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Studies on performance, combustion and emission of a single cylinder diesel engine fuelled with rubber seed oil and its biodiesel along with ethanol as injected fuel

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ABSTRACT

Alcohols are gaining interest as an alternate biofuel for compression ignition engines because they contain oxygen and are produced using biomass. Since they have lower cetane number, they are suitable for premixed combustion applications. In this investigation, the authors have tried to improve a single cylinder diesel engine's performance by injecting ethanol into the intake port during the suction stroke. Rubber seed oil (RSO), rubber seed oil methyl ester (RSOME) and diesel are the primary fuels injected directly into the combustion chamber. The injection timing and duration of ethanol injection were optimized for dual fuel operation. The results indicate that increasing ethanol quantity with RSO and RSOME lead to an increase in brake thermal efficiency and reduction in smoke emissions. The maximum brake thermal efficiency achieved at full load is 31%, 29.9% and 29.3% with diesel, RSOME and RSO at ethanol energy shares of 35.2%, 33.5% and 31.6%, respectively. Smoke reduces by 44.26% with RSO, 43.63% with RSOME and 26.47% with diesel at maximum thermal efficiency point. However, HC, CO, and NOx emissions increases with increase in ethanol energy share at all loads. Peak pressure and maximum rate of pressure rise increases with increase in ethanol injection. Combustion duration reduces with ethanol injection, which in turn contributes to a higher heat release rate.

1. Introduction

Diesel engines form the backbone of the transportation and agricultural sector because of higher thermal efficiency and lower fuel consumption as compared to gasoline engines, which is due to its higher compression ratios, leaner air-fuel mixtures, and lower pumping losses. Developing countries like India, rely heavily on diesel engines to transport people as well as goods, the rate of which is increasing day-by-day. This leads to increased diesel consumption, a massive outflow of foreign exchange and concern for the environment. Fuels of bio-origin (straight vegetable oils), which are renewable and have properties close to diesel [1–3] can be the solution to these problems. However, straight vegetable oils have high viscosity and low volatility, boiling point and cetane number. This causes incomplete combustion, engine deposits, engine oil contamination and high smoke emissions [4,5], making them unfit for direct use in diesel engines. Trans-esterification can reduce the viscosity of the straight vegetable oil so that problems associated with higher viscosity can be reduced [6].

Biofuels can be obtained from both edible oil as well as inedible oils. The price of edible oil such as sunflower, soybean and palm oil are high as compared to diesel. Converting these oils into biodiesel further increases the price, making it an unviable fuel for developing countries like India. Inedible oil such as linseed, castor, karanji, neem, rubber and jatropha are available in large quantities in India, and they can be easily converted to biodiesel at low cost. In this experimental setup, rubber seed oil is taken as the pilot fuel and ethanol as the ignition improver in a diesel engine. Rubber tree (*Hevea brasiliensis*) belongs to Euphorbiaceae family. It originated from South America and has been cultivated in South East Asia since 1876. The tree grows rapidly at altitudes below 200 m at temperatures of about 27–30 °C [7]. It is a prominent plantation crop which holds vital economic importance for India. The tree not only provides rubber latex but also a variety of ancillary products, rubber seed being one of them. The production of rubber seed is 150 kg/ha in India. The average oil yield from the seed is 40% to 60% of the kernel by weight. The oil extracted has application limited to soap and lubricating industries. Rubber seed oil has 17–20% saturated fatty acids, 17–22% unsaturated fatty acids and viscosity of more than 30 cSt. As a result, the rubber seed oil as a fuel has less

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Nomenclature

ATDC After Top Dead Center
ECU Electronic Control Unit
RPM Revolution Per Minute
BSEC Brake Specific Energy Consumption
CA Crank Angle
RSOME Rubber Seed Oil Methyl ester
RSO Rubber Seed Oil
Diesel 100% Diesel fuel at full load
Diesel 75% Diesel fuel at 75% load
Diesel 50% Diesel fuel at 50% load
Diesel 25% Diesel fuel at 25% load
RSO 100% RSO at full load
RSO 75% RSO at 75% load
RSO 50% RSO at 50% load
RSO 25% RSO at 25% load
RSOME 100% RSOME at full load
RSOME 75% RSOME at 75% load
RSOME 50% RSOME at 50% load
RSOME 25% RSOME at 25% load
NOx Oxides of Nitrogen
HC Hydrocarbon
CO Carbon Monoxide
CO_2 Carbon Dioxide

thermal efficiency and increased smoke emission as compared to diesel [8]. The important properties of rubber seed oil and ethanol compared with diesel is given in Table 1.

