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Experimental investigation of performance, emission and combustion characteristics of waste plastic pyrolysis oil blended with diethyl ether used as fuel for diesel engine

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ABSTRACT

The oil obtained by pyrolysis of waste plastics can be used as an alternate fuel for diesel engine without making any modification to the engine. The WPPO (waste plastic pyrolysis oil) mixed with 5% and 10% DEE (diethyl ether) were used as fuels for single cylinder water cooled, DI engine and its performance, emission and combustion characteristics were found. The experimental results indicated the reduction in smoke levels with that of baseline waste plastic pyrolysis oil. The BTE (brake thermal efficiency) increased when compared to pure plastic pyrolysis oil and diesel. The pollutants such as CO (carbon monoxide) and NO_x (nitrous oxide) were reduced in the blend. It was observed that addition of oxygenates had improved the combustion process and reduced the emissions. The investigation revealed that blending of DEE with plastic oil increases the Cetane rating which is superior to neat diesel.

1. Introduction

The steady increase in energy consumption coupled with environmental pollution has promoted research activities in alternative and renewable energy fuels. Many countries in the world are continually developing materials and methods for effectively utilizing the alternative fuel resources, available in their region [1]. Among the various alternative fuels, plastic pyrolysis oil has received significant attention in recent years, due to its environmental benefits. Plastics have woven their way into our daily lives and now poses a tremendous threat to the environment. Over 100 million tonnes of plastics are produced annually worldwide, and the used products have become a common feature at overflowing bins and landfills [2]. Plastic is a material used all over the world because of its desirable properties. But the main problem with it is the waste plastic will not decompose as other materials do. This led the world to have a consideration to avoid its usage. The plastic waste can be utilized to make fuel for the engine. The process of making fuel from plastic is called pyrolysis. The assorted waste plastic is fed into a reactor along with 1% (by weight) catalyst and 10% (by weight) coal and maintained at a temperature of 300–400 °C at atmospheric pressure for about 3–4 h. The pyrolysis process involves the breakdown of large molecules into 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, 5–10% residual coke and the rest is LPG (liquid petroleum gas). Many researchers have investigated the feasibility of using the waste plastic oil in the diesel engine. It was concluded that the waste plastic oil has properties, similar to that of diesel fuel and could be used as a substitute to diesel [3,4]. Low auto ignition temperature and high Cetane number are the desirable properties of DEE (diethyl ether) to use as fuel in diesel engines [5]. The aim of our experiment is to investigate the relevance of the diesel-DEE blend for the diesel engine without any modification on the engine.

2. Experimental setup

The Single Cylinder, water cooled, 4 stroke diesel engine was coupled with an eddy current dynamometer. A control panel

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Abbreviations: HC, unburned hydrocarbon; O_2, oxygen; CO, carbon monoxide; NO_x, nitrous oxide; CO_2, carbon dioxide; WD05, waste plastic pyrolysis oil blended with 5% diethyl ether; WD10, waste plastic pyrolysis oil blended with 10% diethyl ether; WPPO, waste plastic pyrolysis oil; DEE, diethyl ether; BSFC, brake specific fuel consumption; BT, brake torque; BP, brake power; TFC, total fuel consumption.

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having a burette was used to measure the quantity of fuel which goes into the engine. The dynamometer controls are there in the control panel. It has a device to show the temperature measured at different places in the engine. The AVL Digas' 444 Exhaust Gas Analyzer was connected to the tailpipe to find the constituents of CO, CO_2, HC, NO_x and O_2 in the exhaust gas which interfaces with RS 232 C pickup coil temperature probe. AVL 437C smoke meter was used to measure the smoke opacity and to find the exhaust temperature. The AVL Digas' 444Analyzer and AVL 437C smoke meter was interfaced with a computer with the help of A/D convertor. The readings were taken after running the engine in diesel mode for half an hour in order to get stabilized values. The exhaust gas Analyzer was calibrated with zero gas before the experiment. The engine setup is shown in Fig. 1 and the engine specifications are given below in Table 1. The fuels used were diesel, WPPO (waste plastic pyrolysis oil), WD05 (waste plastic pyrolysis oil blended with 5% diethyl ether), WD10 (waste plastic pyrolysis oil blended with 10% diethyl ether). The fuel blends were prepared just before starting experiments to provide homogenous mixture. A mixer was mounted inside the fuel tank in order to prevent phase separation. The properties of fuel used are given in Table 2.

3. Performance and emission

3.1. Brake thermal efficiency

Brake thermal efficiency indicates the ability of combustion system to accept the experimental fuel and provides a comparable means of assessing how efficiently the fuel was converted into mechanical output [6]. Low heat release rate during the premixed combustion phase, is the reason for lower thermal efficiency for tyre pyrolysis oil with diethyl ether operation up to part load [7]. Fig. 2 shows the curve between the load and brake thermal efficiency. The brake thermal efficiency at high loads for diesel and waste plastic pyrolysis oil is 28% and 27.75%, whereas for WD05 and WD10 is 27.51% and 29.12%. The thermal efficiency is higher for WD10. The addition of DEE increased the BTE (brake thermal efficiency) [8,9]. The presence of oxygen in the DEE helps in the complete combustion of the fuel raising the BTE. The BTE is almost same at the lower loads for all combinations of WPPO and DEE and then increases slightly with increase in concentration of DEE to WPPO. At higher concentration of DEE, the increase in BTE may be due to the ability of DEE to reduce the surface tension or interfacial tension between two or more interacting immiscible liquids helped the better atomization of fuel, which improves the combustion. Also the lower fuel consumption may be one of the reasons for increased brake thermal efficiency.

