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Performance, emission and combustion characteristics of a DI diesel engine using waste plastic oil

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ABSTRACT

Increase in energy demand, stringent emission norms and depletion of oil resources have led the researchers to find alternative fuels for internal combustion engines. On the other hand waste plastic pose a very serious environment challenge because of their disposal problems all over the world. Plastics have now become indispensable materials in the modern world and application in the industrial field is continually increasing. In this context, waste plastic solid is currently receiving renewed interest. The properties of the oil derived from waste plastics were analyzed and compared with the petroleum products and found that it has properties similar to that of diesel. In the present work, waste plastic oil was used as an alternate fuel in a DI diesel engine without any modification. The present investigation was to study the performance, emission and combustion characteristics of a single cylinder, four-stroke, air-cooled DI diesel engine run with waste plastic oil. The experimental results have showed a stable performance with brake thermal efficiency similar to that of diesel. Carbon dioxide and unburned hydrocarbon were marginally higher than that of the diesel baseline. The toxic gas carbon monoxide emission of waste plastic oil was higher than diesel. Smoke reduced by about 40% to 50% in waste plastic oil at all loads.

1. Introduction

Plastics have become an indispensable part in today's world. Due to their lightweight, durability, energy efficiency, coupled with a faster rate of production and design flexibility, these plastics are employed in entire gamut of industrial and domestic areas. Plastics are produced from petroleum derivates and are composed primarily of hydrocarbons but also contain additives such as antioxidants, colorants and other stabilizers [1,2]. Disposal of the waste plastics poses a great hazard to the environment and effective method has not yet been implemented.

Plastics are non-biodegradable polymers mostly containing carbon, hydrogen, and few other elements like nitrogen. Due to its non-biodegradable nature, the plastic waste contributes significantly to the problem of waste management. According to a nationwide survey which was conducted in the year 2000, approximately 6000 tonnes of plastic waste were generated every day in India, and only 60% of it was recycled, the balance of 40% could not be disposed off. Today about 129 million tonnes of plastics are produced annually all over the world, out of which 77 million tonnes are produced from petroleum [3]. In India alone, the demand for plastics is about 8 million tonnes per year. More than 10,000 metric tonnes per day of plastics are produced in India and almost the same amount is imported by India from other countries. The per capita consumption of plastics in India is about 3 kg when compared to 30 kg to 40 kg in the developed countries. Most of these come from packaging and food industries. Most of the plastics are recycled and sometimes they are not done so due to lack of sufficient market value. Of the waste plastics not recycled about 43% is polyethylene, with most of them in containers and packaging.

2. Waste plastic oil in diesel engines

Diesel engines are most preferred power plants due to their excellent driveability and higher thermal efficiency. Despite their advantages, they emit high levels of NO_x and smoke which will have an effect on human health. Hence, stringent emission norms and the depletion of petroleum fuels have necessitated the search for alternate fuels for diesel engines. On the other hand, due to the rapid growth of automotive vehicles in transportation sector, the consumption of oil keeps increasing. Most of the research work has been done by mixing oil developed from waste plastic disposal with heavy oil for marine application .The results showed that waste plastic disposal oil when mixed with heavy oils reduces the viscosity significantly and improves the engine performance. However, very little has been done to test their use in high-speed diesel engines. A pilot level method of recycling waste plastic disposal in India produces waste plastic oil of 25,000 liter/day. The kind of plastic materials are Polyethylene, Polypropylene, Teflon,

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Nomenclature

LPG	liquid petroleum gas	X_1	uncertainty of total fuel consumption
TFC	total fuel consumption	X_2	uncertainty of brake power
NO_x	oxides of nitrogen.	X_3	uncertainty of brake thermal efficiency
UHC	unburned hydrocarbon.	X_4	uncertainty of CO
CO	carbon monoxide	X_5	uncertainty of unburned hydrocarbon
CO_2	carbon dioxide	X_6	uncertainty of NO_x
TDC	top dead centre	X_7	uncertainty of smoke number
CA BTDC	crank angle before top dead centre	X_8	uncertainty of exhaust gas temperature
Y	total percentages uncertainty	X_9	uncertainty of pressure pickup

Nylon and Dacron. For marine application, waste plastic oil is used in marine diesel engine [19]. An industry plastic waste with marine heavy fuel oil reduces the viscosity of the heavy oil significantly. Plastic bags, bottles, ropes and nets trap, choke, starve and drown many thousands of marine animals and seabirds around the world each year are threat the marine creatures [20].

