Renewable Energy 81 (2015) 490–498

Contents lists available at ScienceDirect

Renewable Energy

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

Comparative assessment of a biogas run dual fuel diesel engine with rice bran oil methyl ester, pongamia oil methyl ester and palm oil methyl ester as pilot fuels

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ARTICLE INFO

Article history:
Received 11 September 2014
Accepted 10 March 2015
Available online 5 April 2015

Keywords:
Dual fuel diesel engine
Biogas
Rice bran oil methyl ester
Pongamia oil methyl ester
Palm oil methyl ester

ABSTRACT

The present study tries to explore the potential of three different types of biodiesel viz. Rice bran oil methyl ester (RBME), Pongamia oil methyl ester (PME) and Palm oil methyl ester (POME) as pilot fuels for a biogas run dual fuel diesel engine designed for power generation. The results indicated that under dual fuel mode, RBME-biogas produced a maximum brake thermal efficiency of 19.97% in comparison to 18.4% and 17.4% respectively for PME-biogas and POME-biogas at 100% load. The emission study divulged that under dual fuel mode, on an average, there was an increase of CO emission by 25.74% and 32.58% for PME-biogas and POME-biogas, respectively in comparison to RBME-biogas. Furthermore, on an average, the HC emissions for PME-biogas and POME-biogas increased by 11.73% and 16.27%, respectively in comparison to RBME-biogas. On the other hand, on an average, there was a decrease in NO_X emission by 5.8% and 14%, respectively for PME-biogas and POME-biogas respectively in comparison to RBME-biogas.

1. Introduction

Biogas run dual fuel diesel engines can be a panacea to the problem of acute power shortage particularly in rural areas in India. Biogas, a renewable fuel, is produced from anaerobic fermentation of organic material. The main combustible constituent of biogas is methane. The higher Octane number of biogas makes it apposite for engines with a relatively higher Compression Ratio (CR) in order to maximize thermal efficiency [1]. Besides, the carbon content in biogas is relatively low compared to that of the conventional diesel fuel, resulting in diminution in pollutants [2]. Biogas can be used in both Compression Ignition (CI) engines and Spark Ignition (SI) engines for power generation. However, the derating of power is evident in biogas run SI engine due to its extreme sensitivity towards biogas composition leading to cycle to cycle variation [3]. Biogas run dual fuel diesel engines are free from such shortcomings.

1.1. Dual fuel diesel engine

Conventional internal combustion engines operate on a mono fuel either liquid or gaseous. However, biogas run dual fuel diesel engines operate on both liquid and gaseous fuel simultaneously. This is due to the fact that the temperature attained at the end of the compression stroke inside the combustion chamber of CI engines is around 553 K. However, the autoignition temperature of biogas is around 1087 K [4]. Therefore, simply compressing the biogas air mixture will not ignite the charge. Hence, a small amount of liquid fuel must be supplied which initially ignites and acts as an ignition source for biogas. The liquid fuel used is called the Pilot fuel. The gaseous fuel i.e. biogas is called the primary fuel on which the engine mainly runs. It is seen that in a dual fuel engine, the combustion starts in the same fashion to that of a CI engine. However, in the later part of combustion, the flame propagates in a manner similar to that of an SI engine. A simple diesel engine can be converted into dual fuel diesel engine by connecting a gas mixer at its inlet manifold. Further, a fuel control mechanism needs to be installed to limit the supply of liquid fuel. The power output of the engine is normally controlled by varying the flow of quantity of biogas. It is possible to achieve a substitution of diesel up to 85% by using biogas [5]. The most remarkable feature of dual fuel diesel engine is the ability to switch over from dual fuel operation to diesel mode almost instantaneously in case of shortage of the primary fuel.

1.2. Pilot fuel and its importance

The pilot fuel has a tremendous influence on the dual fuel combustion as it elicits the combustion process. The combustion

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http://dx.doi.org/10.1016/j.renene.2015.03.019
0960-1481/

process of a biogas run dual fuel diesel engine is more complex than single fuel combustion. Prior to ignition of pilot fuel, the biogas air mixture undergoes pre-ignition chemical reaction during the relatively longer compression stroke. The pre-ignition reaction results in the formation of active radicals and partial combustion products that are believed to affect the ignition of the injected pilot fuel [2]. Most of the studies on biogas have been conducted with diesel fuel as the pilot fuel. The study of different types of pilot fuel for biogas run dual fuel diesel engine is of immense importance taking in consideration of recent fuel crisis. The different pilot fuels studied for biogas run dual fuel engine are diesel [1,2,4–10,12–15,17–19], Soybean biodiesel [2], Jatropha biodiesel [4], Palm oil biodiesel [10], Jatropha oil [11] and emulsified biodiesel [16]. Thus, few studies have been reported on biogas dual fuel combustion using biodiesel as pilot fuel.

