Fuel 107 (2013) 570–577

Contents lists available at SciVerse ScienceDirect

Fuel

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

Combustion and emission characteristics of a direct injection compression ignition engine using rapeseed oil based micro-emulsions

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HIGHLIGHTS

- A stable and homogeneous rapeseed oil based micro-emulsions was prepared.
- The main properties of the micro-emulsions were measured.
- The combustion characteristic parameters of the engine were calculated and analyzed.
- The performance and emissions characteristics of the engine were compared and studied.
- The influence of engine load and speed on micro-emulsions engine were studied.

ARTICLE INFO

Article history:
Received 24 August 2012
Received in revised form 12 October 2012
Accepted 24 January 2013
Available online 8 February 2013

Keywords:
Rapeseed oil
Ethanol
Micro-emulsion
Combustion characteristics
Emissions

ABSTRACT

The main objective of this paper was to study the performance, emissions and combustion characteristics of a diesel engine using the micro-emulsions consisting of rapeseed oil/diesel blend, ethanol and a surfactant. The main fuel properties were investigated and compared with that of diesel. The experimental results show that the viscosity and density of the micro-emulsions was decreased and approached that of diesel with the ethanol addition up to 30% by volume. The start of combustion of the micro-emulsion was later than that of diesel and the peak cylinder pressure, peak pressure rise rate and peak heat release rate were higher than those of diesel. The corresponding crank angles were retarded with the increase of ethanol addition. The combustion durations of the micro-emulsions were slightly shorter at low engine loads, and almost similar to that of diesel at high engine loads. For the micro-emulsions, there were slightly higher brake specific fuel consumptions (BSFCs), while almost identical brake specific energy consumptions (BSECs). Drastic reduction in smoke was observed with the micro-emulsions at high engine loads. Nitrogen oxides (NO_x) emissions were found slightly lower at low engine loads for the micro-emulsions.

1. Introduction

Due to the exhausted world petroleum reserves and the impact of environmental pollution from increasing exhaust emission, there is a great attention for suitable alternative fuels such as biofuels in almost every region. Vegetable oils based on rapeseed, soybeans, and others are promising alternative fuels for diesel engines because vegetable oils are renewable and sulfur free and offer potential reductions in carbon dioxide (CO_2) emissions. Vegetable oils have different features from conventional fossil fuels and a number of studies about vegetable oil have been conducted in diesel engines [1–4]. It is widely known that neat vegetable oils cause serious problems such as carbon deposits and have poor durability because of the higher viscosity and lower volatility [5–7]. Therefore, four technologies have been evaluated to reduce the high viscosity of vegetable oils in order to overcome these problems: (1) vegetable oil/diesel blends, (2) pyrolysis, (3) vegetable oil transesterification to fatty alkyl esters or biodiesel, and (4) vegetable oil-based microemulsifications [8–15].

As an alternate approach, ethanol is a renewable energy source. It can be made from very common crops such as sugar cane and corn. Therefore, ethanol–diesel blends can be used in diesel engines without modification. However, ethanol–diesel blends are

Abbreviations: BMEP, brake mean effective pressure (MPa); BSEC, brake-specific energy consumption (MJ/kWh); BSFC, brake specific fuel consumption (g/kWh); CA, crank angle; CI, compression ignition; CO, carbon monoxide (%); CO_2, carbon oxides (%); DI, direct injection; HC, hydrocarbon (ppm); k, coefficient of light absorption of the smoke (1/m); LHV, lower heating value (kJ/kg); NO_x, nitrogen oxide (ppm); PM, particulate matter; ppm, parts per million; SOC, start of combustion; TDC, top dead center.

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http://dx.doi.org/10.1016/j.fuel.2013.01.046

limited by the fact that they are immiscible over a wide range of temperatures [16–18]. Surface active agents, or surfactants, can be used as emulsifiers to stabilize the miscibility of ethanol and diesel. Microemulsion-based biofuels, or hybrid fuels, are transparent and thermodynamically stable Winsor Type II micro-emulsions in which the polar ethanol phase is solubilized in reverse micelles occurring in the non-polar phase. Therefore, in microemuslion-based biofuels, ethanol is used in place of water as the polar phase which disperses in the vegetable oil as non-polar phase stabilized by surfactants or amphiphilic molecules under appropriate conditions [19,20]. Attaphong et al. [21] produced a kind of vegetable oil reverse micelle micro-emulsions as an alternative method of reducing vegetable oil viscosity and evaluated the phase behavior of carboxylate-based extended surfactant micro-emulsion systems with the goal of formulating optimized systems for biofuel. The results indicated that carboxylate-based extended surfactants were able to form reverse micelle micro-emulsions, thereby eliminating the phase separation and precipitation. In addition, fuel properties such as viscosity and temperature dependence were favorable and thus support the development of these surfactant-based fuel systems for use in diesel engines. Lujaji et al. [22] evaluated the effects of croton oil–butanol–diesel blends on the performance and emissions of diesel engine. It was observed that BSFC of blends was found to be higher when compared with that of diesel. Butanol containing blends show peak cylinder pressure and heat release rate comparable to that of diesel on higher engine loads. CO_2 and smoke emissions of the blends were lower in comparison to diesel. Qi et al. [23] used Span 80 as emulsifier to produce biodiesel–ethanol micro-emulsions and evaluated the performance and combustion characteristics. The results indicated that, for the micro-emulsions, there was slightly higher BSFC, while lower BSEC. Drastic reduction in smoke was observed with the micro-emulsions at high engine loads. NO_x emissions were found slightly lower under all rang of engine load, but carbon monoxide (CO) and hydrocarbon (HC) emissions were slightly higher at low and medium engine loads. Singh et al. [24] produced one kind of micro-emulsions consisting of coconut oil, aqueous ethanol and a surfactant (butan-1-ol), and investigated the fuel properties, engine performance and exhaust emissions. The experimental results show that the effective thermal efficiency of the micro-emulsions was comparable to that of diesel. The exhaust emissions were lower than those for diesel, except CO emissions. Kumar and Khare [25] studied the micro-emulsion of linseed oil and mahua oil with neat diesel and alcohol in varying proportion, evaluated their properties in view of their suitability as a diesel fuel and their performance and emission characteristics, and concluded that the micro-emulsion of vegetable oil can partially substitute the diesel fuel with no difficulty.

