

## Performance and Exhaust Emissions of a Diesel Engine Using Pyrolysis Oil from Waste Frying Oil and Castor Oil Mixture

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### ABSTRACT

Due to scarcity of crude oil price and increase in the environmental pollution there is a necessity to search for alternative fuels for internal combustion engines. In this investigation a 1:1 ratio mixture of waste frying oil and castor oil was used as a raw material in pyrolysis process. The pyrolysis oil obtained was then blended with diesel fuel at different ratios and the different blends were used as fuels in a diesel engine. The performance and emission characteristics of a twin cylinder, four-stroke, water cooled, direct injection diesel engine, were studied. The different fuels of pyrolysis oil-diesel blends were namely P10 (10% pyrolysis oil blended with 90% diesel), P30 (30% pyrolysis oil blended with 70% diesel) and P50 (50% pyrolysis oil blended with 50% diesel). The results obtained from the study were analysed and compared with diesel fuel values and are presented in this paper.

**Key Words:** Engine Performance, Emissions, Pyrolysis oil, Waste frying oil and Castor oil, Diesel Fuel.

### 1. INTRODUCTION

The use of vegetable oils in diesel engines is not new but highly attractive in the present scenario. This is because of their abundant availability, renewable in nature while used as energy sources. Rudolf Diesel reportedly used groundnut (peanut) oil as a fuel for demonstration purposes in 1900. Many research works were carried out on the use of vegetable oils in

diesel engines in the 1930's and 1940's. Due to the energy crises in the late 1970's and early 1980's, it has been necessary to seek alternative energy sources to conventional sources of energy, petroleum-based fuels. Vegetable oil occupies a prominent position in the development of alternative fuels. India being an agriculture based country produces around  $6.7 \times 10^6$  tons of non edible oils such as Jatropha, linseed, castor, karanj (Pongamia Glabara), Neem (Azadirachta indica), Palash (Butea monosperma), and Kusum (Schelchera Trijuga). These oils can be used as alternative fuels in compression ignition engines after modifying the fuel structure or properties or modifying the engine [1-9]. On the other hand edible oils such as groundnut oil, coconut oil, mustard seed oil are restricted for use in IC engines oil as they are used in domestic purpose. Waste cooking oil or used frying oil which is obtained from these oils can be used as an alternative fuel in compression ignition engines with some fuel modification or engine modification [10, 11]. The main hindrance to use the non edible oil or waste cooking oil as fuels in compression ignition engines are due to the problems caused by them like carbon deposit, injector coking and wear and tear in fuel injector. Viscosity of vegetable oils and their structure are important characters that result in such problems. Hence, the vegetable oils must be converted into engine adopted fuel. There are various methods available to reduce the viscosity of such vegetable oils or waste cooking oil. They are (i) Blending (ii) Micro emulsification (iii) Preheating (iv) Transesterification (v) Pyrolysis and thermal cracking.

Among these different methods, pyrolysis is useful in deriving fuels from different kind of feed stocks. For example plastics, industrial and automotive waste

oils, wood pyrolysis oils, fresh and waste fats and vegetable oils [13–16] etc. have been proposed as pyrolysis raw material to produce alternative fuels. The pyrolysis of different vegetable oils was used for fuel supply in different countries during the First and Second World Wars. For instance, a Tung oil pyrolysis batch system was used in China as a hydrocarbon supply during World War II. Since then several studies on vegetable oil pyrolysis is used as an alternative method to obtain chemicals and fuels [15]. Studies of pyrolysis carried out in the absence of a catalyst were done using oil from Soybean [16], Palm tree, Babassu, Pequi, Macauba and Canola [15] as raw materials. In these works, the characterization of pyrolysis gas and liquid products were reported and some reactions were proposed. The formation of linear and cyclic paraffins and olefins, aldehydes, ketones, and carboxylic acids were observed during thermal decomposition. The direct thermal cracking of soybean oil in a distillation apparatus was also studied and the fuel properties of the liquid product fractions were characterized. Indeed, it was observed that this product has low viscosity and a high cetane number compared to pure Soybean oil. The cetane number of pyrolyzed Soybean oil is enhanced from 37.9 to 43 and the viscosity is reduced from 32.6 to 10.2 cSt at 38°C, but it still exceeds the specified value of 7.5 cSt for diesel fuel [16]. It is worthwhile to mention that despite of 10 wt. % of carboxylic acid content (average acid number of  $\approx 132$ ), the liquid fuel obtained give an acceptable copper corrosion value. The main aim of the present study is to use oil obtained from pyrolysis of a mixture of waste cooking oil and castor oil in a ratio of 1:1. The oil was blended with diesel fuel at different blend ratios from 10% to 50% at 10% regular interval. Performance and emission characteristics of the twin cylinder, water cooled, four stroke and DI diesel engine were obtained and compared with diesel fuel and presented in this paper.

