Energy 57 (2013) 722–732

Contents lists available at SciVerse ScienceDirect

Energy

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

Effects of ambient oxygen concentration on biodiesel and diesel spray combustion under simulated engine conditions

Ji Zhang [a], Wei Jing [a], William L. Roberts [b], Tiegang Fang [a,*]

[a] Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27695, USA
[b] Clean Combustion Research Center, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

ARTICLE INFO

Article history:
Received 11 December 2012
Received in revised form
29 March 2013
Accepted 23 May 2013
Available online 8 July 2013

Keywords:
Biodiesel
Diesel
Spray combustion
Constant-volume chamber
Chemiluminescence
Luminosity

ABSTRACT

This study investigates the effect of ambient oxygen concentration on biodiesel and diesel spray combustion under simulated compression-ignition engine conditions in a constant-volume chamber. The apparent heat release rate (AHRR) is calculated based on the measured pressure. High-speed imaging of OH* chemiluminescence and natural luminosity (NL) is employed to visualize the combustion process. Temporally and spatially resolved NL and OH* contour plots are obtained. The result indicates that AHRR depends monotonically on the ambient oxygen concentration for both fuels. A lower oxygen concentration yields a slower AHRR increase rate, a lower peak AHRR value, but a higher AHRR value during the burn-out stage when compared with higher ambient oxygen concentration conditions. OH* chemiluminescence and NL contours indicate that biodiesel may experience a longer premixed-combustion duration. The 18% ambient O_2 condition works better for biodiesel than diesel in reducing soot luminosity. With 12% O_2, diesel combustion is significantly degraded. However, both fuels experience low temperature combustion at 10% O_2. These results may imply that biodiesel is able to achieve the desired lower soot production under a moderate oxygen level with higher combustion efficiency, while diesel needs to be burned under very low ambient oxygen concentration for low soot production.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

The utilization of biodiesel, *i.e.*, fatty acid methyl ester (FAME), as an alternative fuel in compression-ignition engines has been researched due to its renewable characteristics and lower emissions [1,2]. The adoption of these oxygenated biofuels has been proven effective for the reduction of soot emissions [1–6]. The oxygen content in biodiesel enables more complete combustion, especially in the rich diffusion flame, and promotes the oxidation of soot [2]. As the fuel-bound oxygen content increases, a larger fraction of fuel carbon is converted to carbon monoxide (CO) in the fuel-rich flames rather than soot precursors. Moreover, biodiesel lacks aromatics, eliminating a direct chemical pathway to the formation of polycyclic aromatic hydrocarbons (PAHs) leading to soot [2,7]; thus lower soot production is expected for biodiesel. In addition, the hollow internal structure of biodiesel soot, likely created by the fuel-bound oxygen, enables a higher oxidation rate compared to the soot generated from diesel [7]. In a more recent study, a blend of rapeseed derived FAME with diesel was shown to dramatically reduce soot generation in an optical engine [8].

With the obvious reductions in soot, it should be remarked that the use of biodiesel may slightly increase nitrogen oxides (NO_x) emissions. It is hypothesized that biodiesel combustion may present a higher flame temperature, leading to the increased NO_x emissions through the Zel'dovich mechanism [1,2]. However, this hypothesis has not been widely accepted. Open-air flame experiments have shown that biodiesel combustion has a very comparable flame temperature to the diesel flame [9], and simulation results actually show a slightly lower flame temperature for biodiesel [10]. Engine test and simulation results suggested that the biodiesel distillation temperature and fuel-bounded oxygen lead to near stoichiometric equivalence ratios in the rich premixed portion of the flame which ultimately contributes to the increased NO_x emission [11]. Another engine performance test using biodiesel (rapeseed methyl ester, RME) and diesel showed that under the similar percentages (by volume) of oxygen concentration, NO_x emissions for both fuels were reduced to similar values, but the smoke emissions were significantly lower for RME [12]. Tan et al. [13] studied regulated and unregulated emission from a light duty diesel engine with Jatropha biodiesel and diesel. Their results showed no obvious NO_x emission difference from the pure diesel

---

* Corresponding author.
E-mail address: tfang2@ncsu.edu (T. Fang).

0360-5442/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2013.05.063

fuel at low and medium engine loads, whereas the hydrocarbon emissions showed a continuous reduction with increasing biodiesel blend ratios. Due to the complexity of biodiesel feedstock, coupling of physical and chemical process and real engine cylinder geometry, a satisfactory explanation remains elusive.

In theory, the application of exhaust gas recirculation (EGR) can reduce the flame temperature such that soot and NO_x formation peninsula in the ϕ-T map can be avoided [14], but too much EGR might reduce the overall combustion and cycle efficiency due to incomplete combustion. It is found that soot formation occurs at about 1400 K and above, but the oxidation of soot particles ceases at about 1300 K and below [15,16]. The measured soot production is thus a result of the competition between these two processes. In the research of Kong et al. [17], detailed chemistry was applied to engine modeling and their results showed that both NO_x and soot could be reduced under high EGR levels. In another numerical study [18], a multi-zone combustion model was applied to a turbocharged heavy duty diesel engine at full load. Results revealed that the decrease of EGR gas temperature had a positive effect on brake specific fuel consumption (BSFC), soot (lower values) while it had only a small positive effect on NO_x. An experimental investigation also showed an effective reduction of NO_x even for diesel-biodiesel blends when combustion occurred in the low temperature regime [19]. A recent study indicates that EGR can enhance the soot reactivity by creating internal porous structure, which allows rapid internal burning during oxidation [20]. A further study demonstrated that the thermal, dilution and chemical effects of EGR account for 45%, 35% and 20%, respectively, of the total reactivity of soot respectively [21].

