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Full Length Article

Effect of tyre derived oil-diesel blend on the combustion and emissions characteristics in a compression ignition engine with internal jet piston geometry

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HIGHLIGHTS

- Light fraction of pyrolysis oil (LFPO) is used as alternative fuel in diesel engine.
- Study of diesel engine fueled 40LFPO10DMC blend with internal jet piston geometry.
- 40LFPO10DMC + IJP blend improves the performance and reduces emissions of the engine.
- The BTE of the 40LFPO10DMC + IJP was found higher about 4.5% compared to diesel.

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ABSTRACT

In recent years there have been significant developments seen in utilization of different derivatives obtained from pyrolysis of waste automobile tyres, as alternative fuels for CI engines. In an investigation, a blend comprising 40% light fraction pyrolysis oil obtained from a tyre recycling plant, 50% diesel and 10% an oxygenate additive Dimethyl carbonate (40LFPO + 10DMC) was examined as an alternative fuel in a single cylinder, direct injection (DI) compression ignition (CI) engine. Even with the oxygenate additive, the 40LFPO blend exhibited inferior performance and higher smoke emission than those of diesel operation at full load in the same engine. Turbulence inducement is one of the methods to improve the combustion behavior of a CI engine. Therefore, in this investigation, an attempt was made to create more turbulence in the combustion chamber by providing internal jets in the piston, when the engine was run with the 40LFPO10DMC. The investigation results in terms of combustion, performance and emissions were compared with those of the engine run with the conventional diesel fuel with and without turbulence inducement, and presented in this paper. The hydrocarbon (HC), carbon monoxide (CO) and smoke emissions were found to be reduced by about 32.9%, 66% and 13% respectively, than the conventional piston at full load, while they were found to be lower by about 66.6%, 2.4% and 21.2% respectively, than those of diesel fueled engine with the internal jet piston at full load. The brake thermal efficiency of the 40LFPO10DMC blend was found to be improved with internal jet piston compared to that of diesel and 40LFPO. It was higher about 4.5% and 5.3% than those of diesel and 40LFPO blend respectively at full load.

1. Introduction

Today, developing a cleaner environment is one of the foremost tasks of any country. According to the Environmental Protection Agency's (EPA's) clean and green policy, six objectives are focused today which include: (i) protect human health and the environment by taking necessary steps (ii) utilization of waste land (iii) maintain and improve water resources and quality (iv) reduce air emissions and greenhouse gas (GHG) production (v) minimize material use and waste production and (vi) conserve natural resources and energy. Some of the methods adopted by many countries to meet these objectives are: (i) utilization of renewable energy resources to a maximum extent possible (ii) introducing cleaner and clean diesel technologies and strategies (iii) water conservation and efficiency approaches (iv) sustainable site design (v) reuse and recycling of different materials with in regulatory requirements that are available in municipal, industrial and other sites (vi) environmentally preferable purchasing, and (vii) introducing greenhouse gas (GHG) emission reduction technologies [1].

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Nomenclature

ASTM	American society for testing and materials	ID	ignition delay
bTDC	before top dead centre	LFPO	light fraction of pyrolysis oil
°CA	degree crank angle	NDIR	non-dispersive infrared
CI	compression ignition	NO	nitric oxide
CO	carbon monoxide	NO_x	oxides of nitrogen
CO_2	carbon dioxide	P	instantaneous cylinder pressure (N/m^2)
CV	calorific value (MJ/kg)	$\frac{\partial Q_n}{\partial \theta}$	rate of heat release (J/°CA)
DI	direct injection	SOI	start of fuel injection
DMC	Di methyl carbonate	TDC	top dead centre
EGT	exhaust gas temperature	TPO	tyre pyrolysis oil
FC	fuel consumption	U_y	uncertainty
HC	unburnt hydrocarbon	V	cylinder volume (m^3)
HRR	heat release rate	Y	physical parameter
IC	internal combustion	γ	ratio of specific heats

Recycling and reuse of wastes, in particular pyrolysis and gasification of wastes offer advantages such as production of energy and chemicals, solution to environmental pollution, and cost benefits. Several researchers have made attempts to obtain energy or fuels in the form of oil [2,3], gas [4], solids [5] from pyrolysis of different organic wastes [6–10]. On the other hand, researchers have also made attempts to explore the possibilities of using crude and distilled pyrolysis oil [11,12], pyrogas [13] or carbon black [14] as alternative energy sources.

