Energy Conversion and Management 169 (2018) 194–205

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Performance and emission evaluation of a marine diesel engine fueled by water biodiesel-diesel emulsion blends with a fuel additive of a cerium oxide nanoparticle

Jiaqiang E[a,c], Zhiqing Zhang[a,b,c,*], Jingwei Chen[a,c,*], MinhHieu Pham[a,c], Xiaohuan Zhao[a,c], Qingguo Peng[a,c], Bin Zhang[a,c], Zibin Yin[d]

[a] State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha 410082, China
[b] Maritime college, Qinzhou University, Qinzhou 535000, China
[c] Institute of New Energy and Energy-saving & Emission-reduction Technology, Hunan University, Changsha 410082, China
[d] College of Marine Engineering, Jimei University, Xiamen 361021, China

ARTICLE INFO

Keywords:
Biodiesel
Marine diesel engine
Performance and emissions
Fuel additive
Combustion
CeO_2 nanoparticles

ABSTRACT

In this paper, the study investigates the combined application of water additive and metal-based additive in the biodiesel-diesel blend fuel. Varied mixtures of biodiesel- diesel (B5), water (i.e. 2%, 4% and 6% wt.) and cerium oxide (CeO_2) nanoparticles (90 ppm) components are compared with pure diesel in terms of their combustion emissions and performance. The experiments are carried out on a marine medium-speed diesel engine. The results showed that the water additive in the biodiesel-diesel fuel was beneficial to improving the mixing of air and fuel due to the micro-explosion. Nevertheless, by further increasing water additive to 6%, the effect of micro-explosion would be dominated by the impact of increased viscosity leading to combustion deterioration. Proper water additive is beneficial to improving performance and decreasing the CO, PM, NO_x and HC emissions. As well as the metal-based additives in the blend fuels can further improve the overall combustion quality and decrease the emissions. More specifically, the metal-based additives are beneficial to improving the brake power and brake thermal efficiency (BTE) and decreasing the brake specific fuel consumption (BSFC) and emissions due to the improved combustion caused by the catalytic activity during the combustion process. Thus, the relationship between the additives and performance and emission characteristics of blend fuel is very important.

1. Introduction

One of the most serious issues faced by the engine manufacturer and transportation sector is to satisfy the demand of increasingly stringent emissions regulations to reverse the unfavorable impacts on climate change and to protect the environment [1,2]. Land and maritime transportation contribute more than 25% of the total greenhouse gases emissions [3]. The improvement of engine technology and the exploration of less polluting energy carriers have been one of the major solutions to overcome these serious challenges [4,5]. The biodiesel fuel is a biodegradable energy from the transesterification of vegetable oil or animal fat [6,7]. Due to the unique advantages of degradation, low emission, carbon neutral and non-toxic, the biodiesel fuel is defined as "environmentally friendly fuel" and is the most likely alternative for mineral diesel fuel [8].

As mentioned earlier, the biodiesel fuels were produced from various vegetable oils and animal fats such as rape seed, rubber seed, fish oil and so on [9]. More specifically, the alkali-catalyzed transesterification is the most common method to product the biodiesel fuel [10]. The biodiesel is produced by the transesterification of vegetable oils or animal fats with ethanol and methanol taking place in the presence of catalysts such as KOH, NaOH and so on [11]. Through this series of normal procedures, the triglycerides were transformed into ethyl esters and fatty acid methyl [12].

Many researchers have investigated the performance and emission characteristics of diesel engine fuelled with various biodiesel-diesel blends and pure biodiesel fuel [13]. In most of the previous studies the biodiesel- diesel blends have the positive effects on engine emissions and performance parameters [14]. In generally, the results obtained showed that the combustion of various biodiesel-diesel blends could reduce PM, HC and CO emissions. However, it is unfavorable for controlling the NO_x emission. In order to reduce NO_x emission caused by the various biodiesel-diesel blends, many kinds of fuel additives have been used to carry out the experiments over the past decades [15].

* Corresponding authors at: State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha 410082, China.
E-mail addresses: zhangzhiqing64@163.com (Z. Zhang), chenjingwei@hnu.edu.cn (J. Chen).

https://doi.org/10.1016/j.enconman.2018.05.073
Received 23 March 2018; Received in revised form 11 May 2018; Accepted 19 May 2018
0196-8904/

Among various additives studied, many research centers and companies have an increased interest in water additive due to the great impact on reducing NO_x emission [16]. Several methods have been reported to control the emissions from diesel engine, such as water fumigation, direct water injection and water-diesel emulsion [17]. Among these ways, the water-diesel (or water biodiesel-diesel) emulsion (WDE) method is the most effective ways [18]. It is due to the fact that the method can decrease the NO_x emission without changing the internal structure of the diesel engine [19]. Thus, the method has obvious advantages compared with other methods [20]. However, some literature have reported that the combustion of WDE fuel increases the amount of HC emission due to the low in-cylinder temperature caused by the higher latent heat of water during the evaporation process [21]. Kumar et al. had also found the similar results [22]. Ithnin et al. had found that PM and NO_x emission were decreased in response to all different levels of water additive rates [23]. But some literature also reported that the combustion of WDE fuel decrease PM, HC and CO emissions [20,24].

