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Performance and Emissions Characteristics of an Automotive Diesel Engine Fueled with Petroleum-Based Fuel from Plastic Pyrolysis Oil and its Diesel Blends

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ABSTRACT

An interesting alternative fuel for Diesel Engines in the form of liquid oil derived from waste plastics, to solve the problem arises from the depletion of fossil fuels and disposal problem of the very large amount of plastic wastes produced from households and industrials. This present paper describes the production and testing of Liquid fuel derived from waste plastics by the pyrolysis process at different proportions (10 %, 20%, and 30%). The fuel produced is then tested in a fully instrumented diesel engine, without any engine modifications. The chemical properties such as GCMS, and FTIR results of the oil derived from waste plastics, compared with the diesel fuel, and found that it has similar properties to that of diesel fuel. The experimental investigation on the pyrolysis oil with diesel blends shows a notable increase in engine performance and a significant reduction in emission characteristics while compared with commercial diesel fuels. Thus, the results specify that modified plastic pyrolysis oil can be considered for an alternative fuel to diesel engines with better performance and reduce emission.

KEYWORDS: *Alternative fuel; pyrolysis oil; plastics; diesel fuel; GCMS; FT-IR; modified fuel; disposal problem of plastics*

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INTRODUCTION

Diesel engines are the most widespread power generation units, because of its high fuel conversion proficiency, reliability and robustness. Typically, they run on diesel fuels, but the interest in the use of alternative energy sources has been strongly increasing in the last years, in order to address the concerns about the future petroleum products availability and the associated hike in fossil fuels price, leads the humanity to check-out the petroleum products and pressurize to enter into the electronic age. But unfortunately, most of the countries were depends on the fossil fuel related machines to run automobiles and industrial level engines. In this scenario, it's too difficult to make a conversion from fossil fuel age to electronic age. It leads to huge economical loss in several sectors. In order to maintain the fossil fuels, we need develop alternative fuels to diesel engines. For this, our researchers found an interesting method to produce Diesel-like oil from wastes. This solution earns double advantage of recovering valuable energy content from waste commodities and mitigating the waste disposal problem. The typical waste commodities in the form of petroleum derived product called plastics, yields high heating values, so that can be conveniently converted into engine fuel [1, 2].

Thus to address the disposal problem and environmental issues by plastic commodities, Energy recovery method was introduced. In this process the liquid fuels (gasoline, diesel, gas, and char) can be produce in most efficient way [3, 4]. Though, the energy shortage can be solved to a great extent. The conversion of plastic waste commodities into their basic monomers or hydrocarbon; this practice is considered as tertiary (or chemical) recycling [5, 6]. Despite the number of studies and projects on the conversion of plastic waste commodities into fuel [7].

Some of the researchers named Mani, Soloiu, Brajendra, Mindad [8, 9, and 10] made some researches on waste pyrolysis process and its influencing factors for better yield. Most of their works explored about type of liquid hydrocarbon extractions, boiling temperature, residual time, and type of catalyst. More precisely, investigation of finding best suitable alternative fuel for conventional diesel fuel from types of plastic commodities ranges from poly-styrene, Poly-VC, poly-propylene, acrylonitrile-butadiene-styrene, High Density PE, Low Density PE and various mixtures [11, 12, and 13]. As far as, engine performance and of the diesel engines were concerned to analyses the efficiency, and they found that the fuels obtained from polymers shows similar characteristics with the conventional diesel fuel. So, by concluding from the analysis of thermal recycling that the plastic waste commodities are more suitable for engine applications [14, 15].

The present paper defines the experimental investigation carried out on a four-stroke diesel engine. The production, chemical and physiochemical Characterisation of pyrolysis oil with diesel fuel at different proportions. Thus, to find the comparison with both the fuels (based on petro diesel standards such as ASTM D 975) [16]. Blends of waste plastic pyrolysis oil with diesel were prepared at different proportions and the resultant fuel properties were measured. Based on the available results, it is anticipated to results comparable with diesel fuel. Then it will made to run on diesel engine. Initially, the engine runs on standard Commercial Diesel Oil and on blends of Waste Plastic Oil at different proportions derived from the pyrolysis of plastics. This study examines the performance of pyrolysis oil with a view towards possible future inclusion into existing diesel fuel standards for automobiles, without any engine modifications.

METHODS AND MATERIALS

Different types of plastic commodities are used as feedstock for the processing of pyrolysis process, ranging from PET, LDPE to HDPE includes plastic containers, bottles, carry bags and so on (from domestic areas). These waste plastic materials were cleaned with detergent water, to remove the foreign contaminants such as oil and mud forms. Cleaned feedstocks was then allowed to dry using driers and cut into small pieces ranging from 2-5 cms in size, using mechanical crushers.

