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Analyzing the performance of fly ash catalyst in catalytic fuel reformer

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Abstract
Recycling and reuse of waste material into useful form of energy is the main objective of this research work. For this purpose the waste engine oil (WEO) is selected as the source for the energy generation. WEO is cracked by using fly ash catalyst in the catalytic fuel reformer (CFR). The reformulated gas from CFR is condensed using water cooled condenser and the oil obtained from the condenser is named as WEOFA. To know the suitability of utilizing this reformulated gas in the IC engines, the properties of WEOFA is analyzed as well as the chemical composition is analyzed using FT-IR and GC-MS. The analyzing results revealed that the WEO is capable of using as a source of energy for the IC engines..

Keywords: Waste engine oil, fly ash, fuel reformer, catalyst

1. Introduction

With the ever increasing demand and cost of petroleum based fuels on one side and the continuous reduction of fossil fuel sources on the other and the detrimental effects related with the use of fossil fuels on the environment, have encouraged researchers to give more significance for finding new and alternate sources of fuels instead of fossil fuels. According to some studies, it is estimated that crude oil will last only for roughly 80 more years, gaseous fuels for about 150 years, and coal for 230 years [1]. Therefore, scientists and researchers all over the world are now working hard to discover new sources of energy for the future, and also to develop new technologies that allow recycling or re-using waste material as a source of energy [2].

Large and increasing volumes of used lubricating oil are produced each year that, after use, are considered hazardous wastes. This is so because waste oils typically consist of a mixture of undegraded base oil and additives which high concentrations of metals, varnish, gums, and other asphaltic compounds coming from overlay on bearing surfaces and degradation of the fresh lubricant component [3, 4]. The used oil is disposed in many ways including incineration, landspreading, and dumping on the ground and into water. All used oil eventually creates environmental hazards. However, combustion and incineration of wastes is often difficult and cleaning of flue gases is complex and expensive because they contain important quantities of contaminants. As a solution to this problem of disposal, waste lubricating oil could be collected and processed via a re-refining process to become "re-refined lubricating oil" with an equivalent quality to new lubricating oil[5] or via direct upgrade from thermal cracking or catalytic cracking. In thermal cracking, hydrocarbons with higher molecular weight in lubricating oils can be transformed to lighter hydrocarbon products by thermolysis at higher temperature, which is accompanied with the formation of coke; large amounts of gas and naphtha with lower quality are produced due to over cracking. Fly ash is a waste material, accumulating at staggering rates as it is generated in very large volume, from the coal based thermal power plants. The disposal of waste is now becoming difficult which is not only occupying valuable land resources but also causing a threat to surface and ground water bodies. Development of innovative methodologies for utilization of this industrial waste in various value added materials has become an essential objective of the present research and development work related with fly ash management and utilization. Every year, more than 300 billion tons of fly ash is generated all over the world [6, 7]. It is a chemical ensemble of silica, alumina, iron oxide, lime, magnesia and alkali in varying amounts with some unburnt activated carbon, with a specific surface area typically between 250 and 600 m^2/kg. Till today, fly ash is mainly consumed in the production of building materials, agriculture, metal recovery, water and atmospheric pollution control, dye removal, etc [8-12]. These applications could succeed up to some extent to utilize the huge volume of fly ash. Nevertheless, the search of new applications of the fly ash as catalytic material is still ongoing. Our interest is utilizing the fly ash in the catalyticapplication. The main component for catalyzing is SiO_2 and Al_2O_3, which are present in the fly ash.

This study investigates the influence of catalyst with the waste engine oil when it is heated in the CFR. After that process, typical characteristics of the fuel such density, viscosity, flash point and fire point, calorific value, etc were tested. Effects of catalyst and their characteristics were discussed.

2. Materials and methods

The CFR was used to convert the WEO into gaseous state. To know the suitability of utilizing this gas in the diesel engine the reformed gas was condensed using water cooled condenser and the liquid sample was collected for analyzing purpose.

2.1 Nature of Waste Engine Oil (WEO)

Require amount of WEO were collected from auto garage of our department to conduct the research work. Then the WEO was stored in a tank at room temperature for several days to settle down the large suspended particles present in it. Basically WEO consisted of hydrocarbons with 18 to 40 carbon atoms. This oil can be either paraffinic or napthenic in nature depending on the chemical structure of the molecules.

