Energy 118 (2017) 127–138

Contents lists available at ScienceDirect

Energy

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

Experimental investigation on the behavior of a direct injection diesel engine fueled with Karanja methyl ester-biogas dual fuel at different injection timings

Debabrata Barik [a, b, *], S. Murugan [a], N.M. Sivaram [b], E. Baburaj [c], P. Shanmuga Sundaram [c]

[a] Internal Combustion Engines Laboratory, Department of Mechanical Engineering, National Institute of Technology, Rourkela 769008, India
[b] Department of Mechanical Engineering, Karpagam Academy of Higher Education, Karpagam University, Coimbatore 641021, India
[c] Department of Mechanical Engineering, Karpagam College of Engineering, Coimbatore 641032, India

ARTICLE INFO

Article history:
Received 11 August 2015
Received in revised form
4 November 2016
Accepted 6 December 2016

Keywords:
Biogas
Karanja methyl ester
Combustion
Performance
Emission

ABSTRACT

The present investigation explores the possibility of using Karanja methyl ester (KME) as a pilot fuel in a biogas run direct injection (DI) diesel engine of rated power 4.4 kW at 1500 rpm, with compression ratio of 17.5:1. The biogas was inducted with the intake air, and KME was injected directly into the combustion chamber. The injection timing of the pilot fuel, in the biodiesel dual fuel mode (BDFM) was varied from 21.5 °CA bTDC to 27.5 °CA bTDC in steps of 1.5 °CA. The BDFM with injection timing was denoted as BDFMX, where X indicates the injection timing. BDFM24.5 (biodiesel dual fuel mode of 24.5 °CA) gave better performance and lower emissions than those of other injection timings. The results showed that, the brake specific fuel consumption (BSFC) for BDFM24.5 was found to be higher by about 23.9% than that of KME, at full load. About 6.6% increase in the brake thermal efficiency was observed for BDFM24.5 in comparison with BDFM23.0, at full load. BDFM24.5 gave a reduction in the CO, HC and smoke emissions of 17.1%, 18.2% and 2.1%, in comparison with the BDFM23.0, at full load, respectively. But, the NO emission for BDFM24.5 was higher by about 5.5% than that of BDFM23.0, at full load.

1. Introduction

Currently, the world is very keen to search the alternative energy sources, because of the steep increase in fuel cost, overcome the crisis of fossil fuel depletion, and reduce the environmental pollution. Although harnessing energy from solar and wind energy are focused by several researchers, utilization of biofuels which can be derived from variety of biomass sources, is also of great interest today. This is because of renewable nature, abundant availability and low CO_2 generation of biomass sources. Three biomass based biofuels are mainly focused as alternative fuels today for IC engines, which are (i) alcohols (ii) biodiesel and (iii) biogas. Many developed countries and some of the developing countries use ethanol in the range of 10–15% in blended form with gasoline, while biodiesel was used by 5–10% with diesel fuel in vehicles for transport applications. In this context, production of biodiesel from different edible and non-edible oils has been investigated and reported by several researchers [1–4]. Biodiesel is biodegradable, nontoxic, environment friendly and non-explosive [2]. Biodiesel can be used in pure form or blended with diesel, without any major modification to the engine and its components [3,4].

Due to the increasing demand of biodiesel, many commercial biodiesel plants are being installed and in operation worldwide. In biodiesel plants, after extraction of oil from the oil seed, the de-oiled seed cake remains as a solid organic waste. The edible de-oiled cakes are used for manure preparation and cattle feed. The non-edible de-oiled cakes cannot be used as cattle feed, or can be used in agrarian farms directly, because of its toxic nature (i.e., existence of crucin and saponins). Hence, the non-edible de-oiled cakes are basically dumped in open land, which emit various anthropogenic gases, such as methane (CH_4), nitrous oxide (N_2O), hydrogen sulfide (H_2S), ammonia (NH_3), carbon dioxide (CO_2) and volatile organic compounds (VOCs), which cause increase in the global warming potential (GWP) [5]. Recently, extraction of energy from such non edible oil cakes through pyrolysis [6–8] and anaerobic digestion [5,9–11] have been documented. Pyrolysis oil, gas and char are produced from the pyrolysis process, while biogas

* Corresponding author. Department of Mechanical Engineering, Karpagam Academy of Higher Education, Karpagam University, Coimbatore 641021, India.
E-mail address: debabrata93@gmail.com (D. Barik).