A. Experimental Setup of Plastics Pyrolysis Process

A small scale externally heated fixed bed pyrolysis batch reactor was used for production of liquid oil from plastic wastes. Basic Instruments includes temperature controller and sensor, condenser, heating coil, insulator, storage tank, and valves are considered to be primary tools of the pyrolysis process. Feeds tocks in the form of PET, low density and high-density PE bags and containers were cleaned and cut it into small pieces, and allowed to shred it into reactor using shredder. The reactor is initially heated up to 500 0C, with the help of a temperature sensor attached on the walls of stainless-steel pyrolysis reactor, the temperature is maintained to a particular level, as mentioned above. The temperature is an important influencing factor for this process. So, using the sensor, the range is maintained.

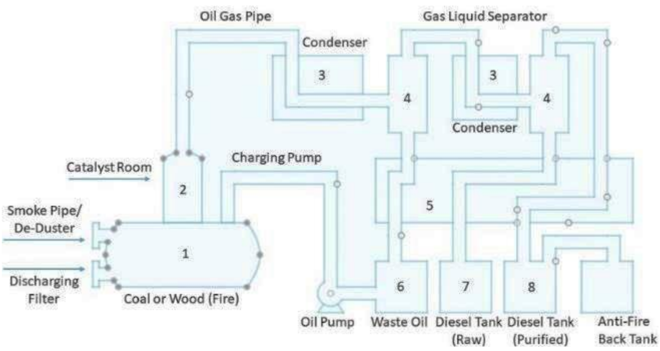

Fig.1. Diagrammatic Representation of Pyrolysis Reactor Setup – Preparation of Plastic pyrolysis oil

Besides, a nitrogen hole was provided to allocate uniform heating across the chamber. This also helps to create inert environment in the chamber. Always, the process temperature is maintained at 300 – 500 0C for about 2-2.5 hrs. The vapor produced from the reactor were carried out through condensers and allowed to cool by water and the condensed oil was collected in collectors. The collector will collect char products or the first from of product. It is then allowed into the reactor for maximum utilization. At the same time, other two collectors will collect the raw form of liquid oil and last one condenses and cool the vapor content, it will form Purest form of Liquid oil (Plastic Pyrolysis Liquid Oil). The final product of the process in the solid called char, was collected from the base of the reactor after completion of pyrolysis process. Figure. 1 Shows the diagrammatic representation of Pyrolysis reactor setup [22, 23].

B. Fuel Properties

Fuel properties of the liquid oil (derived from plastics) were tested by the following methods which are summarized in Table 1. The physical properties of the Plastic Pyrolysis Oil obtained such as density (ASTM D1298), kinematic viscosity (ASTM D445) [16], flash and fire point (ASTM D92) [17], calorific value (ASTM D240) [19], cetane number (ASTM D613) [20] were analysed based on the ASTM standards which were also reported by other researchers [18, 21].

Table 1. Testing methods for fuel properties measurements

Properties	Test method
Density	IP 131/57
Kinematic viscosity	ASTM D-445
Flash point	ASTM D-93
Fire point	ASTM D-93
Calorific value	Bomb calorimeter 12/58

C. Performance Test of the Blends in a Diesel Engine

The experimental setup consists of a Kirloskar Diesel engine having the configuration of 1500 rpm constant speed, four strokes, 5hp and 500cc, which is mechanically loaded by means of a brake drum dynamometer, water cooled with loading units. The performance of modified fuel blends in diesel engine was Investigated and compared with conventional diesel fuel. Different blends of the pyrolysis oil with diesel fuel were prepared. It includes P10 (10% pyrolysis oil and 90% diesel), P20 (20% pyrolysis oil and 80% diesel), and P30 (30% pyrolysis oil and 70% diesel). The engine is fueled with the above-mentioned fuel, and the results are compared. For the testing of fuel blends, the schematic of engine setup is shown in Fig. 2. Before starting the experimentations, the engine was fully warmed up and fueled with conventional diesel fuel for testing [24]. The parameters like Brake thermal efficiency and Specific fuel consumption were reported with variation in load at different blend ratios. An AVL smoke meter is coupled with the engine, used to measure the smoke density and the rest of the pollutants [25]. The parameters like Smoke density, Oxides of Nitrogen, Carbon Monoxide Emission and Carbon Dioxide Emission were reported with respect to the variation in load at different blend ratios.

