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ORIGINAL ARTICLE

Performance, emission and combustion characteristics of a semi-adiabatic diesel engine using cotton seed and neem kernel oil methyl esters

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KEYWORDS

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Abstract The performance, emission and combustion characteristics of a diesel engine are investigated using two methyl esters: One obtained from cotton seed oil and other from neem kernel oil. These two oils are transesterified using methanol and alkaline catalyst to produce the cotton seed oil methyl ester (CSOME) and neem kernel oil methyl ester (NKOME) respectively. These biodiesels are used as alternative fuels in low heat rejection engine (LHR), in which the combustion chamber temperature is increased by thermal barrier coating on piston face. Experimental investigations are conducted with CSOME and NKOME in a single cylinder, four stroke, direct injection LHR engine. It is found that, at peak load the brake thermal efficiency is lower by 5.91% and 7.07% and BSFC is higher by 28.57% and 10.71% for CSOME and NKOME in LHR engine, respectively when compared with conventional diesel fuel used in normal engine. It is also seen that there is an increase in NO_x emission in LHR engine along with slight increase in CO, smoke and HC emissions. From the combustion characteristics, it is found that the values of cylinder pressure for CSOME and NKOME in LHR engine are near to the diesel fuel in normal engine.

1. Introduction

The world over, energy resources are getting scarcer and increasingly exorbitant with time. These situations have forced the researchers to search for alternative fuels. Vegetable oils have the greatest potential as alternative fuels for the diesel engines due to a very significant fact that they are renewable in nature and could produce less exhaust emissions [1]. Biodiesel is one of the most promising alternative fuels to meet these problems. It is renewable, biodegradable, non toxic and has almost very close property to that of diesel fuel [2–6]. Therefore, in recent years systematic efforts have been made by several research workers [7–10] to use vegetable oils as fuel in engines. The viscosity of vegetable oils is many times higher than that of diesel fuel. The high viscosity is due to the large molecular mass and chemical structure of vegetable oils which in turn leads to problems in pumping, combustion and atomization in the injector systems of a diesel engine. Due to the high viscosity, in long term operation, vegetable oils nor-

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mally introduce the development of gumming, the formation of injector deposits, ring sticking, as well as incompatibility with conventional lubricating oils [11–15]. The viscosity is reduced when triglycerides are converted into esters by transesterification reaction. Thus, three smaller molecules of ester and one molecule of glycerin are obtained from one molecule of fat/oil. Glycerin is removed as by-product and esters are known as biodiesel. [16]. In normal diesel engine, about one-third of the total energy is rejected to the cooling water. The basic concept of the low heat rejection engine is to reduce this heat loss to the cooling water and converting the energy in the form of useful work [17]. Various important advantages of the LHR concept are reduced hydrocarbons, fuel economy, carbon monoxide emissions and smoke, reduced noise due to a lower rate of pressure rise and higher energy in the exhaust gases [18–21]. Low cetane fuel can be used in LHR engines [22]. Within the LHR engine concept, the combustion chamber of a diesel engine is insulated by using high temperature resistant materials on engine components, such as cylinder head, valves, cylinder liners and exhaust ports. By eliminating the need for a conventional cooling system and reducing lost energy, the overall performance of this engine system will drastically improve. This could potentially result in 50% volume and 30% weight reductions in the entire propulsion system [23]. Some of the research works have revealed that exhaust emissions decrease because of higher combustion temperature. Higher oxides of nitrogen are one of the major problems to be improved in an LHR diesel engine as insulation leads to an increase in combustion temperature by about 200–250 °C compared with an identical diesel engine [24].

For the investigation, the tests are conducted with CSOME, NKOME and diesel in coated piston and uncoated piston engine and then performance, emission and combustion analysis are compared. LHR engine fueled with cotton seed oil methyl ester, neem kernel oil methyl ester and with conventional diesel engine fuel used in normal engine are referred to by CSOME, NKOME and DF, respectively, throughout the paper.

