Fuel 98 (2012) 272–279

Contents lists available at SciVerse ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Effects of open combustion chamber geometries on the performance of pongamia biodiesel in a DI diesel engine

S. Jaichandar [a,*], K. Annamalai [b]

[a] Dept. of Automobile Engineering, Sree Sastha Institute of Engineering and Technology, Chennai, Tamil Nadu-600 123, India
[b] Dept. of Automobile Engineering, Madras Institute of Technology, Chromepet, Chennai, Tamil Nadu-600 044, India

ARTICLE INFO

Article history:
Received 3 February 2012
Received in revised form 21 March 2012
Accepted 4 April 2012
Available online 19 April 2012

Keywords:
Biodiesel
Diesel engine
Combustion chamber
Performance
Emissions

ABSTRACT

The present work investigates the effect of varying the combustion chamber geometry on the performance of a diesel engine using biodiesel in terms of brake specific fuel consumption, brake thermal efficiency as well as exhaust emissions and combustion characteristics. Engine tests have been carried out using a blend of 20% Pongamia Oil Methyl Ester (POME) with standard diesel as fuel and with three types of combustion chambers namely Hemispherical combustion chamber, Toroidal combustion chamber and Shallow depth combustion chamber without altering the compression ratio of the engine. The test results showed that brake thermal efficiency for toroidal combustion chamber is higher than for the other two types of combustion chambers. Significant improvement in reduction of particulates, carbon monoxide and unburnt hydrocarbons is observed for toroidal combustion chamber compared to the other two. However oxides of nitrogen were slightly higher for toroidal combustion chamber. The combustion analysis shows improved characteristics for toroidal combustion chamber compared to baseline engine at all loads of operation.

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1. Introduction

The fossil fuels are depleting rapidly and the prices are going up day by day. As a result alternative fuels have received much attention due to its ability to replace fossil fuels. Moreover, the environmental issues concerned with the exhaust gases emission by the usage of fossil fuels also encourage the usage of alternative fuels such as biodiesel [1]. In this context, there has been growing interest on alternative fuels like vegetable oils to provide a suitable diesel oil substitute for internal combustion engines. The main drawback of vegetable oils is associated with their high viscosity, 15–20 times greater than the standard diesel fuel. Thus, although short-term tests using neat vegetable oils showed promising results, problems appeared after the engine had been operated for longer periods. Researchers have suggested different techniques for reducing the viscosity of the vegetable oils. The different techniques are blending with diesel fuel, micro-emulsification with methanol or ethanol, thermal cracking, and conversion into biodiesels through the transesterification process. Among these transesterification process is most widely used [2–5].

The advantages of biodiesels are that they are renewable, can be produced locally, cheap, higher lubricity, higher cetane number, minimal sulphur content and less pollutant for environment compared to diesel fuel. On the other hand, their disadvantages include the higher viscosity and pour point, and lower calorific value and volatility. Moreover, their oxidation stability is lower, they are hygroscopic, and as solvents may cause corrosion in various engine components. For all the above reasons, it is generally accepted that blends of diesel fuel, with up to 20% bio-diesels, can be used in existing diesel engines. Various researchers [6,7] have shown that biodiesel fuel exhibits physical, chemical and thermodynamic properties which are similar or some even better than to those of petroleum diesel fuel. However certain properties such as viscosity, calorific value, density and isothermal compressibility of biodiesel differ from petroleum diesel fuel. These properties strongly affect injection characteristics, air–fuel mixing characteristics and thereby combustion characteristics of biodiesel in a diesel engine.

Barsic and Humke [5,8] studied the performance and emission characteristics of a DI naturally aspirated diesel engine using 100% sun flower oil, 100% peanut oil and 50% (by vol.) mixtures of either sun flower oil or peanut oil with No. 2 diesel oil. They observed that the engine power and thermal efficiency decreased, specific fuel consumption was increased by 10% and emissions increased marginally. The attributed reasons were higher densities, higher viscosities, relatively lower heating values and thermal cracking of the vegetable oil fuel droplets at elevated temperatures. Machacon et al. [9] evaluated performance and emission characteristics of coconut oil diesel fuel blends without any engine

* Corresponding author. Tel.: +91 44 26850493; mobile: +91 09444984748.
E-mail address: jaisriram18@yahoo.com (S. Jaichandar).

0016-2361/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2012.04.004

modifications. Increased coconut oil percentage in diesel fuel resulted in increased brake specific fuel consumption and decreased brake mean effective pressure. A large number of such studies on performance, combustion and emission using raw vegetable oils and methyl/ethyl esters of hazelnut oil [10], sunflower oil [11–13], rapeseed oil [14,15], cottonseed oil [16,17], tobacco seed oil [18], frying oil [19], rice bran oil, palm oil [20], mahua oil [21], used cooking oil [22], jojoba oil [23], jatropha oil [24,25] karanja oil [26], soybean oil [27–30], coconut oil [31] and rubber seed oil [32] have been carried out without modifying the diesel engines. Most of the studies reviewed, report 5–8% decreases in thermal efficiency, 8–10% increases in brake specific fuel consumption, increases in NO_x emissions and sharp reductions in particulate, CO and HC emissions [33,34].