2.2 Description of the reformed WEO gas production system

A CFR was designed and fabricated to convert the WEO into diesel like fuel. The reactor was installed in the Engine Research Laboratory, Department of Mechanical Engineering, Annamalai University. Schematic representation of the CFR was shown in figure 1.

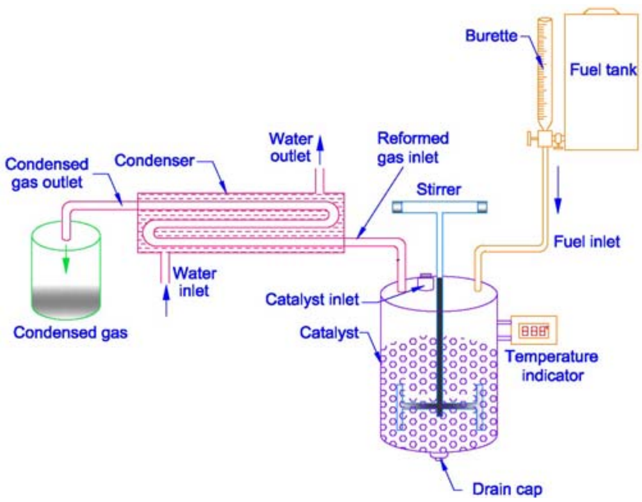

Fig 1: Schematic diagram of the catalytic thermal reactor

The system was consisted of several components such as fuel tank, control panel, reactor, thermocouple, stirrer, condenser, fuel storage tank. The fuel tank is used to supply the WEO into the reactor. The reactor of the system has a cylindrical shape with inner diameter of 15 cm and the length of 45 cm. The reactor was designed and fabricated to heat the WEO along with the catalyst. It includes an electrical heating unit which can be used to heat the WEO with catalyst upto 800 °C. The electrical heater has resistance heater and a voltage control which is used to adjust the heating rate. The heating control is performed by control panel. The stirrer is used to mixing the WEO with catalyst uniformly and also to distribute the temperature uniformly. The thermocouple is used to measure the temperature in the reactor. The condenser unit is used to condense the reformed WEO gas from the reactor. A water cooled condenser was used to condense the reformed WEO gas.

2.3 Preparation of fly ash catalysts

The fly ash samples were collected from Neyveli Lignite Corporation of Tamil Nadu. Similar to red mud samples the fly ash also subjected into the shaker and the powder form of fly ash samples were collected. The NaOH was added as the bonding material into the sieved fly ash. Then the fly ash was prepared in the form of pellets of 20 to 30 mm diameter. The pellets are subjected into the oven and heated the pellets about 80 °C for the period of one hour. Then the dried pellets are allowed to cool in the room temperature.

2.4 Properties

The different properties of the diesel fuel, fresh engine oil (FEO), WEO and WEOFA were analyzed. Fuel properties like density, kinematic viscosity, flash point, fire point, calorific value and specific gravity were analyzed. The density was measured according to ASTM D1298 method, kinematic viscosity was measured according to ASTM D445 method, flash point and fire point were measured as per ASTM D93, specific gravity was measured as per ASTM D1298 method and calorific value was measured as per ASTM D240.

2.5 Compositional analysis

2.5.1 FT-IR

A Bruker-Alpha FT-IR spectrometer with a resolution of ±1 cm^{-1} was used. Spectra were recorded at room temperature (298 K) in the region of 4000 to 400 cm^{-1} and NaCl cell of path length 0.1mm was used. The spectrometer possesses auto align energy optimization and dynamically aligned interferometer. It is fitted with a KBr beam splitter, a DTGS-Detector and Everlgo™ mid-IR source. A bsaseline correction was made for the spectra recorded

2.5.2 GC-MS

Liquid samples were dissolved in methanol and analyzed using GC-MS instrument (Varian-saturn-2200 MS/MS). The GC-MS was operated in non-isothermal mode, ramping at 250 °C using a 30 m fused silica capillary column (cross linked 5% PH ME siloxane, I.D. 0.25 mm film thickness 0.25 µm).

