Applied Energy 114 (2014) 865–873

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Characterization of a diesel engine operating with a small proportion of methanol as a fuel additive in biodiesel blend

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HIGHLIGHTS

- Biodiesel blend with methanol additive improved the combustion pressure.
- The brake specific fuel consumption was found to be high compare to diesel.
- NOx increase, while CO and CO_2 were found to be decreased.

ARTICLE INFO

Article history:
Received 15 January 2013
Received in revised form 30 May 2013
Accepted 8 June 2013
Available online 3 July 2013

Keywords:
Methanol
Biodiesel blend
Engine performance
Combustion characteristics
Exhaust emission
Diesel engine

ABSTRACT

Biodiesel has been a lucrative commodity in the current global economic trade as there is mounting concern for issues relating to the environment and oil depletion. Biodiesel has been proven to be the next alternative renewable fuel as it is environmentally friendly, sustainable and possesses similar combustion characteristics to petroleum diesel. However, due to the higher density and viscosity of biodiesel, pure biodiesel is not widely used in diesel engines. Therefore, the purpose of alcohol as a fuel additive is to improve the viscosity and density in the biodiesel blend. The focus of this study is to evaluate the performance and emissions of a small proportion of methanol (5% by volume) in a B20 blend and mineral diesel separately. A compression ignition (CI) Mitsubishi 4D68 multi-cylinder DI diesel engine was used in this work. Engine performance, combustion and exhaust emission characteristics were evaluated at two specific conditions. The first condition was an increase in engine speed from 1500 rpm to 3500 rpm at partial engine load and the second condition involved maintaining a constant speed of 2500 rpm at three different engine loads (0.05 MPa, 0.4 MPa and 0.7 MPa). Lower brake power was noticed when operating with B20 and B20 M5 blend. However, an increase in brake specific fuel consumption (BSFC) of 4–6% was observed when the engine was fueled with B20 and B20 M5. The results indicate that NOx emissions increase (up to 13%) while lower carbon monoxide (CO) and Carbon dioxide (CO_2) (up to 17–18%) are observed in contrast with the mineral diesel.

1. Introduction

The global biodiesel market has experienced skyrocketing growth over the past 20 years with increasing annual production in order to cater for increasing demand, especially from Europe and the United States which have mandated levels of biodiesel use. According to a report from market research reports database, Axis Research Mind, the market value of biodiesel is expected to increase 26% reaching $62 million (€43.4 million) by 2015 [1]. In 2009, world total biodiesel production reached 14.7 billion gallons and by 2015, the biodiesel production has been predicted to reach 26 billion gallons. Europe has been named to be the world's largest biodiesel market which produced around 70% of the world's total production capacity; followed by the United States with around 12.8% of the market [1].

The growing global consumption trend in biodiesel also reflects the increasing production of biodiesel in Asian and South American regions, especially from tropical crop oils including palm oil, jatropha, coconut, rubber and others. Biodiesel sectors also contribute to the sustainable development and economic growth across these regions. This means more land will be cleared to plant the crops and more biodiesel plants will be opened to process those crops. Unemployment rates will decline and the GDP of the countries will increase rapidly. Responding to huge profits coming from the biodiesel industry, more biodiesel processing companies from Europe and the United States have aggressively expanded their operations in these regions with the establishment of new biodiesel plants to cater for the booming global demand for biodiesel. For example, in

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0306-2619/$ - see front matter
http://dx.doi.org/10.1016/j.apenergy.2013.06.012

2010 Neste Oil (based in Finland) launched the world's largest biodiesel production facilities in Singapore. These facilities have the capacity of 800,000 tonnes a year for the processing of vegetable oils and animal fats [2].

Fossilized fuels have been extensively associated with issues related to global warming, greenhouse gas emissions, scarcity of oil reserves, price volatility and political instability in many regions [3–5]. Considering these factors, renewable alternative fuels from feedstock and livestock have been promoted widely with the support from governments in the form of subsidies and strict emission regulations. In recent years, many studies have established that these renewable fuels produce lower or no sulfur and aromatic-hydrocarbons, they are less toxic, biodegradable and possess comparable combustion characteristics with petroleum diesel fuels [6,7]. Additionally, renewable fuels or biodiesel properties are similar to that of mineral diesel fuels and they can be used directly in the form of mineral or blended in diesel engines without any modification [8,9]. On the other hand, dissimilarities in chemical composition for the alternative fuels are likely to attribute to the basic differences in properties affecting engine performance, combustion and exhaust emission characteristics [10,11]. Due to the increasing demand in the biodiesel industry, countless studies on biodiesels have been conducted to evaluate the effect on engine performance, combustion and exhaust emission characteristics when operating with biodiesel, using mineral diesel as a reference fuel [12–19].

