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Combustion, performance and emission characteristics of a diesel engine with internal jet piston using carbon black- water- diesel emulsion

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ABSTRACT

Earlier investigations on the utilisation of Carbon black-water-diesel emulsion in a DI (direct injection) diesel engine reported that the engine performance was inferior to that of diesel operation at full load in the same engine. The HC (hydrocarbon), CO (carbon monoxide) and smoke emissions were reported to be higher than those of diesel operation at full load. The poor mixture formation and lower cetane number of the CBWD10 were believed to be the reasons for these results [1]. In this investigation, attempts have been made to improve the combustion and performance of the engine run on the CBWD10 emulsion by enhancing in-cylinder turbulence by providing two holes on the piston crown (internal jet piston). The performance characteristics for the CBWD10 emulsion with an internal jet piston is 1.9% higher than with a conventional engine piston at the full load, respectively. The internal jet piston operation with the CBWD10 emulsion exhibited the CO, HC and the smoke emissions lower by about 23.5%, 7.2% and 5.2% respectively compared to those of the engine operated with conventional piston.

1. Introduction

Soon after the energy crisis occurred in the world in the late 1970's, many developed countries have made efforts to produce variety of alternative fuels to be used in heat and power application. In the last three decades, attempts have also been made to find innovative technologies to reduce the cost of fuel, and environmental pollution. Although several research works are being carried in the production of cleaner and greener fuels and emission reduction techniques, research works are also being carried out in the area of reuse and recycling which offer some alternative fuels ad chemicals. For instance, organic substances such as charcoal, coal, carbon nanotube blend, CB (carbon black) and orange powder in the form of slurry have been investigated for their possible utilisation as an alternative fuel in diesel engines for small power generation. Research reports indicated that when CWS (coal water slurry) was tested in a diesel engine, the BSFC (brake specific fuel consumption) was found to be dropped by about a maximum of 20%, and the efficiency was found to increase by about a maximum of 15% at full load when the fuel injection timing was varied from 17°CA to 18°CA [2]. With the nozzle opening pressure of about 30 MPa or higher, the sprays were found to be similar for the CWS, diesel and water [3]. In another study, the CWS was successfully ignited and combusted in a two-cylinder 645 EMD diesel engine, by using diesel fuel as a pilot injection [4]. The injection timing of the pilot fuel played an important role in the CWS combustion. The coal fuels with higher reactivity exhibited better ignition characteristics, and yielded higher indicated thermal efficiencies for the specific injection timings, due to faster burning rates [5].

In recent years many researchers have reported that the in-cylinder air motions in DI (direct injection) diesel engines were altered through different arrangements, such as shaping the piston cavity [6–8] to study the engine behaviour in terms of combustion, performance and emissions. The direct methods of generating turbulence were found to be more flexible in terms of managing its timing and intensity than those obtained from swirl and squish motions. This turbulence arrangement generally pushes air into the air cell during the compression stroke and injects compressed air into the combustion chamber. The effect of turbulence induced late in the combustion period by burnt gas from an auxiliary chamber installed in the cylinder head [9]. The

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Nomenclature

DI	direct injection
CB	carbon black
CWS	coal water slurry
CBWD	carbon-black-water-diesel
BP	brake power
BTE	brake thermal efficiency
EGT	exhaust gas temperature
bTDC	before top dead centre
°CA	degree crank angle
CO	carbon monoxide
HC	hydrocarbon
NO	nitric oxide

brake thermal efficiency of the diesel engine was improved with improvement in air entrainment and increased swirl in the combustion chamber [10]. The use of an air cell is the usual approach for controlling soot through well-timed turbulence enhanced mixing in the combustion chamber. The researchers [11] reported a considerable reduction in the smoke level and attributed it to the kinetic energy of the gas jet. They also reported that the shortening of combustion duration at high loads, improved the thermal efficiency. The limits of the gas jet mixing on in-cylinder turbulence and observed that a properly timed gas mixing will have beneficial effects only at higher loads [12]. They reported that, increase in the turbulence at the end of the combustion period helps to reduce soot without adversely influencing the NOx emission level. The effect of geometry combustion chamber on fuel sprays behaviour and found that a re-entrant type combustion chamber and fuel distribution was good than a simple cylindrical combustion chamber [13,14].