The total ion chromatogram produced for each sample was analyzed using varian analysis software and the NIST mass library. The chromatograph integrator was programmed in two different modes, allowing the quantification of compounds by both species and size. In this way, a single GC-MS analysis permitted the identification of the products and the classification of the sample by chain length. The GC-MS was not calibrated for the individual compounds in the samples; hence, the compounds are quantified as total ion content percentage (TIC%) - an integration of the chromatogram's peaks.

3. Results and discussion

Some of the important properties of diesel fuel, FEO, WEO and WEOFA were shown in table 1. The WEO showed a lower density but higher calorific value than that of the FEO. It is thought that some of the heavier hydrocarbons in FEO were decomposed into lighter hydrocarbons in WEO. The lower calorific value of the FEO was likely due to the presence of carbon and long-chain carbon compounds of lower calorific value in the oil matrix. The density and viscosity of the WEOFA were found to be lower than that of the WEO due to the cracking of heavy hydrocarbons to lighter compounds.

Table 1 Properties of Diesel, FEO, WEO, WEORM and WEOFA

Property	Measurement Standards	Diesel	FEO	WEO	WEOFA
Specific gravity @ 27°C	ASTM D1298	0.8298	0.881	0.879	0.8361
Kinematic viscosity @40°C in CSt	ASTM D445	2.57	85	52	1.54
Flash Point in°C	ASTM D93	50	215	197	33
Fire Point in °C	ASTM D93	56	-	-	36
Gross calorific value in MJ/kg	ASTM D240	44.67	43.6	45.4	41.22
Density@15°C in gm/cc	ASTM D1298	0.8072	0.879	0.858	0.8221

The density of WEOFA was quite close to that for diesel. The flash point of the WEOFA was found to be lower than that of diesel. The low flash points suggest that the un-refined WEOFA contained components that have a lower boiling point range than diesel. The WEOFA posses lower kinematic viscosity than that of diesel.

FT-IR spectroscopy was used to identify the functional groups present in WEO and it can offer information regarding the chemical change of the functional groups which may play an important role in investigating the influence of catalyst with WEO. The representative FT-IR spectra of the diesel fuel and WEOFA in the 4000–400 cm^{-1} wave number region are presented in Figure 2.