To reduce the flame temperature, cooled EGR is considered an effective strategy. It has been shown that soot formation could be minimized with high levels of EGR [22], but the overall combustion and cycle efficiency might be reduced. Maiboom et al. [23] investigated the EGR effect on a high-speed direct injection (HSDI) diesel engine. At low-load conditions, use of high EGR rates at constant boost pressure is a way to drastically reduce NO_x and particle matter emissions but with of the penalty of increased BSFC and other emissions (CO and hydrocarbon), whereas EGR at constant AFR may drastically reduce NO_x emissions without the penalty of higher BSFC and soot emissions but is limited by the turbocharging system. Zheng et al. [24] proposed an adaptive strategy: use single injection with heavy EGR at low load; use two to five shots of late-early injection for medium load; and use six to eight shots of early injection and EGR for high load. The efficiency using this strategy was shown to be close to that of conventional diesel combustion, but soot and NO_x were significantly reduced.

Recently, the EGR effect on soybean biodiesel and diesel has been studied in a constant-volume chamber [25]. The lowest oxygen concentration was 15%, while different ambient temperatures were investigated. Lower ambient temperature and lower oxygen concentration were shown to have different effects on the diesel and biodiesel combustion. Incomplete combustion is often cited as the reason for the reduced thermal efficiency with the addition of EGR. Pickett [26] investigated spray combustion under different oxygen concentrations in a constant-volume combustion chamber and showed that the combustion efficiency remained high when the ambient temperature was greater than 1000 K, even though the flame temperature was kept within 1500–1600 K using dilution. Soot formation under high EGR conditions with diesel was studied by Idicheria and Pickett [27]. Low temperature combustion was demonstrated and soot generation was found to first increase and then decrease as the ambient oxygen concentration decreased from 21% to 8%.

Based on this brief literature review, it is clear that a more thorough understanding of the effects of EGR on the fundamental processes of biodiesel spray combustion is still needed. In a previous paper, low temperature diesel combustion under low ambient temperatures was studied [28]. In this work, ultra-low sulfur diesel and biodiesel from the transesterification of waste cooking oil are studied. Five different ambient oxygen concentrations from 21% to 10% are used to simulate different EGR levels. A high-speed imaging technique is employed to study the transient combustion processes. A unique contour resolution of temporally and spatially resolved NL and OH* intensities is developed to understand the complicated combustion process. The possible mechanisms of ambient oxygen concentration effects on the fuel combustion, soot formation and oxidation are discussed. The different behaviors for biodiesel and diesel are studied under these reduced oxygen concentration conditions.

2. Experimental system

2.1. Constant-volume chamber

A constant-volume chamber was used to simulate diesel engine compression conditions in this work (Fig. 1). While more details are available in a recent publication [29], the system is briefly described here. The chamber was made of 4340 alloy steel with a volume of 0.95 L and six ports in the chamber: for this work five of the ports were fitted with metal plugs and one was fitted with a quartz window of 100 mm in diameter. A lean premixed gas mixture is burned in the chamber to generate a high-temperature, high-pressure environment that simulates typical diesel engine in-cylinder conditions during the compression stroke. The percentage of the component gas in the mixture is controlled by its partial pressure according to the ideal gas law. The oxygen is excessive such that the gas mixture after premixed combustion preserves a designed oxygen concentration for the subsequent fuel combustion. Three gases are charged into an accumulator in a sequence of C_2H_2, O_2/N_2, and air to assure proper mixing, and then pumped into the chamber. The ambient density was kept at 15.0 kg/m^3 in this study. The ignition system for the premixed combustion consisted of a spark plug and a plasma coil. Following spark ignition in a no-fuel-injection case, the chamber pressure was recorded by a pressure transducer and the temperature trace was determined by the ideal gas law. Then for a fuel-injection case, the fuel was injected when the desired ambient temperature was reached.

A common rail fuel injection system was used to deliver fuel at a given pressure. The rail pressure, rated at 1350 bar, was controlled

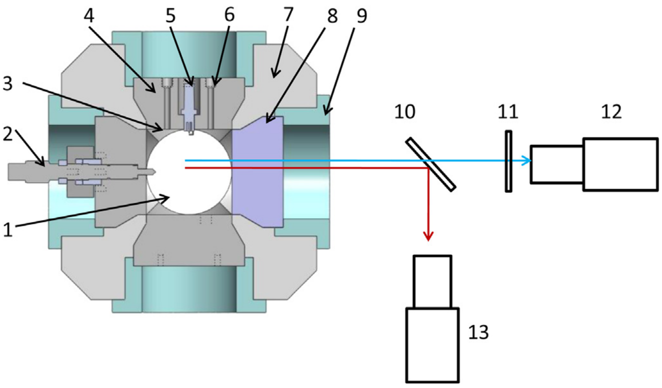

Fig. 1. Experimental system: 1. Combustion chamber; 2. Fuel injector; 3. Pressure transducer; 4. Metal plug; 5. Spark plug; 6. Intake/Exhaust lines; 7. Chamber body; 8. Quartz window; 9. Plug/Window retainer; 10. Low pass filter; 11. Band-pass filter (310 nm, 10 nm FWHW); 12. High-speed camera with intensifier; 13. High-speed camera.

Download English Version:

https://daneshyari.com/en/article/1733115

Download Persian Version:

https://daneshyari.com/article/1733115

Daneshyari.com