## 2. PROPERTIES OF PYROLYSIS OIL

The comparison of fuel properties of castor oil waste frying oil mixture, pyrolysis oil from castor oil waste frying oil mixture and diesel fuel are given in Table 1. It is observed from the table that the properties of pyrolysis oil similar to diesel fuel. Specific gravity, flash point and fire point were reduced after pyrolysis of the castor and waste frying oil mixture. Viscosity in the mixture was reduced after pyrolysis about 50%.

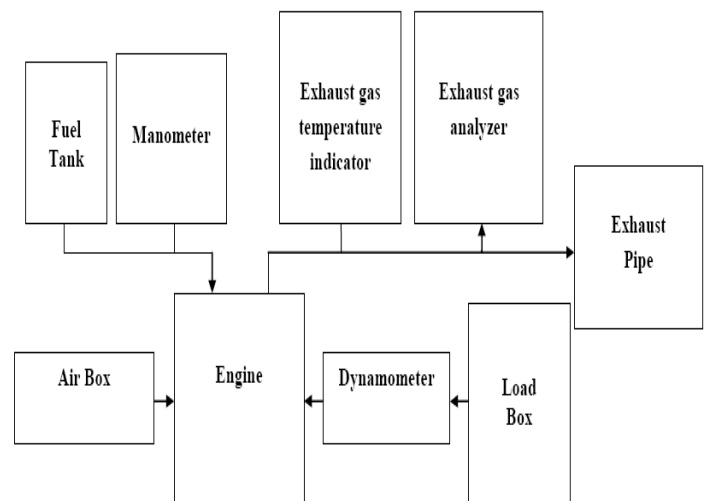
**Table 1 Comparison of Pyrolysis oil with Diesel Fuel**

Properties	Diesel Fuel	C-W oil mixture	Pyrolysis oil
Specific gravity at 15 °C	83	0.9231	0.90
Net calorific value(MJ/kg)	43.8	37	35.8
Flash point(°C)	50	318	72
Fire point(°C)	56	350	114
Kinematic viscosity at 40 °C(cost)	2.58	41.66	18.36

This indicates that the fuel can be utilized in a diesel engine without engine modification. It can be used as alternative fuel by blending the pyrolysis oil with diesel fuel.

## 3. EXPERIMENTAL SETUP

The schematic diagram of the experimental setup is given in Figure 1.



**Figure 1 Schematic Diagram of Experimental Setup**

The specifications of the engine used in the experimentation are given in Table 2. The engine was coupled to an electrical dynamometer to provide brake load and is controlled by system provided in the control panel.