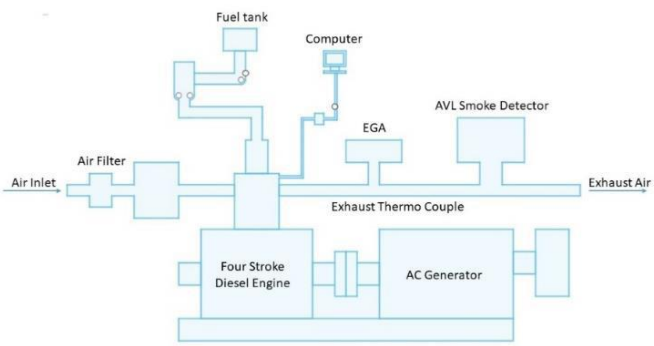

Figure.2 Schematic representation of engine setup

RESULTS AND DISCUSSION

A. Physiochemical Properties

The physiochemical properties of plastic pyrolysis liquid oil are compared with diesel fuel. The parameters like Flash point, Fire point, Kinematic Viscosity, Density and Calorific value of the fuel oils are measured as per the standards. As per the available contents, the plastic pyrolysis liquid oil has high volatile content is almost 77% by weight which is suitable for pyrolysis conversion of organic solid wastes to liquid product.

Table.2 Physiochemical properties of modified fuel with diesel

Properties	Plastic pyrolysis oil	Diesel
Viscosity at 40 C (cSt) °	1.99	4.12
Density at 40 C (g/cc) °	0.78	0.85
Flash point (C) °	19	55
Fire point (C) °	25	60
Calorific value (kcal/kg)	10450	10530

B. Effect of Temperature on Product Yield

Three different types of products were derived from the pyrolysis of plastic commodities. It was noted that the liquid yield was available only at temperatures above 350 0C for all catalysts. Temperature is also considered as one of the important influencing factor of pyrolysis process. Yield of the product is influencing based on the temperature we are applying [26, 27].

From the available Figure (4) it is clear that, about 39% of Liquid oil was obtained at 340 0C, but the range of yield being almost for upto 380 0C. After that, a significant change occurs upto 450 0C. The oil Percentage increased to a range of 85% at 450 0C. From the graphical representation itself, we can conclude that, the yield of oil is maximum occurs at a range after 400 0C. From the obtained results of liquid oil yield, the catalyst combination of silica alumina and zeolite (70% SA1, 30% Z1) is selected as the best catalyst with the optimum reaction temperature as 425 0C.

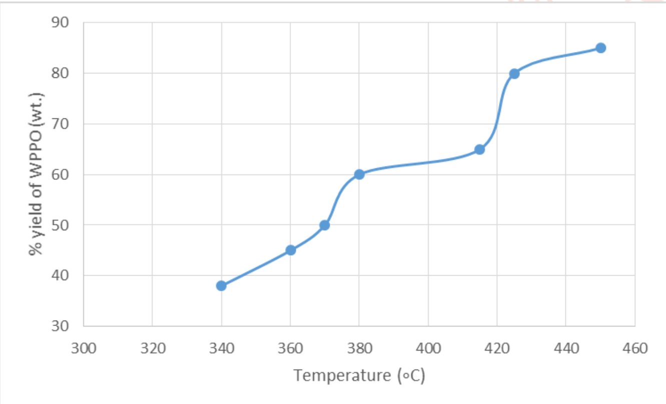

Figure.4. Effect of Temperature on Product Yield

C. Engine Performance

1. Brake Thermal Efficiency

The variation of Brake thermal efficiency with respect to load is presented in Figure 7. Brake thermal efficiency of an engine is defined as the ratio of brake power output to the net input power. Brake thermal efficiency increases with brake power only up to a limit beyond which it drops. Here, with increase in the concentration of plastic oil in the blends of diesel, the efficiency increases and it drops after a particular concentration level, sometimes it may be because of the higher fuel consumption, due to the influence of physiochemical properties such as viscosity [28]. From the graphical representation, the brake thermal efficiency of conventional diesel fuel is compared with the plastic oil blends from 10% - 50%, and shows similar characteristics with diesel fuel. The BTE of the all load conditions, upto 30% exhibits better output, than that to the conventional diesel fuel. After that, it drops. This may be because of lower calorific value of plastic pyrolysis oil at higher proportions. The variation of air-fuel ratio with brake power influences the output to a great extent.

