Fuel 225 (2018) 343–348

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

A comparative study on performance, combustion and emission characteristics of diesel engine fuelled by biodiesel blends with and without an additive

M. Mohamed Musthafa*, T. Ashok Kumar, T. Mohanraj, R. Chandramouli

School of Mechanical Engineering, SASTRA Deemed University, Thanjavur 613401, India

ARTICLE INFO

Keywords:
Diesel
Palm oil methyl ester
Di-*tert*-butyl peroxide
Cetane number
Performance
Emissions
Chemical kinetics

ABSTRACT

Biodiesel is a fuel containing mono-alkyl esters which are derived from vegetable oils or animal fats. Biodiesel fuels are well-adopted now a day's having multiple benefits such as a renewable energy source, less pollutant emissions of carbon monoxide, hydrocarbons and particulate matter and so on. The oxides of nitrogen (NO_x) emissions reported in the literature are ambiguous for biodiesel blended fuels with reference to baseline diesel NO_x. Authors have come out with different conclusions of no change in NO_x, a decrease NO_x and an increase in NO_x. This study aims to reduce NO_x emission of palm oil methyl ester blended with diesel fuel (B20), by using Cetane number improver-di-*tert*-butyl peroxide (DTBP) and to improve ignition performance of the test fuel. Single cylinder, four stroke, water cooled diesel engine loaded by eddy current dynamometer was used for this study. The engine was run with diesel, B20 fuel and B20 with 1% DTBP additive by volume basis. The performance, combustion and emission results were compared. The results revealed that B20 with additives shows an increased thermal efficiency by 2–3.5% and decrease specific energy consumption by 10–15% compared to diesel and B20 fuel. Significant reduction of CO and NO_x in trade off with slight increase in HC for the B20 fuel without additives was observed.

1. Introduction

Diesel engines are used in wider application like transport vehicles, marine engines, power generation and agriculture purpose because of their lower fuel consumption, higher thermal efficiency and reduced tail pipe emissions, compared to gasoline engine. The rapid exhaust of crude oil reserves and increasing petroleum prices resulted in increases the research interest in alternate fuels. In the recent years an importance is given to the use of plant oils and its esters. The biodiesel is focused more because of its environmental aspects and its potential as an alternative fuel for diesel engines without any significant modification in existing engine [1]. Many researchers have suggested the biodiesel as a replacement, either completely or partially blended, because they reduce the exhaust emissions. Biodiesel by weight contains less carbon, sulphur, water and more oxygen than the petroleum diesel [2]. Various studies have shown that with the decrease of carbon monoxide (CO), carbon dioxide (CO_2), particulate matter, sulphur compounds (SO_x), volatile organic compound and unburned hydrocarbons except the NO_x emissions [3]. NO_x is formed by the oxidation of nitrogen in the atmosphere at elevated temperature (above 1700 K), and prompt NO_x by the formation of free radicals in the flame front of hydrocarbon flames. It is believed that the NO_x formation is mainly due to thermal (Zeldovich mechanism) and prompt or Fennimore mechanism. However, in biodiesel, a significant amount of NO_x is formed due the prompt or Fennimore mechanism (< 1000 K) [4] The National Renewable Energy Laboratory (NREL) reported that di-*tert*-butyl peroxide (DTBP) and ethyl-hexyl nitrate (EHN), are Cetane improver for reducing NO_x up to 4% in B20 blends [5]. Residual methanol in biodiesel is responsible for a decrease in the Cetane number. The Cetane number of biodiesel is always more than 47, which is higher than the petroleum diesel [6]. Researchers report that Cetane index of biodiesel and diesel is about 60 and 42 respectively. The higher the Cetane index provides, the better the combustion and an improvement in the engine thermal efficiency. Biodiesel having 10–11% excess oxygen by weight resulting into complete combustion than diesel in an engine and high Cetane number of fuel reduces the ignition delay period [7–10]. As biodiesel is completely suspend with diesel, the blending of both fuels in any ratio is possible and recommended in order to improve its qualities. However, the differences in chemical nature of biodiesel and petroleum diesel may cause effects in the physicochemical properties, influencing engine performance and emissions [11]. From the literature study, it is concluded that up to 20% of biodiesel with diesel fuel

* Corresponding author.
E-mail address: mohamedmustafa@mech.sastra.edu (M.M. Musthafa).

https://doi.org/10.1016/j.fuel.2018.03.147
Received 27 February 2017; Received in revised form 16 March 2018; Accepted 20 March 2018

