used. However, before the use of DLF, a characterization step was required to check for the heating value that was relevant to power output and the chemical content that was relevant to gas emissions.

3. Results

The fuel produced, shown in figure 1, was subjected to multiple tests. Its physical and chemical properties such as density and viscosity were obtained and compared with the properties of DLF, and was then compared with the original UEO to check the efficiency of the chemical treatment. The devices used for measuring the properties of the material are shown in figures 2 to 5. One of the most important chemical properties of any fuel is the energy content that can be determined using a calorimeter. In order to compare the obtained value with the calorific value of the diesel, which is 45 MJ/kg, tables 1 and 2 show the properties of UEO and DLF.

The physical properties of DLF and UEO are presented in table 2. This table shows the properties of DLF under different chemical treatment methods in comparison with UEO.



Figure 1. Samples of used engine oil and DLF after different treatment methods.



Figure 2. Flash point testing.

Table 1. Physical properties of UEO without treatment.

Properties	Waste engine oil
Flash point	202 °C
Pour point	-35 °C
Freezing point	-37 °C
Viscosity at 100 °C	12.44 cst
Viscosity at 40 °C	79.57 cst
Density	0.880 g/cm ³



Figure 3. Freeze point testing.

It can be clearly seen in table 2 that different properties can be obtained when the preparation method is changed. For example, using 20% of diesel instead of 10%, the viscosity at 100 °C is decreased from 4.64 cSt to 4.18 cSt, which is significantly lower than UEO that is 5.25 cSt. However, adding methanol increases the viscosity value to 7.15 cSt. This may be attributed to a chemical reaction that might happen and produce more viscous products mainly when vanadium oxide is used that accelerates and enhances the chemical reactions. However, without adding methanol, it is just physical mixing with less viscous fluids.

The flash point is lower without using methanol; for example, it is 180 °C for the physical mixing with 10% of diesel; however, it is increased to 232 °C when methanol is added. If it is compared to the flash point of diesel, it is 120 °C, and with UEO it is 206 °C, so the preparation method improves the quality of UEO but it is still lower than the pure diesel. The heating value of UEO is important to check the advantages of using the treated UEO as a fuel. Table 3 shows the heating value of UEO prepared by different procedures.



Figure 4. Viscosity testing device.

It can be seen in table 3 that the values of DFL produced from UEO are less than the value of pure diesel by 2 MJ/kg, which is a considerable difference. However, DFL prepared by mixing the treated UEO with diesel only gets a lower value than that mixed with methanol by 0.21 MJ/kg, where methanol contributes more to increase the combustion efficiency of the diesel engine. Thus the gas emissions and the power output from the combustion in diesel engine are used to select the best preparation method. Table 4 shows the percentages of the normal emissions from the diesel engines.

The results in table 4 show that less pollutant concentrations are obtained when methanol is added. The improvement in the pollutant

concentration is even better than that of pure diesel. For example, NO is 44, 30, and 13 for DLF mixed with diesel, diesel, and DFL mixed with methanol and vanadium, respectively. For CO, the values are high but a little higher for methanol; this is because some carbon atoms in methanol are combusted to

form more CO (higher carbon content). The exhaust gas temperature was noticed to be lower for methanol treated fuel (60 °C compared to 79.6 °C for fuel mixed with diesel only), which contributed less to thermal pollution.

Table 2. Physical properties of UEO compared to DFL for 4 different preparation methods.

Test	Method	Unit	*Fuel 1	*Fuel 2	*Fuel 3	*Fuel 4	*Fuel 5	*Fuel 6
Appearance	VISUAL	-	Clear	Clear	Clear	Clear	Turbid	Turbid
Color	ASTM D-1500	-	< 0.5	3.5	3.5	3.0	-	-
Density @ 15 °C	ASTM D-1298	kg/L	0.8305	0.8695	0.8655	0.8677	0.8698	0.8734
Viscosity@100 °C	ASTM D-445	cSt	1.62	5.25	4.64	4.18	5.39	7.15
Viscosity@40 °C	ASTM D-445	cSt	4.52	31.07	24.30	20.98	31.15	41.90
Viscosity index	ASTM D-2270	-	120	99	106	101	107	133
Flash point	ASTM D-92	°C	120	206	180	166	218	232
Pour point	ASTM D-97	°C	-1	-3	-2	-2	-26	-33
Cloud point	-	°C	-2	-8	-4	-5	-8	-3
Freezing Point	-	°C	-7	-11	-12	-9	-13	-10
Water content	-	%	-	0	-	0	0	0
Bottom sediment (mass%)	-	%	-	0.05	-	0.05	0.4	0.15

*Fuel 1 is the regular diesel, fuel 2 is the used engine oil without treatment, fuel 3 is treated UEO with 10 mass% Diesel/90% UEO, fuel 4 is the treated UEO with 20 mass% diesel/80% UEO, fuel 5 is the treated UEO with 5 mass% CH₃OH/95% UEO/ 3g V₂O₅, and fuel 6 is the treated UEO with 10 mass% CH₃OH/90% UEO/3g V₂O₅.

Table 3. Heating (calorific) value of UEO obtained by different methods compared to diesel (values are obtained by Intertek laboratory, UAE, No. KWT/16/4720)

Samples	Calorific meter, MJ/kg
20% diesel and 80% base oil	43.0
10% methanol and 90 base oil with 3 g of V ₂ O ₅	43.21
Diesel	45

Finally, the diesel engine efficiency can be calculated using equation (1):

$$\eta = \frac{\text{Power output}}{\text{Power input}} \quad (1)$$

where the power output is the result of multiplying the energy content by the mass flow rate of the fuel

(kJ/s), and the power output is the value of the power measured out from the diesel engine (kJ/s). The results obtained show that from 1.0 kg/s of fuel follow into the diesel engine, the efficiency of DLF with methanol results in 22.4% efficiency compared to 20.3% of DFL mixed with diesel only.

Table 4. Emissions from the combustion of diesel-like fuel compared with regular diesel.

Fuel type	Emissions, ppm					
	CO	NO	NO ₂	Flue Temp, °C	NO _x	H ₂ O
Diesel	172	30	24.9	69.3	55	6
20% Diesel + 80% UEO	193	44	24.3	79.6	69	5
10% Methanol + 90% UEO + 3 g V ₂ O ₅	306	13	21.7	66.5	35	2



Fig. 5. Gas analyzer for gas emission measurements.

4. Conclusion

A large amount of waste engine oil is disposed of every single day. Waste engine oil can be an alternative source of producing energy. It can be useful by considering the sustainability matters and excluding pollutions as much as possible. This work was based on treating the waste engine oil to convert it to a diesel-like fuel, so it could be used in diesel engines. The main objective of this work was to decrease the harmful emissions that have a negative impact on the environment by applying physical and chemical treatments on the waste engine oil, so it could be used in diesel engines with minimized pollution on the environment.

By testing both samples of the treated fuel (20% diesel/80% UEO and 10% methanol/90% UEO with 3 g of vanadium oxide V₂O₅) on the diesel generator, both of them were successful, and the diesel generator started working with a high efficiency. The emission tests were carried out using a portable emission analyzer. Readings of the emissions were taken for the diesel and both treated

fuels. The data showed that the diesel had the least amount of emissions compared to both treated fuels. The 20% diesel/80% base oil had more emission than 10% methanol/90% base oil with vanadium oxide.

As for the energy content, the tests were carried out in Intertek Sharjah, UAE. The results of the diesel and the treated fuels were close, as shown in the tables. A diesel engine runs using DLF; it shows a relatively comparable performance when compared with regular diesel engines using pure diesel.

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