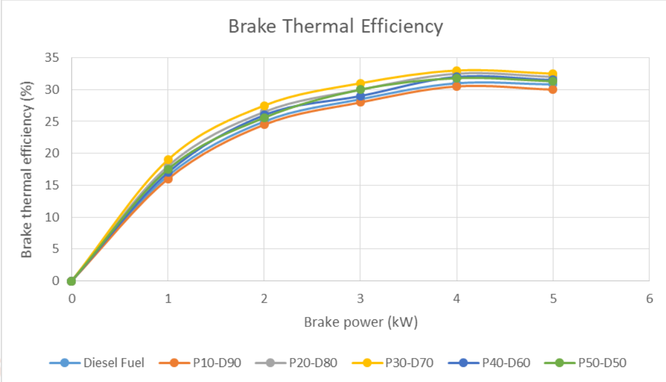

Figure.7. Brake thermal efficiency of modified fuelv

2. Specific Fuel Consumption

The variation of specific fuel consumption with respect to load is presented in Figure 8. Specific fuel consumption is defined as the amount of fuel is required for producing unit brake power. The engine is fueled with commercial diesel fuel and plastic pyrolysis liquid oil blends at various loads are have been measured. It is observed that the modified fuel have lower specific fuel consumption than conventional diesel fuel, because of its fuel consumption arising from its calorific value. The values of commercial diesel fuel and the modified liquid oil blends of SFC is nearly same.

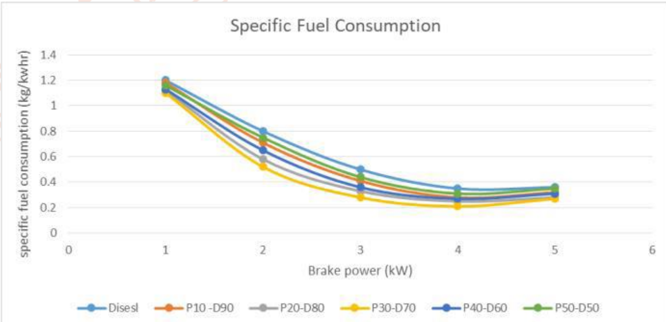

Figure.8. Specific fuel consumption of modified fuel

D. Emission Characteristics

From the performance test analysis it can be seen that the test results of P10 and P20 showed close similarities with that of diesel fuel, blends of fuel with Pyrolysis oil at P30 shows better characteristics than that of the diesel fuel. Remaining concentration proportions has fall down in engine performance.

So for the analysis of the emission characteristics, the engine was run with P-10, P-20, P-30 and diesel, and the emission was analysed using an exhaust gas analyzer. An exhaust gas analyzer was used to measure emissions characteristics such as Oxides of Nitrogen (NOx), Carbon Dioxide (CO_2), Carbon Monoxide Emission (CO). Smoke was measured by an AVL smoke meter coupled with the diesel engine.

1. Carbon Monoxide Emission

The variation of carbon monoxide (CO) emission with brake power is tested with Modified fuel blends and compared for conventional diesel fuel as shown in Figure 9. CO emission is commonly due to the lack of oxygen content, incomplete combustion and poor air fuel composition mixture [29]. The physiochemical property called Viscosity for higher concentration blends is less.

In such cases, the fuel will enter into chamber increases and due to the improper addition of air mixture leads to incomplete combustion. Air fuel ratio relative to stoichiometric proportions is considered to be one of the important component in the production of CO. Also, it was stated in the literature, that the increased CO emission is due to low in-cylinder temperature during the combustion in diesel engine [30].

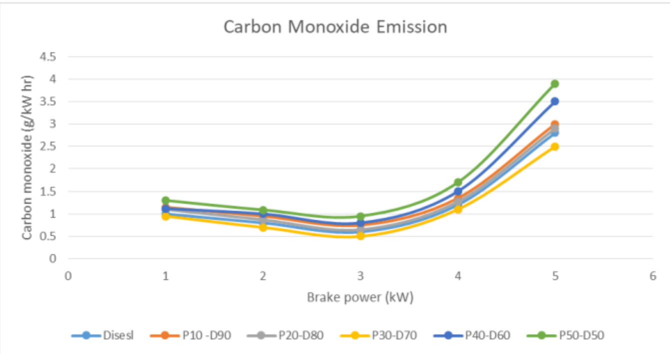

Figure.9. Carbon monoxide emission of modified fuel vs. diesel fuel

2. Carbon Dioxide Emission

The variation of Carbon Dioxide emission with load power is tested with Modified fuel blends and compared for conventional diesel fuel as shown in Figure 11. CO_2 emission is due to the incomplete combustion, which results in high heat release. From the graphical representation, it is clear that the carbon dioxide emission is lower in case of modified fuel blends at 30% (P-30) than that of conventional diesel fuel.

The increased CO_2 emission with PPO blends is mainly due to high availability of oxygenated compounds in PPO which during combustion results in improved combustion at higher loads and produces high CO_2 emission compared to diesel fuel.