2. Experimental test rig, instrumentation and programme

The engine used in this study is 5.2 kW, computerized Kirloskar make, single cylinder, four stroke, vertical, water cooled, direct injection diesel engine. The important engine specifications are given in Table 1. Fig. 1 shows the schematic diagram of the experimental setup used for the investigation. An eddy current dynamometer is used to load the test engine. Exhaust emission from the engine is measured by AVL DiTEST 1000 (Five gas analyzer) and smoke emission is measured by AVL DiSMOKE 480 (smoke meter).

Cotton seed oil methyl ester (CSOME) is produced in a small scale setup consisting of magnetic stirrer with heater and thermostat, magnetic pallet, condenser, separating flask and reaction flask constructed and installed at the IC Engine Laboratory of Department of Mechanical Engineering in Poojya Doddappa Appa College of Engineering, Kalaburagi, Karnataka, India. The capacity of the reaction flask is 3 l. It consists of three necks: one for condenser, and the others for inlet of reactant as well as for placing the thermometer in the thermo well to observe the reaction temperature. Crude is selected for the preparation of biodiesel. 3.5 g of sodium hydroxide (NaOH) and 200 ml of methyl alcohol (CH_3OH) are used for esterification of 1 l of cotton seed oil. The catalyst is dissolved in the alcohol then the alcohol–catalyst mixture is poured into the cotton seed oil which is heated and mixed thoroughly. The temperature of the cotton seed oil, alcohol and catalyst mixture is maintained at 60 °C for an hour. When the transesterification is finished the mixture is taken into a separating funnel to settle. After the settlement of the biodiesel and the glycerin, the glycerin is drained. The biodiesel is washed thoroughly with pure water to remove alcohol and catalyst residue. After washing, the biodiesel is heated to a temperature of 110 °C in order to remove the traces of water in the form of vapors. Further, the same procedure is repeated for the production of neem kernel oil methyl ester (NKOME) which is used as the other biodiesel in this study. The diesel fuel, as a reference fuel, is obtained from a local supplier and it is used to obtain baseline data of the engine. Some fuel properties of cotton seed oil methyl ester, neem kernel oil methyl ester and diesel fuel are determined at the IC Engine Laboratory and are presented in Table 2.

Table 1 Specification of the test engine.

Manufacturer	Kirloskar Oil Engines Ltd., India
Model	TV-SR II, naturally aspirated
Engine	Single cylinder, direct injection diesel engine
Bore/stroke/compression ratio	87.5 mm/110 mm/17.5:1
Rated power	5.2 kW
Speed	1500 rpm, constant
Injection pressure/advance	200 bar/23° before TDC
Dynamometer	Eddy current
Type of starting	Manually
Air flow measurement	Air box with 'U' tube
Exhaust gas temperature	RTD thermocouple
Fuel flow measurement	Burette with digital stopwatch
Governor	Mechanical governing (centrifugal type)
Sensor response	Piezo electric
Time sampling	4 μs
Resolution crank	1° crank angle
Angle sensor	360° encoder with resolution of 1°

Variable load tests are performed for 0, 0.52, 1.3, 2.6, 3.9 and 5.2 kW at a constant rated speed of 1500 rpm, with an injection pressure of 200 bar, and cooling water exit temperature of 60 °C. A unique heating arrangement is made in the oil filter to heat CSOME and NKOME in order to reduce their viscosity before injecting into the test engine. The CSOME and NKOME are heated at 60 °C, and after heating the viscosity of these methyl esters is reduced to 3.13 mm^2/s and 3.15 mm^2/s respectively. Fig. 2 shows the arrangement of heaters in the oil filter with thermostat. First the diesel is used as fuel in the uncoated piston engine (normal diesel engine). After completion of the test on normal diesel engine (NDE), the piston face is coated with metal matrix composite materials. The metal matrix thermal barrier coating is made of 25% ZrO_2 + 75% Al_2O_3 of 0.1 mm thick, 50% ZrO_2 + 50% Al_2O_3 of 0.1 mm thick and 100% ZrO_2 of 0.1 mm thick by using plasma coating method over the base of Ni-Cr bond coat of 0.150 mm thickness. Fig. 3 shows the Composition of thermal barrier coating with dimensions. Now the engine is converted to a LHR condition. The same test procedure is repeated for LHR engine using CSOME and NKOME as fuel