**Table 2 Engine Specifications**

Make/Model	Kirloskar TV 1
Brake power, kW@1500 rpm	7.37
Bore , mm	80
Stroke, mm	110
Compression Ratio	17.5:1
Nozzle Opening Pressure, bar	200
Injection Timing, °CA	27

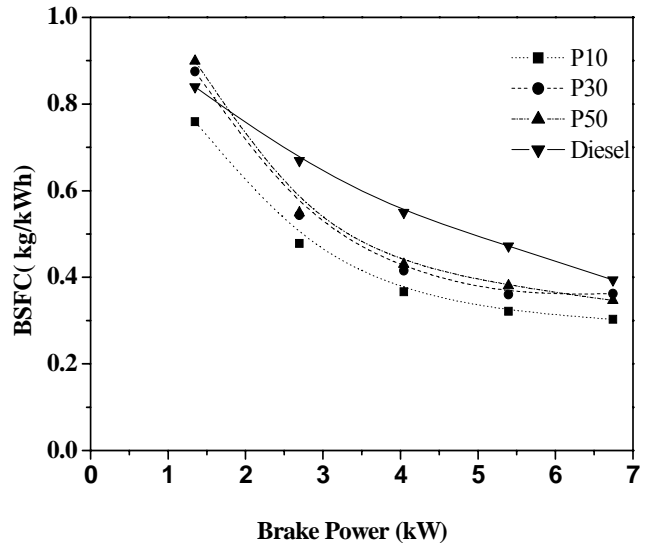
An air box with U-tube manometer connected to the intake of the engine. The air consumption of the engine was measured with the help of U-tube manometer. Fuel consumption was measured with the help of U-tube manometer fitted in a control panel. One end of the limb of U-tube manometer was connected to fuel tank and another end connected to fuel supply system. A temperature indicator provided with k-type thermocouple was used to measure the exhaust gas temperature. Exhaust emissions from the engine were measured with the help of AVL digas analyzer and smoke density was measured with the help of AVL 437 C diesel smoke meter. A probe was used to receive sample of exhaust gas from the engine.

## 4. RESULTS

### 4.1. Engine Performance

#### 4.1.1. Brake specific fuel consumption

The variation of brake specific energy consumption at brake power for pyrolysis oil diesel blends is shown in Figure 2. Brake specific fuel consumption of fuel blends is very similar to neat diesel fuel. It increases at low loads and decreases at full loads.



**Figure 2 Variation of BSFC with brake power**

There is an increase in brake specific fuel consumption with blending at low load. The values of brake specific fuel consumption of 10, 30 and 50% blends for full load are 0.3029, 0.3617 and 0.346 kg/kWh respectively where as it is 0.394 kg/kWh for diesel. The decrease in BSFC may be due to more oxygen available in the fuel.

#### 4.1.2. Exhaust gas temperature

Figure 3 depicts the variation of exhaust gas temperature for P10, P30, P50 and diesel fuel for different brake power. Exhaust gas temperature is an indication for the conversion heat into work that takes place in the cylinder. The exhaust gas temperatures were higher for pyrolysis oil-diesel blends than diesel. The exhaust gas temperature increases with blending from 470 °C to 480 °C at full load. This increase in the exhaust gas temperature may be due to the high viscosity of the oil than diesel.

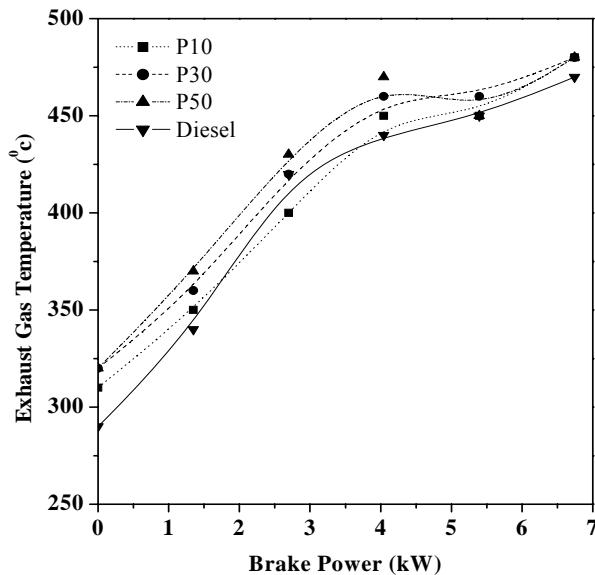


Figure 3 Variation of exhaust gas temperature with brake power

High viscosity fuel is injected up to later part of premixed combustion and there is increased in ignition delay and rapid combustion is formed which lead to high exhaust temperature.