resulted in better performance, controlled combustion and emission of diesel engine [12–15]. Likewise, chemical additives such as di-*tert*-butyl peroxide (DTBP), ethyl hexyl nitrate (EHN) and Di-ethyl ether (DEE) also can be blended directly to diesel and biodiesel blends by some researches. To date, there has been a significant amount of research work carried out in these areas, and many articles have been published in these topics. A few of the papers related to this work are discussed in this section (i) Wang et al. [9] have investigated the effects of DTBP blend with biodiesel on combustion and emissions of the diesel engine. Their results show that the ignition delay and combustion duration is reduced by 1.2°CA and 3°CA respectively with addition of 0.75% DTBP in biodiesel, the maximum cylinder pressure was reduced by 2.5%. HC, CO and NO_x emission decreased by 42.7%, 13.9% and 15.7% respectively. (ii) Venkateswarlu et al. [16] have studied the performance and emissions characteristics of a diesel engine by B30 fuel blended with an additive of 0.5% and 1% on volume of Di tertiary butyl peroxide along with EGR rate is varied from 0% to 20%. They found that an increase in thermal efficiency and decrease in specific fuel consumption, cylinder pressure and exhaust emissions of carbon monoxide, hydro carbon, NO_x and smoke opacity. (iii) Kumar et al. [17] have investigated on the effect of biodiesel fuel blended with ethyl hexyl nitrate (EHN) and exhaust gas recirculation on diesel engine performance and emissions. They found that the biodiesel with Cetane improver under 20% EGR reduces NO_x emissions by 33% when compared to baseline fuel of diesel without EGR. (iv) Ramakrishna et al. [18] have studied the effect of Ethyl Hexyl Nitrate (EHN) as an additive to the diesel-biodiesel blends on engine performance and emissions. They found that an increase in BTE and cylinder pressure, emissions of CO and NO_x were reduced with increase in EHN percentage. (v) Di-ethyl ether up to 0–5% on some vegetable oils such as POME, Neem oil resulting in better performance and improved emission on CI engine [19]. (vi) Di-ethyl ether (0–12%) on Jatropha oil 20% and diesel 80% blend provides best results when compared to conventional diesel [20]. In fact, it is now possible to examine the effect of DTBP additive to Palm oil biodiesel blends (B20) on engine performance, combustion and emission through mainstream literature reviews.

2. Materials and methods

This section describes DTBP properties, biodiesel preparation procedure, properties of the test fuels and experimental setup.

2.1. Di-tert-butyl peroxide (DTBP)

DTBP is available 100 ml bottle pack. It is an organic compound - consisting of a peroxide group flanked by two *tert*-butyl groups. It is amongst the most stable organic peroxides. The peroxide bond undergoes homolysis at temperatures > 100 °C, and for this reason di-*tert*-butyl peroxide is commonly used as a radical initiator in organic synthesis and polymer chemistry. Its chemical formula is $C_8H_{18}O_2$ and other properties as per supplier specification are listed in the Table 1.

2.2. Biodiesel preparation

The refined Palm oil was obtained from local market. Biodiesel was prepared from the refined Palm oil in a laboratory by simple base catalysed transesterification method. Methanolic solution prepared by 1% potassium hydroxide (KOH) is mixed with 30% of methanol by volume of oil. The prepared solution is added into the 60 °C heated refined oil, is stirred for one hour at 50 °C and is finally transferred into a conical flask and allowed to settle for next 24 h. Two layers are formed in the flask, the dense bottom layer is separated out and the remaining biodiesel is washed with distilled water heated up to 50–60 °C in three times to get pure biodiesel. By this process, 92% biodiesel yield is obtained. The prepared biodiesel properties are tested as per ASTM standard and the same is listed in the Table 2.

Table 1
Properties of di-*tert*-butyl peroxide.

Molecular weight	146.23
Specific gravity@25 °C (g/cc)	0.785–0.796
Melting point	Below 40 °C
Active Oxygen	10.75%
Boiling point	109–111 °C
Solubility	Soluble in most organic solvent; insoluble in water

Table 2
Physiochemical properties of test fuels.

Properties	Diesel	Palm oil biodiesel	B20 fuel	B20 with DTBP
Density (g/cc)	0.832	0.873	0.845	0.8402
Viscosity at 40 °C (cSt)	2.74	4.5	3.5	2.62
Flash Point (°C)	46	92	65	57
Fire point (°C)	51	124	97	85
Calorific value (kJ/kg)	45,500	42,144	44,300	45,400
Cetane Number	49	53	52	58

2.3. Experimental setup

The experimental test rig consists of a compression ignition engine, eddy current dynamometer as loading system, fuel supply system for both diesel and biodiesel supply, water cooling system, lubrication system; and various sensors and instruments integrated with computerized data acquisition system for online measurement of load, air and fuel flow rate, instantaneous cylinder pressure, injection pressure, position of crank angle. Fig. 1 shows the photographic view of the experimental setup used in the laboratory to conduct the present study. Table 3 gives the technical specifications of different components used in the test rig. Windows based engine performance analysis software package 'Engine soft' is provided for online thermal performance evaluation. The thermal performance parameters include brake power, brake mean effective pressure, brake thermal efficiency, volumetric efficiency, brake specific fuel consumption, exhaust gas temperature, heat equivalent of brake power and heat equivalent of exhaust gas. The emissions such as Nitrogen oxides (NO_X), Carbon monoxide (CO), Hydrocarbon (HC), Carbon dioxide (CO_2), Oxygen (O_2) and air-fuel ratio were measured by Delta 1600L exhaust gas analyser.

3. Results and discussions

The effect of Di-*tert*-butyl peroxide additive added to palm oil methyl ester on engine performance and emissions are discussed in this

Fig. 1. Photographic view of engine setup.