In addition, some findings have found the water additive in blend fuel could result in increases of BSFC. For instance, Koc and Abdullah have also reported that 15% water in biodiesel blends will increase the BSFC by 7.2% at 2800 rpm [16]. But the water additive in blend fuel can reduce the NO_x emission. Thus, in order to take the advantage of the reduction in NO_x emission and overcome the disadvantages of using water, the metal-based additives into WDE blend fuel have been put as the most effective strategy, which is recognized by more and more scholars [24]. Many scholars have an increased interest in metal-based additives due to the improved combustion caused by the catalytic activity during the combustion process [25,26]. The metals mainly include iron, copper, cerium and platinum. Some researchers have reported that metal-based additives can improve the combustion quality and decrease the BSFC and emissions [27–29]. For instance, Vellaiyan investigated on the effects of 50 and 100 ppm zinc oxide additives into WDE and found that HC, CO, and NO_x emissions were also reduced [30]. Farfaletti et al. studied the effects of WDE blend fuel with CeO_2 additive and found that the new WDE blend fuel with CeO_2 additive could decease the PM, HC and CO emissions compared with the WDE fuel without CeO_2 additive [31]. Keskin et al. also studied the effects of metal-based additives on performance and emission characteristics of diesel engine and argued that the CO, and smoke emissions decreased by 56.42% and by 30.43%, respectively [32].

Accordingly, the present studies are set to look into the effects of the combined application of water additive and metal-based additive (90 ppm) on the combustion and emission characteristics of a marine diesel engine. To achieve that, the experiments were carried out on a medium-speed marine diesel engine fueled with different water-biodiesel-diesel emulsion (i.e. 2%, 4% and 6% water) blend fuels with a fuel additive of CeO_2 nano-particle (90 ppm). The combustion processes of diesel and water-biodiesel-diesel emulsion (WBDE) fuels with and without CeO_2 nano-particle were compared and investigated. The findings could be of interest since both prevention on engine performance losses and emissions reduction were targeted using WBDE strategy.

2. Material and methods

2.1. Fuel properties

Biodiesel is obtained by the transesterification of rapeseed oil with methanol. Transesterification is carried out by the alkali catalysis (KOH) in a tank reactor at 60 °C for one hour. The rapeseed oil methyl ester (RME) is measured by "Biodiesel Analyzer" based on the fatty acid profile. The properties of RME are in agreement with the ASTM standards and shown in Table 1. The RME is mainly made up of methyl linolenate (C18:3, $C_{17}H_{32}O_2$), methyl linoleate (C18:2, $C_{19}H_{34}O_2$), methyl oleate (C18:1, $C_{19}H_{36}O_2$), methyl stearate ($C_{19}H_{38}O_2$, C18:0) and methyl palmitate (C16:0, $C_{17}H_{34}O_2$). Cm:n is the shorthand of fatty acid methyl esters, n is the number of double bond, m is the number of carbon atoms. The physical properties of fatty acid methyl esters (FAMEs) present are shown in Table 2. The more detailed information can be obtained in Refs. [11,33].

Table 1
Fatty acid profile of RME.

Fatty acid methyl esters	% (by volume)
Methyl linolenate (C18:3, $C_{17}H_{32}O_2$)	8.11
Methyl linoleate (C18:2, $C_{19}H_{34}O_2$)	22.27
Methyl oleate (C18:1, $C_{19}H_{36}O_2$)	65.18
Methyl stearate (C18:0, $C_{19}H_{38}O_2$)	0.87
Methyl palmitate (C16:0, $C_{17}H_{34}O_2$)	3.57

Table 2
Physical properties of FAMEs present.

Type (Cm:n)	Kinematic viscosity (mm^2/s) (at 40 °C)	Density (g/cm^3) (at 20 °C)	Molecular weight (g/mol)	Higher calorific value (MJ/kg)
C18: 3	3.11	0.899	292	39.43
C18: 2	3.79	0.887	294	39.68
C18: 1	4.60	0.875	296	39.93
C18: 0	5.59	0.863	298	40.18
C16: 0	4.37	0.864	270	39.56

2.2. Fuel samples preparation

The diesel is blended with 5% fatty acid profile of RME (labeled as B5) by volume. The different levels of water (i.e. 2%, 4% and 6% wt.) without and with 90 ppm CeO_2 are emulsified in 1 L of diesel-biodiesel blends. They are labeled as B5W2, B5W4, B5W6, B5W2c, B5W4c, B5W6c, respectively. The pure diesel is labeled as B0. The diesel engine fueled with different WBDE blends with and without CeO_2 is employed to carry out in the work. The properties of RME are in agreement with the ASTM standards. The kinematic viscosity of fuel is measured according to ASTM D445, the lower calorific value of fuel is measured according to ASTM D240, the density of fuel is measured according ASTM D4052 and the flash point of fuel is measured according to ASTM D93. The major physicochemical properties of the experimental fuel are shown in Table 3. Moreover, the lower calorific value is reduced in response to increasing water concentrations in B5 blend fuel while the kinematic viscosity value showed an opposite trend. The kinematic viscosity value also increased when the 90 ppm CeO_2 is added to WBDE blends. Ithnin et al. investigated the impact of water additive on the kinematic viscosity and found that the viscosity increased with the increase of water additive [23]. In fact, the increased viscosity values might be ascribed to the static electricity attraction and friction between the fuel/water particles in the emulsion fuel, resulting in smaller and better dispersed particles.

Table 3
Properties of WBDE blend fuel.

Type	Kinematic viscosity (mm^2/s) (at 40 °C)	Lower calorific value (MJ/kg)	Flash point (40 °C)	Density (g/cm^3)
B0	2.85	42.7	75	0.8370
B5	2.9	42.10	82	0.8412
B5W2	3.53	41.47	79	0.8472
B5W4	3.55	40.46	76	0.8517
B5W6	3.94	40.14	75	0.8541
B5W2c	3.83	41.07	80	0.8503
B5W4c	3.84	40.36	79	0.8544
B5W6c	3.86	40.03	78	0.8572