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Experimental investigation on the effect of n-pentanol blending on spray, ignition and combustion characteristics of waste cooking oil biodiesel

Yinjie Ma, Ronghua Huang *, Sheng Huang, Yu Zhang, Shijie Xu, Zhaowen Wang *

State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, Wuhan 430074, China

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ABSTRACT

Due to their excellent physicochemical properties, biodiesel and n-pentanol are regarded as two promising alternative biofuels for automobile. However, the fundamental data of spray and combustion characteristics of n-pentanol/biodiesel blends are still scarce. The objective of this work is to investigate the effects of n-pentanol addition to waste cooking oil (WCO) biodiesel in different ratios (0%, 20%, and 40% in volume) on spray, ignition and combustion characteristics in a constant volume combustion bomb (CVCB). Ignition and combustion tests were performed at five ambient temperatures (800, 900, 1000, 1100 and 1200 K) with three oxygen concentration (10%, 15% and 21%), and spray tests were conducted at the same temperature ranges but with no oxygen involved to prevent combustion happening. The result shows liquid length decreases with increase of ambient temperature, and the falling slope increases significantly with the blended n-pentanol concentration. The liquid length of B60P40 is about 6% longer than that of B100 at 800 K condition, while it becomes about 10% shorter than B100 when ambient temperature rises to 1200 K. Although the cetane number of n-pentanol is much less than biodiesel, an increase of n-pentanol ratio has a promoting effect on the ignition event under most conditions. Under these conditions, addition of 40% n-pentanol has cut the ignition delay of biodiesel, on average, by 30.2%. The natural flame luminosity is found to be reduced significantly with an increasing n-pentanol ratio, meaning that addition of n-pentanol could reduce the soot level under all conditions. For example, the time integrated natural luminosity (TINL) of B60P40 is only 41.2% of that of B100 under 1000 K temperature conditions. The result also suggests that, for multi-component fuels, flame lift-off length (FL) is the most reliable factor that influence the soot concentration level under spray combustion processes, rather than ignition delay or soot formation time. Overall, blending n-pentanol into biodiesel has a great soot oxidation potential and could maintain suitable ignition phase at the same time.

1. Introduction

As a high efficiency device for energy conversion, diesel engines have played an important role in modern transportation, power generation and agriculture systems for more than a century. However, increasingly stringent emission regulations and concerns over energy security nowadays have put forward higher request on diesel engines. Developing and applying renewable clean alternative fuel for engines is an effective solution to reduce the dependence on conventional fossil fuels and to alleviate negative impacts of emissions on environmental and human health [1]. Among the reported alternative fuels, biodiesel and alcohols are the most potential ones for the commercial-scale application [2].

Biodiesel is a renewable and eco-friendly biofuel, which transformed from various feedstocks such as plant seeds, microalgae, biological oil and fat [3]. Compared with fossil diesel, biodiesel has similar cetane number and better lubricity. In addition, its desirable chemical characteristics, such as being non-toxic, biodegradable, and carbon neutral [4], which make it quite suitable for diesel engines. Previous investigations [5–7] have reported addition of biodiesel could achieve substantial reduction of unburned hydrocarbon (UHC), particulate matter (PM) and carbon monoxide (CO). However, the poor volatility and high viscosity of biodiesel may cause a series of combustion mechanical problems, such as a poor atomization and incomplete combustion, carbon deposits and the blocking of oil-ways. These drawbacks have

* Corresponding authors.
E-mail addresses: rhhuang@hust.edu.cn (R. Huang), wangzhaowen@hust.edu.cn (Z. Wang).

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Nomenclature

ASOI	after the start of injection
CVCB	constant volume combustion bomb
DBI	diffused back-illumination
FL	flame lift-off length
GC-MS	Gas Chromatography-Mass Spectrometer
ND	neutral density filter
PM	particulate matter
POI	place of interest
SOI	start of injection
SINL	spatial integrated natural luminosity
TINL	time integrated natural luminosity
UHC	unburned hydrocarbon
WCO	waste cooking oil

restricted the pure application of biodiesel and the use of high percentage of biodiesel in diesel blends. Recently, researchers showed great interest in the application investigation of alcohol-biodiesel-diesel and even alcohol-biodiesel multi-component mixed fuel in diesel engines to reduce the concentration of fossil fuel. Short-chain alcohols, such as methanol [8,9] and ethanol [10,11] from renewable sources, have been investigated widely as an additive of biodiesel or diesel due to their more mature production technology. Their high volatility, low viscosity and high oxygen content also could improve fuel spray combustion characteristics and bring down emissions [12]. However, some disadvantages, such as high latent heat of vaporization, low cetane number and low heating value, prevent their large percentage of the application as fuel in diesel engines. In addition, the problem about phase separation would lead to a low engine performance and high emissions at low temperatures when short-chain alcohols were blended with diesel [13].