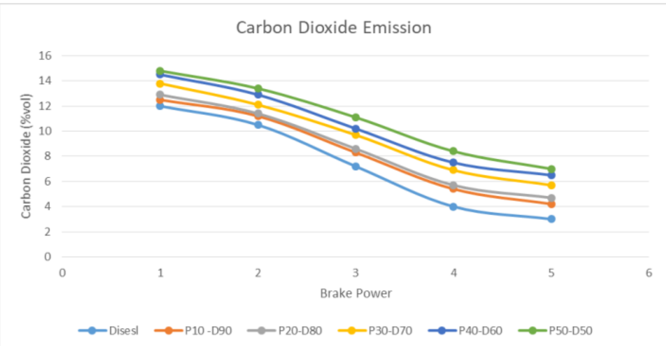

Figure.10. Carbon monoxide emission of modified fuel vs diesel fuel

3. Oxides of Nitrogen

The variation of Oxides of Nitrogen emission with load power is tested with Modified fuel blends and compared for conventional diesel fuel as shown in Figure 8. It consist of Nitric Oxide (NO) and Nitrogen Dioxide (NO2). NO is formed as a result of the oxidation of nitrogen contents in the sucked air during burning of air fuel mixture in combustion chamber. For low proportion levels, blends have less amount of oxygen content, hence reduced in NOx. Mani et.al and Kumar et.al reported the same views in the emission characteristics of Plastic Pyrolsysis blends [31].v

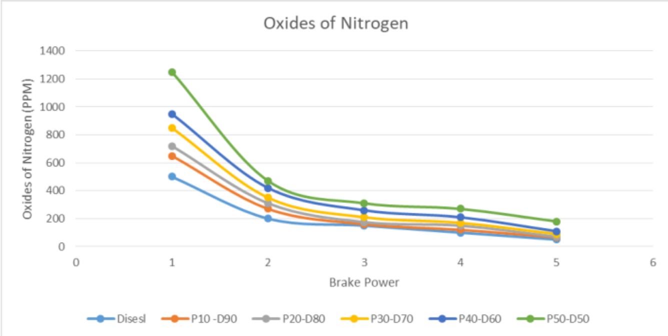

Figure.10. Oxides of nitrogen emission of modified fuel vs diesel fuel

CONCLUSIONS

In this experimental work, the pyrolysis liquid oil is derived from mixed plastics consist of HDPE, LDPE and PET plastic commodities. Thermal catalytic pyrolysis is the efficient way to convert plastic into liquid oil with highest yield. The chemical analysis such as GCMS and FT-IR tests were conducted to find the structure and compounds present in the liquid oil, and compared with the diesel fuel.

Then the experiments were conducted on diesel engine fueled with diesel, and blends of plastic pyrolysis oil at different concentrations, under different loads to investigate the impact of modified fuel on the performance and emission characteristics. Based on the experimental analysis, the major conclusions have been drawn:

- Pyrolysis of mixed plastic waste at 450 °C produces a high-quality and high-yield fuel obtained, which having similar physiochemical properties to conventional fuels like diesel represents an excellent alternative to be used as fuel in diesel engines.
- The chemical results such as GCMS shows that the chemical composition have been examined and found that aromatic compounds such as alkanes and alkenes at essential percentage levels is presented in the pyrolysis plastic oil, and hence the performance analysis was done in a Diesel engine.
- Addition of Plastic Pyrolysis liquid oil upto 50% with diesel to form a modified fuel at different proportions (10, 20, 30, 40, and 50) percentages. The engine performance (BTE) shows slight increase when compared to diesel fuel and hence provides increased efficiency while the SFC characteristics show a decrease in value when compared to diesel and hence shows good fuel characteristics.
- The low calorific value of Plastic Pyrolysis Liquid oil results in high fuel consumption whereas high oxygenated compounds cause elevated exhaust temperature while no rigorous variation in values is observed and hence can be utilized in diesel engines.

- Modified fuel with 30% shows significant output for engine performance. The presence of oxygen content improves the combustion characteristics.
- Emission characteristics such as Oxides of nitrogen, carbon Monoxide and carbon Dioxide emission levels are comparably better than that of the conventional diesel fuel, and it is more suitable for lower blends of modified fuels.
- Rather than considering it as an alternate fuel for diesel engines, the practical importance of this method in waste plastic management adds its value as an alternate fuel.
- The utilization of modified fuel with concentration level of 30% can be utilized in diesel engines with an efficient out in engine performance and with a small reduction in exhaust emission when compared to co
- nventional diesel fuel characteristics.

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