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Combustion, performance and emission of a diesel engine fuelled with diesel doped with carbon black

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A R T I C L E I N F O

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A B S T R A C T

In this investigation, CB (Carbon black) was doped with diesel by following certain sequential processes and the mixture was commonly referred to as Carbodiesel. The mixture containing 5% CB was denoted as Carbodiesel5. Similarly, 10%, 15% and 20% CB in Carbodiesel were denoted as Carbodiesel10, Carbodiesel15 and Carbodiesel20 respectively. All the four Carbodiesels were used as alternative fuels in a single cylinder, four stroke, air cooled, DI (direct injection) diesel engine. The engine behaviour in terms of combustion, performance and emissions of the engine fuelled with the four Carbodiesels was evaluated and compared with those of diesel operation. The results indicated that Carbodiesel10 gave better performance and lower emissions compared to those of Carbodiesel15 and Carbodiesel20 at full load. The nitric oxide (NO) emission for Carbodiesel10 was found to be lower by about 6.2% than that of diesel at full load, while the smoke density was found to be higher by about 11.5% than that of diesel at full load. The engine can run on Carbodiesels without any major engine modification.

1. Introduction

Despite liquid and gaseous fuels being widely used in IC (internal combustion) engines, the use of solid fuels is also of great interest. This is because, the availability of solid fuels is larger than liquid and gaseous fuels, and the cost involved in fuel processing is lesser per kg of the heat produced. Since, coal was discovered; it was used as a fuel in combustion devices such as furnaces, boilers and steam engines for producing heat and power. Solid fuel from biomass was also used largely for power generation in IC engines through appropriate methods. Apart from the solid fuels derived from biomass and coal, organic matter is present in municipal and industrial wastes in a considerable quantity. Some examples of industrial waste which compose organic matter are plastics, rubber, polymers, and cotton wastes. Municipal wastes include waste tyres, glass bottles, metals and non-combustibles. Some of the selected hydrocarbons from these wastes can be converted into useful energy, by appropriate methods like catalytic cracking, pyrolysis, gasification etc. The anthropogenic gases can be reduced, if these solid wastes are processed or recycled instead of dumping in open lands.

Coal dust was used in the form of slurries in the past, because of its large production during the industrial revolution [1]. Many investigations were carried out in several countries on the utilisation of coal slurry fuels, especially COS (coal-oil solutions), CWS (coal-water slurry) and charcoal water slurry in medium diesel engines [2]. The CWS seemed to offer a long-term alternative to fuel oil, and it is also conceived as an attractive fuel for power generation in India [3]. The use of CWS fuels in modified IC engines was proposed as one of the promising alternatives [4,5]. Micronized coal water slurry was successfully injected in a modified diesel engine with a positive displacement injection fuel system, whose injection pressure is as high as 56.5 MPa (8200 psia), the result indicated that higher needle lift pressure led to shorter ignition delay times for the CWS fuel [6]. The apparent viscosity of the CWS increased, with a decrease in the particle size of the coal. The relation between the viscosity and temperature was not linear, and hence, a more suitable cubic model was proposed [7]. The CWS with the smaller particle sizes of coal, exhibited better ignition qualities and resulted in higher indicated thermal efficiencies than those of slurries with the larger particle sizes [8]. The CWS having micronized coal particles with approximately 50 percent coal loading was successfully ignited and combusted in one cylinder of a two-cylinder 645 EMD

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engine by using diesel fuel as a pilot fuel. The results reported that the engine was run over 5.5 h with CWS injection, using a unit injection system, without any major problem. It was also reported that the ignitability and combustion of CWS in the diesel engine did not seem to be a major problem [9].

Charcoal in the form of emulsion with diesel was utilized as an alternative fuel in a CI (compression ignition) engine. A non-ionic type surfactant was used to create a more stable emulsion and a lower viscosity, compared to other surfactants [10]. The investigation proved that the charcoal diesel slurry could produce adequate sprays and burn with very good results in a DI (direct injection) diesel engine. The utilization of the charcoal slurry as a fuel reduced the diesel oil consumption, and helped to reduce the GHG (greenhouse gas) emissions.

An analysis on the performance and emissions of the PCOS (petroleum coke oil slurry) was carried out in a single cylinder, 5.67 kW rated power diesel engine with 2600 rpm speed. The results showed that the PCOS engine can run smoothly, and that the maximum output power decreased under conditions of 1200 and 1600 r/min by about 6.2% and 19% while the maximum brake thermal efficiency was found to be lower by about 5.8% and 4.2%, in comparison with diesel fuel operation [11]. The resultant slurries were subjected to rheological characterizations, including the apparent viscosity and yield stress. The effects of the solid type, particle size distribution of the biomass char and the additives, on the preparation of highly loaded slurries with the desired rheological behaviour were systematically examined in terms of the apparent viscosity and yield stress [12]. The performance, emission, and combustion characteristics of a single cylinder diesel engine run at 1500 rpm speed using CNT (carbon nanotubes) blended water diesel emulsion fuels were studied [13]. It was reported that, the brake thermal efficiency was found to be lower and a substantial reduction in the CO and NOx emissions etc. in comparison with the diesel fuel operation. The reduction was due to the incorporation of CNT (carbon nanotubes) in the water diesel emulsion. The effect of injection pressure on the combustion and exhaust emissions of a DI, diesel engine fueled with an OSPDS (Orange Skin Powder Diesel Solution) was studied. Different injection pressures, viz, 215 bar, 235 bar and 255 bar were used in the study. It was reported that the cylinder pressure with the OSPDS at 235 bar fuel injection pressure, was found to be higher than that of diesel fuel, as well as that at other injection pressures [14,15].

