Industrial Crops and Products 87 (2016) 333–339

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Property development of fatty acid methyl ester from waste coconut oil as engine fuel

M.A. Kalam[a,b,*], M.M. Rashed[a,b,*], H.K. Imdadul[a,*], H.H. Masjuki[a]

[a] Centre for Energy Sciences, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Mechanical Engineering, Dhaka University of Engineering and Technology (DUET), Gazipur, Bangladesh

ARTICLE INFO

Article history:
Received 14 December 2015
Received in revised form 27 March 2016
Accepted 4 April 2016
Available online 3 May 2016

Keywords:
Diesel engine
Blended fuel
Coconut oil
Carbon deposit
Emissions
Performance

ABSTRACT

The properties, performance, and exhaust emissions of a four-cylinder indirect injection diesel engine fueled by FAME from waste coconut oil was evaluated in this study. Polymerization and carbon deposits on fuel-injector nozzles were also monitored. Ordinary diesel (OD) oil was used as a benchmark for comparison purposes. Tests included measuring high heating value, kinematic viscosity, specific density, cetane index, pour point, flash point, and Conradson carbon residue. Results showed that, the high calorific value decreased with increased coconut oil in coconut-oil blends. On average, the calorific value of all coconut-oil blends were about 6% lower than that of OD fuel. Density increased with increased coconut oil in coconut-oil blends because of the higher amount of carbon atoms in coconut-oil molecules. As a result, viscosity also increased with increased coconut oil in blends. Other properties of blended fuels varied according to their physicochemical properties. Results also showed that the brake power output of engine increased by about 5% when fueled by 30% coconut-oil-blended fuel. The average specific fuel consumption of coconut-oil-blended fuels increased by 7–10% compared with OD oil. The exhaust emissions of blended fuel were found to be much cleaner, containing less CO, HC, NO_x, and smoke and benzene concentration. The coconut-oil-blended fuel also produced low particulate emission and carbon deposit on injector nozzles. For each coconut-oil-blended fuel, the engine did not have any starting difficulty and combustion noise at >25 °C. The coconut-oil-based fuel also did not pose a severe environmental threat because of its low sulfur content.

1. Introduction

The increase in energy demand, environmental concern, and massive rate of energy consumption throughout the world has led to the search for novel energy sources and new alternative renewable technologies aimed to be ecofriendly. Fossil-fuel combustion is the primary cause of the global increase of CO_2 emission every year and intensifies air pollution and global warming issues. Diesel vehicles emit significant amounts of nitrogen oxides (NO_x) and particulate matter (PM) (Rashed et al., 2016b). In European countries, vegetable-oil-based fuels named "biodiesel" are being commercially sold (http://www.biodiesel.com/, 2015). Biodiesel is derived from various vegetable and animal fats and offer many advantages over conventional petroleum diesel, such as superior cetane number, good lubricity, and low carbon monoxide and unburned hydrocarbons (HCs) (Imdadul et al., 2015).

Vegetable oil is made from renewable resources and is the most promising self-igniting fuel for diesel engines. In the past, many experiments on the use of vegetable oils as diesel-engine fuel have been carried out (Habibullah et al., 2015a; Mofijur et al., 2013b; Rashed et al., 2016a; Sanjid et al., 2014; Sbihi et al., 2015; Silitonga et al., 2015). Vegetable oil consists of triglycerides, which contain a higher amount of carbon atoms (50%–100% more per molecules) than that diesel oil. Triglycerides are esters composed of one molecule of glycerol and three molecules of fatty acids. Fatty acids comprise from 94% to 96% of the total mass of a triglyceride molecule, which affects the physicochemical properties of an oil, such as viscosity and calorific value (Armendáriz et al., 2015; Mofijur et al., 2014). The most common fatty acids in vegetable oil are stearic, oleic, and linoleic acids. The quantity of free fatty acids predominantly affects the flash point and its ignition characteristics of a vegetable oil (Mofijur et al., 2013a; Rashed et al., 2015; Shahabuddin et al., 2012b). Saturated free fatty acids reduce oxidation stability and the melting temperature of oils. As a result,

* Corresponding authors at: Department of Mechanical Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia.
E-mail addresses: kalam@um.edu.my (M.A. Kalam), rashed.duet31@gmail.com (M.M. Rashed), imdadulduet29@gmail.com (H.K. Imdadul).

http://dx.doi.org/10.1016/j.indcrop.2016.04.021
0926-6690/

vegetable oil containing saturated free fatty acids is produced by combustion at low temperature. A previous research has shown that long-term engine durability is adversely effected by the high viscosity, low volatility, and low reactivity of unsaturated HC chains (Palash et al., 2015; Shahabuddin et al., 2012a; Silitonga et al., 2015; Silitonga et al., 2014).

Operational issues such as starting ability, ignition, combustion, performance, and durability issues (e.g., deposit formation, carbonization of injector tip, ring sticking, and lubricating oil dilution) are the main factors affecting engine operation with vegetable oils. The direct utilization of vegetable oils creates the problem of fuel filter chocking during long-term operation because of their high viscosity and insolubility in vegetable oils. The high viscosity, poly-unsaturation, and extremely low volatility of vegetable oils result in operational and durability issues regarding their broad utilization as diesel-engine fuel. The higher viscosity of vegetable oils also leads to large droplet size fuel, weak fuel atomization, and high spray impingement. Hence, the mixing of fuel and air is not well enough to burn completely into the combustion chamber, leading to poor combustion, as well as reduced power and fuel economy. However, the blending, pyrolysis, and emulsification of vegetable oils may address these issues by decreasing the viscosity and improving the volatility of vegetable oils while retaining their atomic structure and thus their poly-unsaturation. Depending on blend concentration, the mixing of vegetable oils with diesel extremely lessens viscosity, thereby enabling an engine's fuel system to operate with the vegetable-oil–diesel blends without any problem (Agarwal, 1998; Agarwal et al., 2008; Murayama et al., 2000).