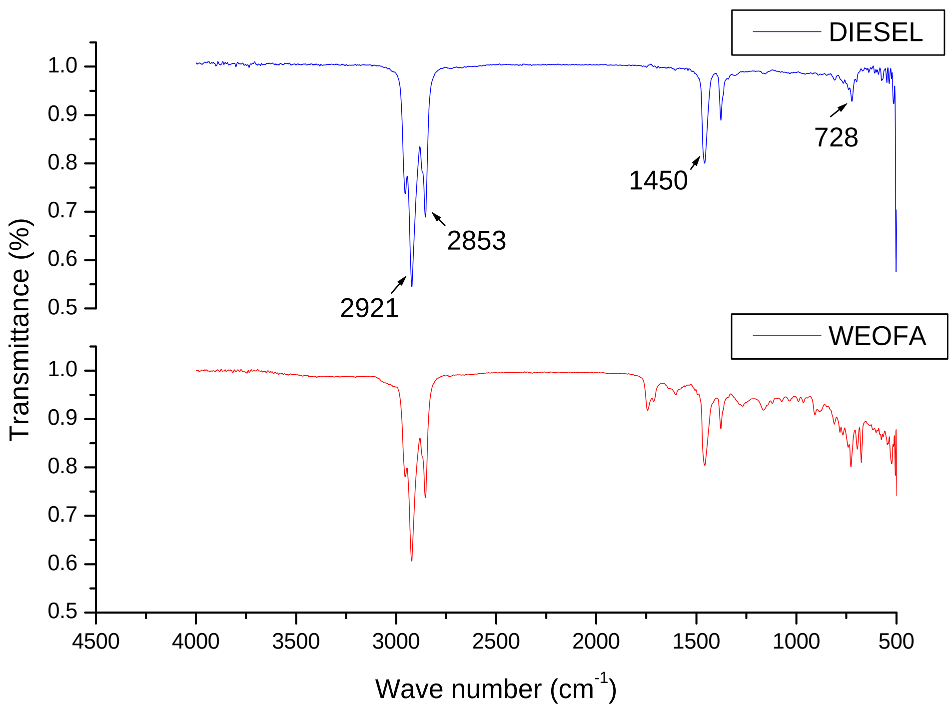

Fig 2: FTIR of Diesel, WEORM and WEOFA

The FT-IR spectrum reveals the presence of different functional groups. The two strong peaks observed at ~2921 cm^{-1} and ~2853 cm^{-1} indicates the presence of C-H groups and which are alkanes. Similarly infrared bands observed at ~1460 cm^{-1} and ~728 cm^{-1} are mainly from the C-H asymmetric bending and C-H out of plane bending respectively, indicating the presence of alkanes. Hence, the FT-IR spectra of WEOFA and diesel fuel bad similar to each other and confirmed that most of the hydrocarbons found in the WEOFA was alkanes and thus a potential to be used as alternate fuel in diesel engine. WEOFA was characterized by GC-MS. The result of GC-MS analysis was shown in figure 3. GC result showed that the WEO containing C_8-C_{24} hydrocarbons was thermally cracked with fly ash as catalyst and the end product that is WEOFA mainly of C_{13} hydrocarbons with the presence of aliphatic hydrocarbons and aromatics. This showed that the occurrence of cracking of compounds to produce some aromatic structures possibly derived from cyclisation and aromatization reaction that occurred during thermally cracked.

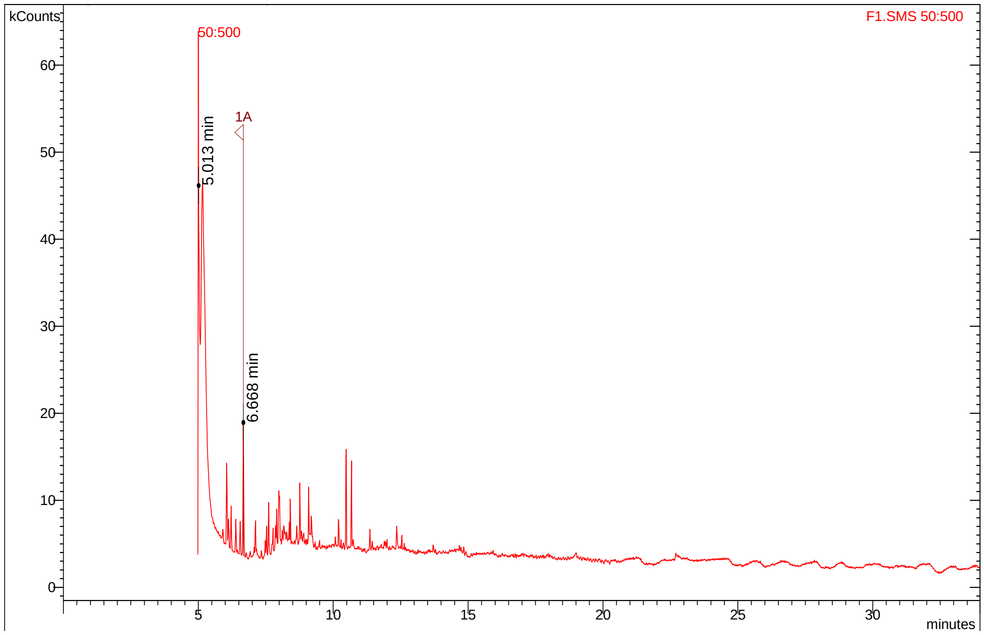

Fig 3: GC-MS chromatograms of WEOFA

The cracking of waste oil to small hydrocarbon components and heterogeneous reactions that occurred during thermally cracked. Hence similar to fossil diesel fuel, WEOFA mainly contain praffins, napthenese and aromatics.

4. Conclusion

In the present study, the possibility of using WEO as diesel like fuel was investigated. The collected WEO was allowed in to the CFR. Fly ash was used as catalyst to thermally crack the WEO in the CFR. The reformed gas from the CFR was condensed using condenser and the sample was analyzed. Characteristics of the diesel like fuel, such as density, flash point, fire point, viscosity, calorific value of WEOFA was tested and found to be close to that of the diesel fuel. FT-IR results confirmed that most of the hydrocarbons found in the WEOFA was alkanes and thus a potential to be used as alternate fuel in diesel engine. The GC-MS results revealed that the heavier hydrocarbon presents in the WEO was cracked into light hydrocarbon because of the catalyst WEOFA and which is similar to that of diesel fuel. Finally it is concluded that the WEO can be used in the form useful energy for the combustion of diesel engine.

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