Other than the experimental biodiesel testing, engine testing simulation can be conducted to simulate the actual condition of the biodiesel combustion period with different inputs and outputs. Examples of engine simulation include GT-Power, Ricardo Wave and current artificial neural network (ANN). In a paper by Najafi et al. [20], it is reported that artificial neural network (ANN) is among some of the most well-known methods to predict the actual combustion period and can be used for the experimental data validation and optimization. These basis allegations have been proven by Sayin et al. [21] who modeled the performance and exhaust emissions of an engine using ANN models to reduce the time and budget expenditure for the engine test set up. In addition, Canakci et al. [22] and Arcaklioglu et al. [23] demonstrated that ANN can be an optimum tool for predicting the performance and exhaust emissions.

To the best of the author's knowledge, Shanmugam et al. [24] has modeled his ANN concept to predict the performance and exhaust emissions of the single cylinder diesel engine operating with hybrid fuel under different load conditions. His report discovered that the use of the developed ANN model has proven to predict the performance and exhaust emissions of the diesel engine with a low root mean square error and a range between 0.975 and 0.999 for the correlation coefficient accurately. Other ANN modeling and prediction works that related to the engine performance and exhaust emissions of diesel engine with biodiesel are Sharon et al. [25], Patil et al. [26], Sarala and Rajendran [27]. However, according to these papers, as their ANN model predicts excellent results when compared to the experimental results, the need for experimental test data is to ensure the accuracy and reliability of the findings.

However, there are a number of biodiesel properties that could potentially be improved as biodiesel's high viscosity and low volatilities cause problems in long-period engine performance tests. The higher viscosity in biodiesel affects the fuel droplet size, poor atomization qualities and fuel penetration in the cylinder which is very important for the combustion quality [28,29]. The unique structure in the chemical bonding of the biodiesel forms higher viscosity that produces problems including injector coking, ring sticking and gumming in diesel engines. Methods such as blending with mineral diesel, pyrolysis, microemulsification (cosolvent blending), and transesterification are required to reduce the viscosity of vegetable oils [30]. However, there are few alternatives that reduce the density and viscosity of biodiesel, one of which is an alcohol-based fuel additive.

Methanol is an alcohol-based fuel additive which has approximately 30% higher oxygen in basis compared to mineral diesel which helps diesel engines to achieve higher complete combustion. The additional oxygen in fuel means a more complete combustion can be achieved. Furthermore, the implementation of alcohol additives tends to reduce PM, HC and CO significantly in the exhaust emission [31–33]. Lapuerta et al. [34] investigated the emissions of diesel–bioethanol blend fuels operating in a diesel engine and found that use of diesel–bioethanol blend fuels tends to reduce PM emissions with no significant increase in other gaseous emissions (NOx, HC,CO). Furthermore, Zhu et al. [35] found a reduction in HC and CO emissions while a decrease in the brake thermal efficiency was observed when the diesel engine was operated with 5%, 10% and 15% of ethanol–diesel and methanol–diesel blend fuels.

In addition, the use of biodiesel as an additive is proven to stabilize the condition of ethanol in the diesel–ethanol blend fuels. Kwanchareon et al. [36] investigated the influence of diesel–biodiesel–ethanol blend fuels on solubility and emission characteristics and concluded that CO and HC decreased significantly at high load while NOx increased when being compared between those blend fuels.

This research work was conducted to evaluate the effect of a small proportion of methanol as a fuel additive in the B20 blend on engine performance, combustion and exhaust emissions when operating with a multi-cylinder diesel engine.

1.1. Experimental section

Tests were conducted on a bench-mounted and instrumented automotive diesel engine. The engine that was used in this study was a four stroke multi cylinder Mitsubishi 4D68 SOHC 2.0 l with specifications outlined in Table 1. This engine is naturally-aspirated, water-cooled and equipped with a GNU vertical rotameter at the engine cooling system as depicted in Fig. 1. The test bench was equipped with Cole Palmer pressure gauges and K-type thermocouples for mean temperatures and pressure measurements in order accurately to characterize and monitor the engine's operating mode. The engine was coupled by a shaft to a 150 kW eddy current dynamometer controlled by a Dynalec controller; measuring and controlling the effective torque and engine speed. Airflow and fuel flow rate were measured by a CENTERTEK anemometer and AIC fuel flow meter respectively. A Kane gas analyzer was used to measure and monitor the exhaust emissions of the engine including NOx, carbon dioxide (CO) and unburned hydrocarbons (UHCs).

Data relating to engine operation parameters; instantaneous in-cylinder pressure and crankshaft angle were recorded and saved using DEWECA. In addition, software named DEWESOFT from DEWETRON was used to record and analyze the readings of the thermocouples from the engine. Tests were conducted at two specific operating conditions which were (i) increasing engine speeds from 1500 rpm to 3500 rpm at partial engine load and (ii)

Table 1
Specification for a Mitsubishi 4D68 diesel engine.

Parameters	Details
Number of cylinders	4 In-line
Combustion chamber	Swirl chamber
Total displacement cm	1.998 cc
Cylinder bore mm × Piston stroke mm	82.7 × 93
Bore/stroke ratio	0.89