2.1. Conversion process

The feed system consists of equipments for sizing hard, thick flexible and thin flexible materials, which normally constitutes the municipal waste stream. The system essentially consists of sorters and sizing equipments like crusher, cutter and shredder. The various sizes and shapes of the material are sorted into categories suitable for crushing, cutting and shredding. The sorted material was crushed or cut or shredded and graded into uniform size for ease of handling and melting in the melting/preheating process. This process of sizing and grading the waste was semi automatic. The graded feed was stored in a hopper before feeding to the process by a conveyor feeder. The sorted feedstock of known composition was stored separately for proportionate feeding for processing nonstandard feed design or processing special feed designs. The dust and other fine wastes collected from the cyclone filter were disposed through a vent with particle size monitoring system. The assorted waste plastic was fed into a reactor along with 1% (by weight) catalyst and 10% (by weight) coal and maintained at a temperature of 300 °C to 400 °C at atmospheric pressure for about 3 hours to 4 hours. The pyrolysis process involves the break down of large molecules to smaller molecules. Produces hydrocarbons with small molecular mass (e.g. ethane) that can be separated by fractional distillation and used as fuels and chemicals. This process gives on weight basis 75% of liquid hydrocarbon, which is a mixture of petrol, diesel and kerosene, 5% to 10% residual coke and the rest is LPG.

2.2. Comparison of waste plastic oil and waste tyre pyrolysis oil

Waste tyre pyrolysis liquids are a complex mixture of C_5 to C_{20} organic compounds, with a great proportion of aromatics [4] whereas waste plastic oil is a mixture of C_{10} to C_{30} organic compounds. Waste plastic oil has high calorific value than the waste tyre pyrolysis oil. Sulphur and distillation temperature is lesser than waste tyre pyrolysis oil. The properties of waste plastic oil, waste tyre pyrolysis oil [5,6] and diesel are compared in Table 1. The gaseous products and chemical composition of waste plastic oil are given in Tables 2 and 3.

3. Experimental setup

The schematic of the experimental set up is shown in Fig. 1. The research engine specifications are given in Table 4. An electrical dynamometer was used to provide the engine load. An air box was fitted to the engine for airflow measurement. The fuel flow rate was measured on volumetric basis using a burette and a stopwatch. Chromel alumel thermocouple in conjunction with a digital temperature indicator was used to measure the exhaust gas temperature. A pressure transducer mounted on the cylinder head with a charge amplifier and a computer were used to measure and record the cylinder pressure. A TDC encoder was used to detect the engine crank angle. An exhaust gas analyzer was used to measure NO_x/HC/CO emissions in the exhaust. Smoke was measured in Bosch Smoke Units (BSU) by an AVL smoke meter. All the experiments were conducted at the rated engine speed of 1500 rpm. All the tests were conducted by starting the engine with diesel only and then switched over to run with waste plastic oil. At the end of the test, the engine was run for some time with diesel to flush out the waste plastic oil from the fuel line and the injection system.

4. Error analysis

Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. Uncertainty analysis is needed to prove the accuracy of the experiments [7]. The percentage uncertainties of various parameters like brake power and brake thermal efficiency were calculated using the percentage uncertainties of various instruments given in Table 5. An uncertainly analysis was performed using Eq. (1).

$$Y = \sqrt{(X_1^2 + X_2^2 + X_3^2 + X_4^2 + X_5^2 + X_6^2 + X_7^2 + X_8^2 + X_9^2)} \quad (1)$$

$$Y = \sqrt{(1)^2 + (0.2)^2 + (1)^2 + (0.2)^2 + (0.2)^2 + (0.2)^2 + (1)^2 + (0.15)^2 + (1)^2}$$

$$Y = \pm 2.28\%$$

5. Results and discussion

A series of performance, emission and combustion tests were carried out on a 4.4 kW constant speed engine using diesel and waste plastic oil and the results are presented.

5.1. Combustion parameters

5.1.1. Delay period

From Fig. 2, it can be observed that the ignition delay of waste plastic oil is considerably longer than that of diesel. The longer delay period of waste plastic oil, results in a rise in-cylinder peak pressure. It may also be seen that the ignition delay is longer by about 2° CA to 2.5° CA for waste plastic oil than that of diesel and the peak pressure increases by 5 bar for waste plastic oil compared to diesel because of longer ignition delay.