Biodiesel along with bioethanol has a great potential as a renewable fuel for CI engines. Biodiesel can be produced by a simple chemical reaction known as transesterification by using edible, non-edible, waste vegetable oils and animal fats [20]. It has minimal sulphur and aromatic content and higher flash point, lubricity, Cetane number, biodegradability and non-toxicity [21]. It also offers improved lubricity over certain low-sulphur petro-diesels and thus, can help to reduce wear of engine components [22]. Further, biodiesel is easy to handle due to its higher boiling point than that of diesel. The work published in recent years [22–27] on biodiesel operated diesel engines highlight two major findings. Firstly, they exhibit a slight power loss, an increase in fuel consumption and emissions of NO_X and carbonyl compounds. Secondly, they also show a reduction in particulate matter, aromatic compounds, HC and CO emissions.

On the other hand, bioethanol was initially considered as an alternative fuel for SI engine due to its higher Octane number. However, in the recent years, bioethanol has emerged as a renewable biomass based fuel for CI engines that can be blended with diesel by using suitable additives [28,29]. These blends also significantly decrease the exhaust emissions and enhance octane number when mixed with diesel fuel. Such enhancement is particularly important in unleaded fuels. In addition, due to their complete burning power, bioethanol has the potential to increase the combustion efficiency [30]. Thus, running diesel engines with biodiesel and bioethanol can be beneficial in terms of environmental impact and energy security.

1.3. Objective

The National Policy on Biofuel of India had proposed an indicative target to supplant 20% of petroleum fuel consumption with biofuels (bioethanol and biodiesel) especially in transportation sector by end of 12th Five-Year Plan (i.e. by 2017) [31]. Keeping this outlook in mind, the objective of the present investigation is to venture the possibility of using rice bran oil methyl ester (RBME), Pongamia oil methyl ester (PME) and Palm oil methyl ester (POME) as pilot fuel for a biogas run dual fuel diesel engine. Further, a comparative study among the three biodiesels under dual fuel mode is carried out on the basis of performance, combustion and emission analysis. The motivation behind such investigation is to lessen our dependence on fossil fuel for power generation. In order carry out the investigation, a 3.5 kW single cylinder, direct injection, water cooled, diesel engine is converted into biogas run dual fuel diesel engine by connecting a venturi gas mixer at the inlet manifold. Experiments were conducted at different loading conditions at injection timing (IT) of 23° before top dead centre (BTDC) and CR of 17.5.

2. Materials and methods

2.1. Test set-up

The test set-up is a single cylinder, four stroke, direct injection, water-cooled, naturally aspirated, 3.5 kW diesel engine (Kirloskar made, India) as shown in Fig. 1. The brief specification of the test set-up used for this investigation is given in Table 1. It is connected to an eddy current and water-cooled dynamometer for loading on crankshaft with the help of electromagnetic force. A controller, fixed on the panel box, controls electric supply for load variation. The load sensor, fitted with the dynamometer, sends the load signal to the digital display in kg. The setup has a stand-alone panel box consisting of air box, fuel tank, manometer and fuel measuring burette.

The fuel measurements are performed by differential pressure transducer (Yokogawa make, Model No: EJA110A-DMS5A-92NN). It is connected through a fuel line and the signal of flow rate is transferred to data acquisition device (DAD). All the analogue signals recorded from different locations of the test rig are supplied to the 'Enginesoft' software for performance analysis. The existing diesel engine is modified for dual fuel operation by connecting a venturi gas mixer in the inlet manifold. The venturi gas mixer is fabricated based on a recent design by Bora et al. [32]. The pressure drop created at the throat of the venturi gas mixer due to its geometry facilitates the induction as well as mixing of the biogas and air. The liquid fuel supply is controlled by using control lever mechanism. The fuel control mechanism is connected to fuel shut off valve. The biogas flow rate is given by the biogas flow meter. The specifications of different instruments used in the experiment are given in Table 2. The properties of the test fuel are given in Table 3.

2.2. Test procedure

The diesel engine is tested initially with diesel for baseline data. During the experiments, the engine is tested with 20%, 40%, 60%, 80% and 100% load. The brake mean effective pressure (BMEP) corresponding to percentage loading conditions is given in Table 4. At any particular specified load condition, the engine is allowed to run for a few minutes till temperatures at the outlet of the cooling water and exhaust gas reaches a steady state condition. The readings of temperatures, air and fuel flow rate, speed, cylinder and fuel pressure variation are automatically recorded by the DAD. Prior to start of the dual fuel mode, diesel is replaced by biodiesel in the fuel tank. The engine is then started and run at no load for a few minutes to clear the entire diesel remaining in the fuel line. At this moment, biogas flow valve is slowly opened. The speed of the engine increases due to additional energy released from combustion of biogas. The flow of biogas is slowly increased till the rpm does not rise any further. At this point, the pilot fuel is slowly reduced through the fuel control mechanism till original rpm run on diesel mode is achieved for that particular load. The engine is allowed to run for a few minutes and then readings are recorded. Biogas flow rate is then noted from the biogas flow meter. The same procedure is followed for all the test cases as given in Table 4.

2.3. Emission measurement

The emission analysis is carried out by using a Testo flue gas analyser. The analyser uses ASTM-D6522 standard for emission measurement.

The working principle of the gas analyser is as follows. During steady engine operation, the flue gas is allowed to surge through a probe and dried out by a condensation trap. Thereafter, each of the CO, HC, NO_X and Carbon dioxide (CO_2) emission concentrations in the flue gas is analysed by individual sensors and readings are then