The inferior performance of biodiesel operated diesel engine in comparison with conventional diesel fuelled diesel engine is mainly due to change in fuel properties, engine design and operating parameters. To achieve improved performance and further reductions in emissions, rapid and better air–biodiesel mixing is the most important requirement. The mixing quality of biodiesel spray with air can be generally improved by selecting the best injection parameters and better design of the combustion chamber. Narayana Reddy and Ramesh [35] have conducted experiments on a direct injection (DI), diesel engine using neat jatropha oil. Injection timing, injector opening pressure and injection rate were changed to study their influence on performance, emissions and combustion and are compared with total diesel operation. Results show that, for neat jatropha oil by increasing 15 bar in injector opening pressure and 3° in fuel injection advance, an improved brake thermal efficiency, the peak heat release rate and reduced emissions (except NO_x) were observed.

To realize the full potential of biodiesel use in internal combustion engines, in addition to injection parameters, investigations on any modifications of engine design, particularly combustion chamber may be required, since the properties of biodiesel are different from diesel. Researchers Hribernik and Kegl [36] have reported that the combustion and emission formation, particularly the increase of NO_x emissions by application of biodiesel varies significantly with different combustion systems and different combustible mixture formation strategies. Pasupathy Venkateswaran and Nagarajan [37] have carried out simulation studies to investigate the effect of piston bowl geometry on both engine performance and combustion efficiency in a direct injection, turbocharged diesel engine for heavy-duty applications using STAR-CD. The simulation results show that, toroidal bowl with lip enhance the turbulence and hence results in better air–fuel mixing. As a result, the indicated specific fuel consumption and soot emission reduced, although the NO_x emission is increased owing to better mixing and a faster combustion process. Prasad et al. [38] studied the effect of swirl induced by piston bowl geometries on pollutant emissions from a single cylinder diesel engine using CFD. Pollutant emission measurements indicated a reduction in emissions for toroidal, with slightly re-entrant type combustion chamber due to improved air swirl.

As the piston bowl geometry design affects the air–fuel mixing and the subsequent combustion and pollutant formation processes in a DI diesel engine an attempt has been made here to investigate the effects of combustion chamber geometry design on biodiesel fuelled diesel engine. In this experimental investigation, engine tests were carried out using three types of open combustion chamber geometries to compare the performance, emission and combustion characteristics of 20% blend of POME with baseline diesel operation, in a four-stroke single-cylinder direct-injection CI engine.

2. Materials and methods

2.1. Biodiesel properties

In India, usage of non-edible oils for the production of biodiesel is found to be best suited when considering the deficit supply of edible oils and their cost of production. Among the non-edible oils, Tree Borne Oil seeds (TBOs) like jatropha and pongamia gain importance. Pongamia Pinnata, an excellent shrub having natural spread across the globe, is one of the promising biofuel crop ideally suitable for growing in the wastelands. Greater potential exists in India for bringing millions of hectares of wasteland under extensive plantation of pongamia, virtually converting unproductive lands into green oil fields. Pongamia seeds contain 30–40% oil. To prepare POME, the transesterification reaction was performed on raw pongamia oil. Transesterification is a chemical process of transforming large, branched, triglyceride molecules of vegetable oils and fats into smaller, straight chain molecules, almost similar to diesel fuel. The process takes place by the reaction of raw pongamia oil with methyl alcohol in the presence of catalyst. The properties of the raw pongamia oil and POME were experimentally evaluated. The properties of raw pongamia oil, POME and its 20% blend with diesel are compared with the standard diesel in Table 1. Most of the properties of bio-fuels like calorific value, viscosity,

Table 1
Properties of diesel, raw pongamia oil, biodiesel from pongamia and its blend.

Properties	Pongamia oil	100% POME	20% POME	Diesel	IS: 15607 specification	Test methods IS1448/ASTM
Density (kg/m^3)	912	898	862	850	860–890	P16
Kinematic viscosity (cSt)	27.84	5.46	3.49	2.9	2.5–6.0	P 25/D 445
Calorific value (MJ/kg)	34	39.15	43.126	44.12		D5865
Flash Pt (°C)	242	196	91	76	120	P 21/D93
Cloud Pt (°C)	14.6	10.2	7.1	6.5	–	D2500
Pour Pt (°C)	–	4.2	3.6	3.1	–	D2500
Cetane no	46	57.9	51	49	51	P9/D613
Sulphur (mg/kg)	0.007	0.005	21	29	⩽50	P 83/D 5453
Carbon residue (% mass)	1.2	0.0035	0.015	0.1	⩽0.05	ASTM 4530
Sulphated ash (% mass)	0.014	0.002	0.001	0.001	⩽0.02	P 4/D874
Water content (mg/kg)	–	340	90	52	⩽500	P 40/D2709
Acid value (mg KOH/g)	5.06	0.42	0.15	0.10	⩽0.5	P 1/D 664
Methanol (% mass)	–	0.09	0.02	–	⩽0.20	EN 14110
Ester content (% mass)	–	98	–	–	⩾96.5	EN 14103
Free glycerol (% mass)	–	0.01	–	–	⩽0.02	ASTM D6584
Total glycerol (% mass)	–	0.19	–	–	⩽0.25	ASTM D6584
Phosphorous (mg/kg)	–	3.2	–	–	⩽10	ASTM D4951
Iodine value (g I_2/100 gm)	96	86.5	–	38.3	⩽120	EN 14104
Oxidation stability at 110 °C (h)	–	11.6	–	–	⩾6	EN 14112

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