In order to solve such problems, more attentions have been paid to use high-chain bio-alcohols, such as butanol and n-pentanol, as main alternative fuels in diesel engines [14,15]. Compared with short-chain alcohols, high-chain alcohols have many advantages over short-chain ones, such as higher cetane number and calorific value, lower latent heat of evaporation [16]. Moreover, high-chain alcohols present better blend stability and could be injected directly to combustion chamber blending with diesel or biodiesel at any ratios [13]. Among these alcohols, n-pentanol is regarded as the most potential next-generation alternative biofuel with its excellent physicochemical property. Li et al. [17] investigated the combustion characteristic of diesel/biodiesel/pentanol ternary blends with compression ignition mode. The concentration of biodiesel and n-pentanol both reach 30%, and the result presents low emissions while maintaining higher indicated thermal efficiency. Zhu et al. [18] studied the effect of blending different ratios of n-pentanol (up to 30%) in biodiesel on particulate emission, showing reduction in PM emissions. Imdadul et al. [14] and Yilmaz et al. [19] respectively reported adding 20% n-pentanol to diesel–biodiesel blends would cause a significant impact on the increase of NOx emissions. Zhang et al. [20] studied the particulate emission characteristics of 20% n-pentanol blended with biodiesel, showing an reduction in polycyclic aromatic hydrocarbons. Imdadul et al. [21] compared the diesel engine performance and exhaust emission which respectively fueled by butanol and n-pentanol added diesel–biodiesel blends, and n-pentanol had showed better overall performance and emission than butanol.

However, compared with the abundant investigations that focused on engine performance and pollutant emissions, a few works were conducted to investigate the effect of blending long-chain alcohols on the spray combustion characteristics of diesel or biodiesel spray in engine-like conditions. Liu et al. [22] investigated fuel spray and combustion characteristics of 0%, 5% and 10% n-butanol blended with biodiesel-diesel fuels. Results showed that n-butanol additive with 5% or 10% has limited effect on the auto-ignition timing but can reduce soot emissions at the near-wall regions. Liu et al. [23] studied the soot concentration in flame of n-butanol/diesel blend and biodiesel in a constant volume chamber. They found the soot mass for n-butanol/diesel blend is 20–30% lower than that of biodiesel under wide conditions though the oxygen content of both fuels is nearly the same. Mo et al. [24] investigate the spray characteristics of soybean biodiesel with butanol blending, showing butanol addition leaded to smaller sauter mean diameter. Wu et al. [25] found addition of acetone–butanol–ethanol (ABE) could improve diesel spray performance and reduce soot formation, and suggested 50% ABE and diesel blend fuel can maintain diesel combustion characteristics. As for C5 alcohol n-pentanol, the effect of blending n-pentanol (up to 40%) on the spray and combustion processes of diesel have been examined recently [26,27]. It was found that addition of n-pentanol provided an obvious improvement on spray characteristic and soot inhibition, but also suggested there was an unexpected increase of soot level under intermediate temperature region for n-pentanol blends. Unfortunately, to the best of the authors' knowledge, there is still lack of the information focused on the spray and combustion characteristics of n-pentanol and biodiesel blend fuels.

It is well known that spray combustion characteristics have an important effect on the engine performance and pollutant emissions. Moreover, the detailed foundation experimental data about alternative fuels spray and combustion processes are also essential for the development and validation of the corresponding chemical kinetics mechanism, which would improve the accuracy of simulation predictions and gain more insight in engine combustion processes [28]. Considering that biodiesel has widely future application as an alternative fuel and its quite different physical and chemical properties, it is worthwhile to understand how the long-chain alcohol n-pentanol influences the spray, ignition and combustion processes of biodiesel.

In order to fill the proposed gap, a series of experiments were carried out in the present study, which focused on spray, ignition and combustion characteristics of long-chain alcohol n-pentanol/biodiesel blends. 0%, 20% and 40% (by volume) n-pentanol was blended with WCO biodiesel to create B100, B80P20 and B60P40 test fuels respectively. These blends were tested in a constant volume chamber, which was used to simulate the in-cylinder condition prior to injection in a real diesel engine. A wide range of experimental conditions, which including various ambient temperature ranged from 800 K to 1200 K and oxygen concentration ranged from 10% to 21%, enough represented the in-cylinder conditions of engines with both traditional and advanced technology (like exhaust gas recirculation). With the aid of various optical imaging diagnostics, the detailed information were systematically analyzed for these blends, such as liquid length, ignition time, flame luminosity and flame lift-off length. The obtained results would expand the understanding of the influence mechanism of