In our early investigation, Carbon black-water-diesel emulsion (CBWD5-20) [1] was used as an alternative fuel in a DI diesel engine. The combustion, performance and emissions of the engine run on the emulsion were assessed in comparison with the diesel fuel operation of the same engine. The brake thermal efficiency of the engine was lower by about 5–10% and the NOx emission was also found to be lower by about 16–41% compared to that of diesel operation at full load. The CBWD10 emulsion was further tested in the same diesel engine with minor modifications carried out with the injection timing and nozzle opening pressure [15]. Investigation results revealed that the BTE of the engine fuelled with the CBWD10 emulsion was increased by about of 4% at an advanced injection timing of 26°bTDC and 220 bar nozzle opening pressure. The reason suggested by the authors was the fine fuel spray and optimised droplet size of CBWD10 achieved at 220 bar fuel nozzle opening pressure.

In this investigation, the authors have made an attempt to improve the engine performance by inducing more turbulence in the combustion chamber, when the engine was run on the CBWD10 emulsion. For this, the combustion chamber of the engine was modified by making two small micro holes in the piston which were used to create effective air motion in the combustion chamber. After assembling the piston into the engine, the CBWD10 emulsion was tested in the engine with the modified piston for determining the combustion, performance and emissions of the engine at different load conditions. The experimental results were then compared with those of diesel operation, and presented in this paper.

Table 1
Physical properties and the ultimate analysis [1].

Properties	CB
Density, kg/m^3	860
Surface area, m^2/g	130
Calorific value, MJ/kg	32.86
C, wt%	86.4
H, wt%	2.86
N, wt%	0.3
S, wt%	0.02
O, wt%	1
Ash content, %	10.24

2. Materials and methods

2.1. Production and characterisation of CB (carbon black)

In the pyrolysis of waste tyres [16], the discarded waste tyres are fed into an externally heated reactor unit. The fed tyres are heated in the absence of oxygen. 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 supplementary gaseous fuel, to preheat the waste tyres to reduce the energy consumption. CB, a solid waste is collected from the reactor unit after the process is complete. This 30% CB is obtained as a waste from the total input [17]. This CB is impure and disposed in the open land. The CB obtained from pyrolysis process of tyres has marginally higher sulphur content. So initially it was mixed with the concentrate sulphuric acid and removed of sulphur contents by desulfurization technique on 60 °C reaction temperature [18].

The important physical properties and the ultimate analysis of CB (carbon black) are given in Table 1.

2.2. Emulsification process and characterisation of the emulsion

2.2.1. Emulsification process

A block diagram of the process involved in the preparation of the emulsion is presented in Fig. 1.

The CB obtained from a pyrolysis plant was dried in direct sunlight for one day, to remove the moisture in it. The CB was then

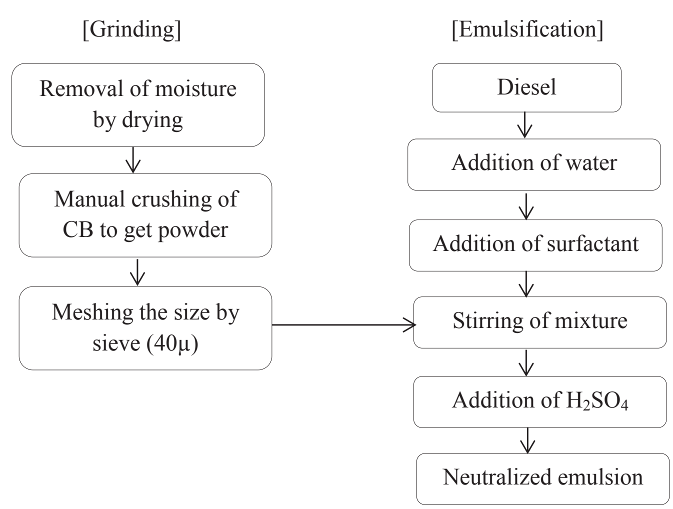

Fig. 1. Emulsification process [1].