Recently, many commercial pyrolysis plants have come up across the world, for tyre recycling. In practice, the pyrolysis of scrap tyres in the pyrolysis plant produces four products; TPO (tyre pyrolysis oil), CB (carbon black), pyrogas and steel wire. While TPO is used as a secondary fuel in furnaces and burners, pyrogas is used as a secondary fuel in the pyrolysis reactor itself [16,17]. The CB (carbon black) is non-disposable and dumped in large quantities in open lands, causing environmental pollution. Unfortunately, this CB can neither be converted into activated carbon (99.9% purity) nor used in any of the major industrial applications [18]. The CB contains a considerable amount of carbon in it, and also possesses a considerable heating value. This energy can be recovered by an appropriate method and used to generate heat and power.

Therefore, the present investigation is aimed at deriving energy from the CB, for small power generation through a diesel engine. For this purpose, a referred to as Carbodiesel was prepared, using the CB. The Carbodiesel was used as an alternative fuel in a stationary single cylinder, four stroke, air cooled, DI diesel engine developing power of 4.4 kW at a rated speed of 1500 rpm. The engine behaviour in terms of combustion, performance and emission was evaluated, compared with that of diesel fuel operation in the same engine, and is presented in this paper.

2. Materials and methods

2.1. Pyrolysis of tyres

In the pyrolysis process, the discarded waste tyres are fed into an externally heated reactor unit. The fed tyres are heated up in the absence of oxygen [19]. The process is carried out at a temperature range of 450–500 °C. The volatile vapour evolved in the reactor is condensed in a water cooled condenser. The condensed liquid, referred to as TPO (tyre pyrolysis oil), is collected in a separate oil tank. Some of the non-condensable volatile vapour is returned to the reactor unit as a secondary gaseous fuel, to preheat the reactor. A solid waste, CB (carbon black), is collected from the reactor unit after the process is complete. Fig. 1 shows the photographic view of the process of the feed stock to the end product through the pyrolysis process.

The percentages of the various product yield of tyre pyrolysis process are 45% TPO, 15% pyrogas, 30% CB and 10% steel wire. This 30% CB is obtained as a waste from the total input. This CB is impure and disposed in the open land.

2.2. Characterisation of CB

The important physical properties of CB are given in Table 1 and the ultimate analysis of CB is given in Table 2.

2.2.1. SEM analysis

It is necessary to understand the structure of the CB, if a solid fuel has to be used in a combustion device. A sample of CB obtained from the TPO plant in a temperature range of 450–500 °C was initially ground to fine powder particles of 40 μ size. The objective of this investigation is to use the Carbodiesel obtained from the CB powder in a stationary diesel engine. The hole size of the injector nozzle of the test engine was 0.25 mm which was larger than 40μ. After grinding the CB into powder form, the CB powder was tested by a SEM (scanning electron microscope) to study the structure of the CB powder. This permits the identification of the elements present in any solid that can be viewed by the SEM. The image of the CB obtained by the SEM is shown in Fig. 2.

Mostly circular crystal filaments and some semicircular crystal filaments are seen. The image also showed the average particle size of the CB powder as 40 μ, which is favourable for solid particle combustion.

2.3. Preparation and characterisation of Carbodiesel

2.3.1. Fuel preparation

In this investigation, a Carbodiesel from the CB was prepared adopting a sequence of processes. A block diagram of the process involved in the preparation of the Carbodiesel is shown in Fig. 3.

The CB obtained from a pyrolysis plant was dried in direct sunlight for one day, to remove the moisture in it. The CB was powdered with the help of a hammer. Then, the powder was further classified by a sieve to get a fine powder size of 40 μ. This was done because, the injector nozzle diameter is 0.25 mm which is greater than 40 size of CB particle. The CB was taken at different proportions from 5% to 20%. The CB powder was mixed with diesel at 80 °C and continuously stirred about 15 min using a mechanical stirrer to get a slurry, with a 0.15 kWh unit electricity consumption. For stirring operation, the power consumed was approximately 0.04 kW, which is equivalent to 0.0085% brake power. Finally, the slurry was cooled and filtered to get a Carbodiesel. The Carbodiesel obtained from the CB and diesel in different proportions, and the notations are given in Table 3.