http://dx.doi.org/10.1016/j.energy.2016.12.025
0360-5442/

Nomenclature

A/F	Air/fuel ratio
HC	Hydrocarbon, g/kWh
aBDC	After bottom dead center
HRR	Heat release rate, J/deg.CA
ASTM	American Society for Testing and Materials
HRT	Hydraulic retention time, day
aTDC	After top dead center
ID	Ignition delay, °CA
bBDC	Before bottom dead center
KME	Karanja methyl ester
BDC	Bottom dead center
KO	Karanja oil
BDFM	Biodiesel dual fuel mode
LHV	Lower heating value, MJ/kg
BG	Biogas
MFB	Mass fraction burned
BMEP	Brake mean effective pressure, bar
N_2O	Nitrous oxide
BPR	Biogas premix ratio, %
NDIR	Non-dispersive infrared
BSFC	Brake specific fuel consumption, kg/kWh
NH_3	Ammonia
bTDC	before top dead center
NO	Nitric oxide, g/kWh
BTE	Brake thermal efficiency, %
NO_x	Oxides of nitrogen, g/kWh
CA	Crank angle, deg
PM	Particulate matter
CH_4	Methane
ROPR	Rate of pressure rise, bar/°CA
CI	Compression Ignition
RT	Retention time
CNG	Compressed natural gas
SI	Spark Ignition
CO	Carbon monoxide, g/kWh
SOC	Start of combustion
CO_2	Carbon dioxide, g/kWh
TDC	Top dead center
C_p	Specific heat at constant pressure, kJ/kgK
V	Instantaneous cylinder volume, m^3
C_v	Specific heat at constant volume, kJ/kgK
VOCs	Volatile organic compounds
DAS	Data acquisition system
γ	Ratio of the specific heats
DFM	Dual fuel mode
λ	Excess air ratio
DI	Direct injection
θ	Crank angle, °CA
EGT	Exhaust gas temperature, °C
m_{pb}	Mass of premixed biogas
GWP	Global warming potential
η_{comb}	Combustion efficiency, %
H_2S	Hydrogen sulfide

is produced by the anaerobic digestion process. Compared to pyrolysis oil, biogas produces low pollutants and easily transported when they are used in combustion devices.

The higher octane number of the biogas gives a higher resistance to knock and makes it suitable for engines with a relatively higher compression ratio in order to maximize the thermal efficiency and reduced smoke-NO_x tradeoff level [10,11]. Biogas can be used as a fuel in CI engines in a dual fuel mode, with a minor modification to the engine intake manifold [12–14].

Dual fuel operation, with biodiesel or diesel as a pilot fuel, with gaseous fuels such as methane, propane, compressed natural gas (CNG), hydrogen, and biogas, as primary fuels was investigated with the original injection timing and varying the injection timings by several researchers [15–44]. The ignition delay and peak cylinder pressure increased with the advanced pilot injection timing [17,20,36–38]. The low load performance and BTE of the engine was improved with advanced injections [30,39,40,43]. But, advancing injection timing beyond certain injection timing led to knocking at full and medium load operations [41]. The CO and HC emissions were found to be reduced [21,30,36,38–40,45]. The NO_x and CO_2 emissions were reported to be higher [21,24,27,30,39,40]. The smoke emission was found to be lower in some cases [23,25,37,43] and higher in others [42]. The particulate matter (PM) emission was found to increase with a higher advanced injection [36].

In this study, biogas derived from Karanja seed cake by anaerobic digestion process was used as a primary fuel, while biodiesel obtained from the Karanja oil by transesterification process was used as a pilot fuel in a direct injection diesel engine, modified to operate in dual fuel mode. The combustion, performance and emission characteristics of the engine were analyzed, with varying the injection timing of the pilot fuel. The results of the investigation are compared with diesel operation in the same engine and reported in this paper.

2. Methodologies and experimental details

2.1. Test fuels

The production of KME and biogas from Karanja seed by transesterification and anaerobic digestion respectively are illustrated by the block diagram in Fig. 1. The KME was purchased from Bannari Amman biodiesel industry, Tamil Nadu, India, while biogas was produced from a floating dome type biogas digester installed at NIT Rourkela. The transesterification process for obtaining KME has been documented by several researchers. The biogas production from Karanja seed by anaerobic digestion has been recently documented by Barik and Murugan [5].

2.2. Test fuel properties

The important physical properties of diesel and KME are given in Table 1. The properties of biogas obtained from the mixture of Karanja de-oiled cake and cattle dung are compared with those of biogas produced from only cattle dung (100%) and given in Table 2. A comparison of the gas constituents in biogas were measured with the help of a non-dispersive infrared biogas analyzer and given in Table 3.

2.3. Experimental setup

The experimental investigation was carried out at the Internal Combustion Engines Laboratory of National Institute of Technology Rourkela, India. Fig. 2 shows the schematic representation of the