## 4.2. Engine Emissions

### 4.2.1. Nitric Oxide Emission

Oxide of nitrogen results from reaction of nitrogen and oxygen at relatively high temperatures. NO is a major component in the NO<sub>x</sub> emission [18]. Figure 4 shows the variation of nitric oxide (NO) emission with the brake power for the tested fuels. As the brake power increases the oxides of nitrogen emissions increases. The oxides of nitrogen emissions were higher for pyrolysis oil-diesel blend than diesel. This may be due to the presence of oxygen in fuel blends as vegetable oils have a small amount of oxygen. It can be seen that the oxides of nitrogen emissions decreases with blend ratio. The probable reason may be due to heat release caused by the lower heat content of pyrolysis oil by increasing the oil percentage in blending.

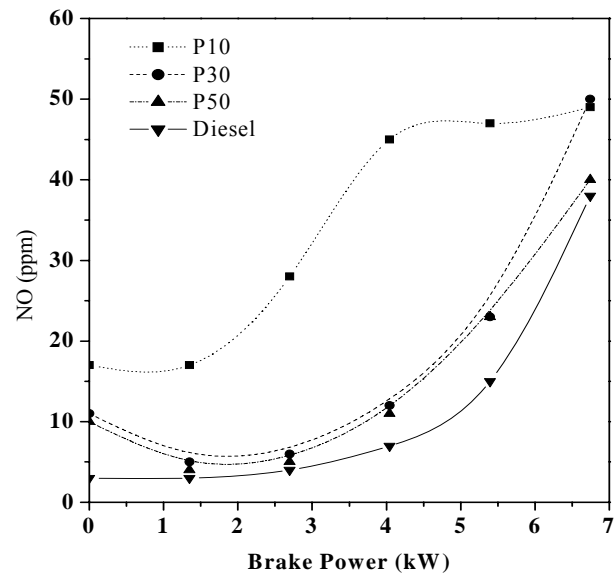


Figure 4 Variation of NO emission with brake power

The values of oxides of nitrogen of 10%, 30% and 50% blends for constant engine speeds at full loads are 49, 50, 48 ppm with respect to 38 ppm of diesel.

### 4.2.2 Unburned Hydrocarbon Emission

Figure 5 depicts the unburned hydrocarbon emissions from the engine exhaust at different brake power. Unburned hydrocarbon emissions are caused by incomplete combustion of fuel air mixture [18, 19]. Hydrocarbons emissions of fuel blends trends are very similar to neat diesel fuel, except for P10. Hydrocarbon emission varies from no load to full load. Unburned hydrocarbons of fuel blends are higher than neat diesel fuel and decrease with increase in blending percentage. The values of unburned hydrocarbons of 10, 30 and 50% blends for constant engine speed at full loads are 1, 6 and 3 ppm as compared to 1 ppm of neat diesel. The probable reason for emission may be some portion of the fuel-air mixture in the combustion chamber comes into direct contact with combustion chamber wall and get quenched. Some of this quenched fuel-air mixture is forced out during the exhaust which contributes to the high hydrocarbon emission [17-19].

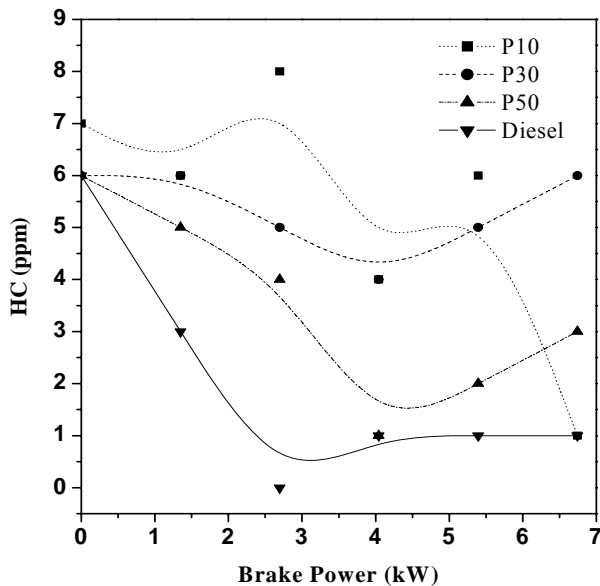


Figure 5 Variation of unburnt hydrocarbon with brake power

Another reason may be non-homogeneity mixture of fuel-air will make lean in some part of combustion chamber and produce hydrocarbon due to scarcity of oxygen though the vegetable oil is oxygenated fuel [19].