The objectives of this study were to prepare rapeseed oil/diesel–ethanol based fuels using the micro-emulsification technique, and to evaluate their relevant properties, engine combustion and exhaust emission characteristics. The methodology for the preparation of the micro-emulsions and the main chemical and physical properties of the fuels were analyzed. The experimental results of the engine combustion and emission characteristics of a direct injection diesel engine operated on these micro-emulsions were analyzed and compared with the baseline data of diesel in an unmodified diesel engine.

2. Equipment and experiments

2.1. Micro-emulsions preparation

The micro-emulsion process consists of introducing the chosen quantity of surfactant, co-surfactant and ethanol into the rapeseed oil/diesel blend. It has been reported that micro-emulsions are instantaneously formed when all the components are put together in required proportions [26]. The aim of surfactant addition is to reduce oil and water superficial tension, activate their surfaces and maximize the superficial contact area to make micro-emulsions. The co-surfactant permits to improve the migration of surfactant at oil/water interfaces and enhance the stability of the micro-emulsions [27,28]. The micro-emulsions investigated in this study consists of vegetable oil/diesel blend, ethanol and surfactant mixture. The rapeseed oil/diesel blend is the based fuel, in which the volume fraction of rapeseed oil is 20% (donated as DRO20). The surfactant used in this study is oleic oil. This kind of chemical products can be characterized by their hydrophilic–lipophilic-balance (HLB) number. Oleic oil has a HLB number equal to 1.0. This surfactant is more lipophilic than hydrophilic and hence appropriate for making water-in-oil emulsions. Ethanol is used in place of water as the polar liquid phase because it is a renewable fuel that can be obtained by fermenting agricultural waste containing sugar. In this study, 1-butanol is chosen as co-surfactant because it is entirely miscible with diesel at ambient temperature [29].

To study the effect of the three-component ratios on the micro-emulsion fuels, the phase boundaries were determined by titration. DRO20 and ethanol blends were made where the ethanol component was varied from 0% to 30% by volume in 10% increments, as seen in Table 1. Mixing them resulted in a temporary emulsion that was milky in color and eventually separated in a few minutes. The oleic oil/1-butanol mixture (at oleic oil/1-butanol volume ratio near to 1.5) was then added through a burette into the blend until it became clear. DRO20, ethanol and oleic oil/1-butanol mixture were hand-shaken gently into a homogeneous mixture. The samples were kept for a period of 24 h to ascertain the stability through physical appearance and a further 7 days. It can be seen from Table 1 that, with ethanol addition increasing, the surfactant mixture quantity for maintaining the steady state of the micro-emulsion is increased. The micro-emulsions are denoted as DRO20E10, DRO20E20 and DRO20E30 respectively.

The main properties of the stocks and the micro-emulsions were measured and given in Table 2. Without engine modification, the fuel properties of the micro-emulsions will affect the engine combustion and emissions. As seen in Table 2, the viscosities and densities of the micro-emulsions are significantly lowered through the addition of ethanol due to its lower viscosity and density. DRO20E30 has a viscosity of 2.72 mm^2/s and a density of 0.83 g/ml, which are close to those of diesel. Ethanol has lower heating value which is approximately 37.2% less than that of diesel. Therefore, it is necessary to increase the micro-emulsions amount to be injected into the combustion chamber to produce same amount of power. Since ethanol has lower cetane number which will result in longer ignition delay, the amount of ethanol added in DRO20 in the following engine experiment is limited to a maximum of 30% by volume to prevent combustion troubles.

2.2. Experimental setup and procedure

The engine used was two-cylinder, naturally aspirated, four stroke, water-cool, 17:1 compression ratio, direct injection diesel

Table 1
Composition of micro-emulsions.

Micro-emulsion[a]	DRO20 (ml)	Ethanol (ml)	Oleic acid (ml)	1-Butanol (ml)
DRO20	50	0	0	0
DRO20E10	45	5	0.6	0.4
DRO20E20	40	10	2.3	1.5
DRO20E30	35	15	2.7	1.8

[a] Appearance: clear, transparent, well-distributed.