A pure vegetable oil's methyl ester reportedly produces more nitrogen oxides (NO_x) than ordinary diesel (OD) oil. The decreased PM emissions by vegetable-oil methyl esters is mainly due to a reduction in aromatic content, which is replaced by vegetable-oil methyl esters, as well as the effect of oxygen on vegetable-oil methyl esters (Kim et al., 2014; Singh et al., 2015; Yilmaz and Vigil, 2014). Meanwhile, vegetable-oil methyl ester blended with diesel oil produces less PM emission without increasing NO_x concentration (Agarwal et al., 2015). Among several vegetable oils available as renewable energy sources, coconut oil appears as a promising alternative renewable fuel for diesel engines (Chinnamma et al., 2015; Mohankumar et al., 2015). Habibullah et al. (2015b) measured engine performance on a diesel engine running on pure coconut oil and blends of coconut oil with diesel and palm oil. They showed that the thermal efficiency of engine running on coconut oil is inferior to that running on conventional diesel oil, and that fuel consumption increases with increased percentage of coconut oil in the blends. Chinnamma et al. (2015) showed that diesel engine fueled with coconut oil methyl esters produces higher power and lower exhaust emissions than OD. A research group (personal communication, Loughborough University, UK) also tested a diesel engine operated with 100% crude coconut oil and observed starting problems, low heat release rate, and low brake power.

1.1. Objectives of this study

The initial phase of this research focused on coconut-oil blends instead of coconut-oil methyl ester because of high fuel cost, suspected material compatibility problems, and promising results from a previous research on coconut-oil blends. Coconut-oil content was gradually increased in the blend with OD oil to reduce viscosity, increase volatility, and solve other unexpected problems in pure vegetable and coconut oils. We aimed to determine the optimum blending ratio of coconut oil with OD whose overall performance was better than OD. This better overall performance may be possible by increasing oxygen concentration with increased coconut oil in coconut-oil blends. Moreover, fuel properties such as specific density, viscosity, cetane number, and heating value of the coconut-oil blends were studied. Combustion pressure and heat release rate were analyzed to monitor thermodynamic behavior.

Table 1
Specification of used diesel engine.

Type	: Water cooled, 4 strokes
Combustion	: Indirect Injection (IDI)
Number of cylinders	: 4
Bore Diameter	: 84 mm
Stroke	: 82 mm
Displacement	: 1817 cc
Compression ratio	: 21:1
Nominal rated power	: 39 kw
Maximum speed	: 5000 rpm
Maximum torque speed	: 1800–3000 rpm
Dimension (L × W × H)	: 700 × 560 × 635 (mm)
Weight (dry)	: 185 kg
Combustion chamber	: Swirl chamber
Cooling system	: Pressurized circulation

2. Materials and methods

The layout of the experimental setup is shown in Fig. 1. The indirect injection (IDI) diesel engine specifications are shown in Table 1. The instrument used in this investigation was fully equipped in accordance with SAE standard J1349 JUN90. Performance test was conducted according to SAE standard procedure SAE J1312JAN90. A constant speed of 2000 rpm with variable loads as 10–100 Nm was selected for performance and emissions tests. The same test procedure and practice were followed for all other blended-fuel systems. The engine was adjusted per the manufacturer's instructions before running the test, and the engine was run-in until corrected brake power was maintained within a variation of 1% over a period of 8 h continuous running. CP Engnering-CADET10 software was used to save and analyze data.

2.1. In-cylinder pressure-measuring equipment

A unit of autoscan engine-combustion-process analyzer incorporating CAS software was used to study engine combustion. A high-revolution encoder was installed on the frame bolted onto the frame of the engine test bed. This flexible coupling enabled the encoder to function well under vibration condition. Then, the encoder was calibrated against the mark top dead center (TDC) of the crankshaft. A Thermo-COMP Quartz pressure sensor 6061B Kistler water-cooled precision cylinder pressure sensor was installed to study pressure rise and the peak pressure of the combustion system. A workshop-machined adapter was used to mount the sensor in one existing bore for glow plug. Cylinder pressure signals were passed onto a 5041C-Kistler-charge amplifier before being recorded on a computer data-acquisition system.

2.2. Exhaust-emission measuring equipment

Bosch gas analyzer model ETT 008.36 was used to measure CO_2 and CO in volume percentages. A Bacharach model 300 combustion analyzer (Siegert version, k-type probe) was used to measure NOx concentration in parts per million. To determine the level of CO_2, CO, and NOx from the sampled portion of exhaust gases, the systems used nondispersive infrared detectors. The measurement systems followed SAE recommended practice SAEJ177 APR82. For unburned-HC analysis, the system uses HORIBA motor exhaust gas analyzer model MEXA 9100D. The unit's uses flame-ionization detection to measure the concentration of unburn HCs. The equipment heats the sampled portion of the exhaust gas in an oven up to 193 °C to ensure that the correct level of HC was determined