### 2.3 Carbon Monoxide Emission

Carbon monoxide occurs only in the engine exhaust [19]. It is resulted as the product of incomplete combustion. From Figure 6 it is concluded that as the brake power increases the carbon monoxide emissions is increased. Carbon monoxide emission is low at low load and high at full load for diesel fuel compared to pyrolysis oil diesel blend. It can be seen that the carbon monoxide emission decreases with blending except for P10. The reason behind increased CO emission may be incomplete combustion. The maximum CO emission was observed at the full power output of the engine. The values of carbon monoxide of 10, 30 and 50% blends at full load are 0.05, 0.05, and 0.02% respectively whereas the value is 0.06% for diesel at full load.

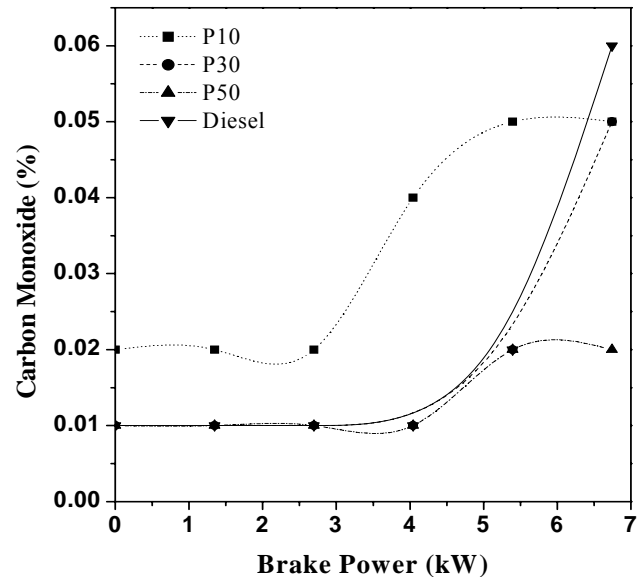


Figure 6 Variation of carbon monoxide with brake power

This trend may be due to proper mixing of air and fuel during the combustion process leading to less CO formation [19].

## 5. CONCLUSIONS

The following conclusions were made on performance and emissions twin cylinder, four stroke, and water cooled engine while running the engine with three pyrolysis oil diesel blends as fuels.

- Brake thermal efficiency using pyrolysis oil is higher than diesel. The brake thermal efficiency decreases with blending, but is more than diesel for every blending.
- Brake specific fuel consumption of fuel blends is lower than neat diesel fuel, brake specific fuel consumption increase with blending.
- Mechanical efficiency increases with brake power. Mechanical efficiency of fuel blends is lower than neat diesel fuel. It varies with blending.
- The exhaust gas temperature increases with brake power. The exhaust gas temperatures were higher for diesel blends than diesel. It can be seen that the exhaust gas temperature increases with blending.

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- Hydrocarbons of fuel blends are higher than neat diesel fuel at full load. It decrease in hydrocarbons is seen with blending.
- Carbon monoxide emissions were lower for diesel blends than diesel at higher loads.
- Carbon dioxide emissions increase with brake power increases. The carbon dioxide emissions were higher for diesel blends than diesel. It can be seen that the carbon dioxide emissions decreases with blending.
- As the brake power increases the oxides of nitrogen emissions also increases. The oxides of nitrogen emissions were higher for pyrolysis oil blends than diesel. However the oxide of nitrogen emission decreases with blending.

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