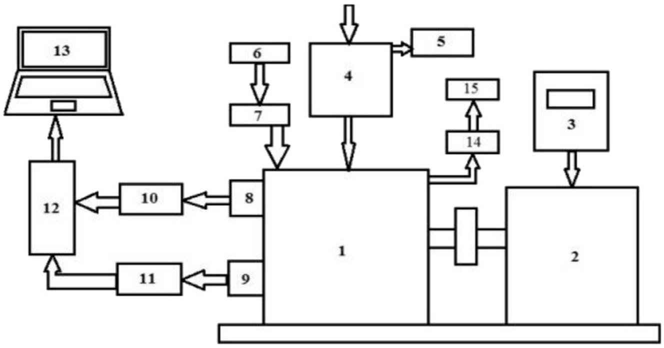

Fig. 1. Experimental setup. 1. Diesel engine; 2. Alternator; 3. Dynamometer control; 4. Airbox; 5. U-Tube manometer; 6. Fuel tank; 7. Fuel measurement flask; 8. Pressure pickup; 9. TDC position sensor; 10. Charge amplifier; 11. TDC amplifier circuit; 12. A/D card; 13. Personal computer; 14. Exhaust gas analyzer; 15. AVL smoke meter.

3.2. Brake specific fuel consumption

Fig. 3 shows the curve between Brake Specific Fuel Consumption with the load. This figure reveals that pure diesel fuel has the BSFC (brake specific fuel consumption) of 0.560 kg/kW h at 20% load and 0.276 kg/kW h at full load. For WPPO, the value is 0.616 kg/kW h at 20% and 0.292 kg/kW h at full load. The BSFC for WD05 is 0.605 kg/kW h at 20% and 0.294 kg/kW h at full load. The BSFC for WD10 is 0.591 kg/kW h at 20% and 0.301 kg/kW h at full load. At high speeds of the engine, the differences between BSFC values of fuel blends become smaller, due to the short combustion period in spite of the increased fuel amount. By excess oxygen and fast burning ethanol molecules, combustion temperature increases. All these factors affect combustion in a better way. As a result of this, BSFC values of WD blends become closer to pure diesel fuel BSFC at high engine speeds. The variation in brake specific fuel consumption with load for different fuels shows decline with increase in load. One possible explanation for this could be due to more increase in brake power with load as compared with fuel consumption. The BSFC in case of blends was higher compared to diesel in the entire load range, due to its lower heating value, greater density and hence higher bulk modulus. The higher bulk modulus results in more discharge of fuel for same displacement of the plunger in injection pump, thereby resulting increase in BSF. As the heating values are higher for blends compared to diesel with further increase in the concentration of additive it is clearly observed that the values of BSFC tend to decrease.

3.3. Unburned hydrocarbon

Unburned hydrocarbon consists of fuel that is incompletely burned. The term hydrocarbon means organic compounds in the gaseous state and solid hydrocarbons are the particulate matter [10]. Unburned hydrocarbon emissions are caused by incomplete combustion of fuel–air mixture. Fig. 4 shows the emissions of HC (hydrocarbon) with increasing loads. For Diesel, unburned hydrocarbon varies from 32 ppm at 20% load and 57 ppm at full load. For WPPO, the values are 53 ppm at 20% load and 91 ppm at full load. For WD05 and WD10, the values are 60 and 76 ppm, at 20% load and 93 ppm and 96 ppm at full load. The addition of DEE with WPPO increases the HC emissions than diesel. The reason behind increased unburned hydrocarbon in waste plastic oil, may be due to higher fumigation rate. The increase in HC emissions with the use of WD10 can be attributed to the leakage of the fuel through the injector nozzle due to the considerably low viscosity of the fuel [11]. DEE additive has a low charge temperature and decreases combustion temperature due to its high heat of evaporation. Additionally, some of the DEE additive mixes with air during fuel injection and accumulates in the ring space between the piston and cylinder. Consequently, the combustion flame cannot effectively reach these spaces, thus yielding high HC emissions [12].

3.4. Oxides of nitrogen

Oxides of nitrogen result from reaction of nitrogen and oxygen at relatively high temperatures. NO is a major component in the NO_x emission [13]. The formation of NO_x for diesel, WPPO, WD05 and WD10 are shown in Fig. 5. The NO_x values for diesel, vary from 129 ppm at 20% load and 855 ppm at full load. For WPPO, it varies from 150 ppm at 20% load and 904 ppm at full load. . For WD05 and WD10, it varies from 91 to 71 ppm at 20% load and 529 ppm and 473 ppm at full load. The NO_x formed is increasing as the load