Biomass produced ethanol has a promising future as a spark ignition fuel due to its higher octane number. However, it is hard to use ethanol as a compression ignition fuel due to its lower cetane number. Therefore, researchers have been trying to find suitable methods for incorporating ethanol into the compression ignition engine [9]. The most tried methods are blending and fumigation. In blending process, blended ethanol and diesel is injected into the combustion chamber [10–13]. However, additional additives are required to stabilize the miscibility of the blend. Hence, there is a limit to which ethanol can be blended with diesel. In fumigation method, ethanol is inducted into the intake air by using either carburetor or injector. This way air utilization can be improved since ethanol injection leads to increase of air density because of a decrease in mixture temperature. However, this method requires minor modifications, such as adding low-pressure fuel injector, additional fuel tank, lines and control to the engine. Thus, this method allows a larger amount of ethanol to be utilized since no additives are required for stability of the blend [14].

Chauhan et al. [15] investigated the effect of inducting ethanol in a small capacity diesel engine using constant volume carburetor. Results indicated a reduction in NOx, CO, CO_2 and exhaust gas temperature, whereas HC emission increased for all loads. Abu-Qudais et al. [16] performed an experimental study to compare the effect of ethanol injection and ethanol-diesel blend on a single cylinder diesel engine. The authors reported improvement in engine efficiency by 7.5% and reduction of 51% in soot mass concentration with ethanol injection method as compared to ethanol-diesel blend. Hansdah and Murugan [17] produced bioethanol by fermenting *Madhucaindica* and carried out experimental work on a single cylinder diesel engine at different flow rates of ethanol injection using a vaporizer and a microprocessor-controlled injector. The results indicated a longer ignition delay of 2–3 °CA, reduction in NOx emissions by 24.2% and reduction in smoke emission by 25% at full load as compared to diesel. Morsy [9] inducted ethanol/water mixtures in the intake air and studied its effect on performance and emission of a single cylinder diesel engine. NOx emissions decreased for ethanol/water mixtures as compared with neat ethanol injection, whereas HC, CO and fuel consumption increased with all mixtures of ethanol and water.

A lot of work has been done on fumigating ethanol in a compression ignition engine with diesel fuel operation. However, limited studies are available, where ethanol is fumigated in a biodiesel powered compression ignition engine. This study tries to improve the performance of a biodiesel powered engine with ethanol injection in the intake port. For comparison purpose, experiments were also performed with diesel.

2. Present work

The principle aim of the present experimental work is to improve the performance, emission and combustion characteristics of a rubber seed oil-fuelled diesel engine with ethanol injection in the intake air manifold. The optimum injection timing, duration, and quantity of ethanol injected was found based on brake thermal efficiency and exhaust gas emissions. The experiments were conducted on a single cylinder direct injection agricultural diesel engine which runs at constant speed and variable load conditions. Tests were also carried out with neat diesel, rubber seed oil and rubber seed methyl ester oil for comparison.

2.1. Ethanol port injection strategy

In this experimental work both primary (diesel) and secondary fuel (ethanol) were injected through mechanical and electronic injection system respectively. The secondary fuel injection system was controlled by a computerized fuel delivery system, while the electronic control unit (ECU) takes information from various sensors and determines how much secondary fuel the engine receives based on this data. The fuel required for each revolution per minute (RPM) and engine load condition was located in the fuel map within the ECU. Once the amount of fuel is identified, the ECU will adjust the fuel mixture for the engine and air intake temperatures. Hence accurate amount of secondary fuel was injected and the time of injection also precisely controlled based on the inlet and exhaust valve opening.

The injection system consists of an electronic pump that supplies ethanol at a maximum pressure of 6 bar, a pressure control valve to maintain the fuel supply pressure and a simple common pressure rail to eliminate pressure fluctuations. A gasoline injector fitted very near to inlet manifold was used to inject a fine spray of ethanol during the suction stroke. The injector position can be seen in Fig. 1. The start of injection and duration of the injector opening was controlled by using an electronic controller.

3. Experimental setup

Experiments were carried out on a Kirloskar TAF-1 single cylinder, air-cooled, direct injection, four-stroke diesel engine, the specification of which is given in Table 2. A shunt wound DC generator, and a load

Table 1
Properties of test fuel.

Property	RSO	RSOME	Diesel	Ethanol
Specific gravity	0.922	0.8812	0.83	0.79
Kinematic Viscosity (cSt)	33.91	5.96	3.8	1.52
Flash Point (°C)	198	140	50	13
Calorific Value (MJ/kg)	37.5	41.07	42.9	26.9
Iodine Value	135.3	135.3	38.3	–
Acid Value	23.8	0.18	0.062	< 0.01
Cetane Number	37	49	47	8