Tudu et al. [15,16] have recently made an attempt to use the light fraction pyrolysis oil (LFPO) obtained from a tyre recycling plant as an alternative fuel in the form of blends with diesel, in a stationary single cylinder, four stroke diesel engine. The LFPO was obtained from the first distillation column of a pyrolysis plant that was used to recycle waste automobile tyres through vacuum pyrolysis method. In that study, 20–60% of LFPO in steps of 20% of volume was blended with diesel fuel and used as fuels in a single cylinder, four stroke, air cooled, direct injection (DI) diesel engine developing a power of 4.4 kW at a constant speed of 1500 rpm. The blends were denoted as XLFPO, where X indicated the percentage volume of LFPO in the LFPO-diesel blend. The combustion, performance and emissions of the engine were determined, analyzed and compared to those of diesel operation in the same engine. The results revealed that the 40LFPO (40% LFPO in the blend) gave better performance and lower emissions than those of 20LFPO and 60LFPO at full load. However, the results were found to be inferior to those obtained with the diesel fuel operation, which was owing to its lower cetane number and higher density. Furthermore, they have also studied the effect of adding dimethyl carbonate (DMC) an oxygenate additive at different percentages to the 40LFPO blend, on the engine combustion, performance and emissions of the same engine. The experimental results revealed that even with the oxygenate additive, the 40LFPO blend exhibited inferior performance and higher smoke emission than those of diesel operation in the same engine.

There have been many methods used to improve the combustion behavior of a CI engine, by modifying the engine parameters or configuration, when fuel modification was not so effective. The methods adopted by the researchers include combustion chamber geometry [17–20], combustion chamber and nozzle geometry [21], combustion chamber, injector geometry [22], injection pressure [23,24], and internal jet piston to induce turbulence [25,26], etc.

One example is that, Senthil Kumar and Mehta [27] have made an attempt to study the effects of introducing small jets by providing two holes in the piston to improve the performance of a DI diesel engine run on neat Jatropha oil. They reported that, the velocity of the jets from the holes was significantly increased. Due to this, the magnitude of the turbulent kinetic energy of internal jets from the holes was found to be higher compared to that of diesel. This turbulent kinetic energy increased the fuel-air mixing and burning rate of fuel in the diffusion phase of combustion, resulting in better combustion. This resulted in lower BSFC and smoke emissions.

This investigation was aimed to study the effect of turbulence inducement in the cylinder by providing two holes at different locations on the piston crown (internal jet piston). The test fuel 40LFPO10DMC was tested without and with turbulent inducements in a single cylinder, four stroke, air cooled direct injection (DI) diesel engine. The combustion, performance and emission parameters were determined for 40LFPO10DMC with internal jet piston, were analyzed and compared with those of results obtained for the diesel, 40LFPO and 40LFPO10DMC operations with a conventional piston.

2. Materials and methods

2.1. Pyrolysis process

For this investigation, LFPO was purchased from a tyre recycling demonstration plant that is installed and commissioned in India. The plant follows vacuum pyrolysis to recycle the segregated and crumbed automobile tyres. Fig. 1 illustrates the schematic layout of the pilot tyre pyrolysis plant. The plant has a cylindrical rotary type pyrolysis reactor (1).

The plant has a batch process with a capacity of 10 tons. The length of the reactor is approximately 6.6 m, and the diameter is 2.8 m. The reactor is rotated with the help of an electric motor (2) and a pulley arrangement. The pyrolysis reactor is initially heated up by waste wood. The wood consumption per batch is about 2 tons. In the pilot plant, the shredded tyres are fed into the pyrolysis reactor. The front end of the reactor has a door with fasteners. The door can be opened or closed by unlocking or locking the fasteners. The other end of the reactor is connected to sealing elements (3) and a flexible connection (4). An oil separator (5) is connected to the reactor by the sealing element and the flexible connection. The volatile vapour evolves during pyrolysis, passes through the oil separator, where heavy oil is separated by gravity and collected in a heavy oil tank (6). A damper (7) is provided at the outlet of the oil separator that connects a bench of water cooled condenser tubes (8–12). Further, the volatile gases enter the bunch of water cooled condenser tubes, where the light oil fractions are converted into liquid. A cooling tower (13) is used to bring down the temperature of the coolant close to atmospheric