



Combustion characteristics of multi-component cedar bio-oil/kerosene droplet



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ABSTRACT

The present study examined the chemical kinetic and combustion characteristics of multicomponent bio-droplets. Specifically, spark ignition was employed to examine the combustion characteristics of kerosene/aqueous phase bio-oil and kerosene/oily phase bio-oil droplets by using thermogravimetric analysis and gas chromatography-mass spectrometry. The experimental groups involved mixing kerosene with 5 wt% or 10 wt% of aqueous-phase or oily-phase bio-oil, and the same amount of energy was adopted to ignite the droplets and observe their combustion behaviors and combustion rates. The experimental results showed that the droplet diameter of the KER group (pure kerosene) decreased according to the d^2 -law, whereas that of the KBO05 group (5 wt% oily-phase bio-oil/95 wt% kerosene) varied inconsistently. In addition, the droplet diameter of the KBO10 group (10 wt% oily-phase bio-oil/90 wt% kerosene) changed drastically, exhibiting notable expansion, shrinkage, and puffing behaviors during the combustion process. The TGA results revealed that the primary mass loss in the fuel substances occurred during the rapid evaporation. Applying the bio-oil as an additive facilitated generating substances that were slightly decomposable, thus inducing polymerization reactions and forming residues. The content of the residues increased with increasing amount of heavy fractions in the bio-oil. Consequently, the activation energy during the combustion stage increased.

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1. Introduction

Alternative fuels are prevalently used in internal-combustion engines, and application techniques associated with bio-diesels are commercially available. However, bio-diesels are converted from edible food, thus raising concerns regarding competition between such biofuels and food sources. Nonedible biomass can be rapidly pyrolyzed to convert fiber, hemicellulose, and lignin to bio-oils [1], and various condensation temperatures can be applied to process such oils into oily-phase and aqueous-phase bio-oils, which can be mixed with diesel fuels and then applied to diesel engines [2]. However, because a bio-oil exhibits a low heating value and specific composition, blended fuels that contain bio-oil and diesel oil decrease the efficiency of diesel engines and generate slag in the nozzles and combustion chambers of such engines [3]. Therefore, our group of the present study adopted experimental and numerical methods to investigate the spray ignition behaviors and oxygen-rich spray ignition behaviors of kerosene and bio-oil [4–6].

The spray ignition characteristics of oil can be examined through the combustion behaviors of oil droplets. Accordingly, various scholars have investigated the evaporation and combustion of a single droplet of a liquid fuel [7–10]. The combustion of multi-component droplets is another complex research topic. Such a droplet is composed of two or more types of liquid. Dissimilar liquid fuels exhibit distinct physical and chemical properties, such as volatility, boiling point, latent heat of vaporization, specific heat capacity, and thermal conductivity [11–13]. During the combustion and evaporation of a multicomponent droplet, factors such as phase equilibrium and coating of the droplet by gas-phase fuel compounds alter the combustion characteristics of the droplet (e.g., combustion rate, flame structure, and soot formation). Consequently, the d^2 -law, which is used to describe the combustion of single-component droplets, is inapplicable to multicomponent droplets. In addition, the combustion characteristics of multicomponent droplets are also affected by heating temperature increment and instantaneous heating time [14]. Kitano et al. [15] employed numerical simulation to examine Jet-A fuel mixed with three fossil fuels of distinct compositions, namely (a) n-decane, (b) n-decane and 1,2,4-trimethyl-benzene, and (c) n-dodecane,

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iso-octane, and toluene. The results revealed that of these three fossil fuels, mixing Jet-A fuel with the blended fossil fuel of n-dodecane, iso-octane, and toluene attained the highest evaporation rate and lowest evaporation temperature. Generally, the fuel components of a multicomponent droplet extend the retention time of the droplet in a boiler or furnace to facilitate oxidation reactions [16]. Numerous studies have investigated the combustion characteristics of bio-oil droplets. For example, Hallett and Clark [17] adopted a numerical method to establish an evaporation model for a single drop of a bio pyrolysis oil, which was composed of four components, namely organic acids, aldehydes/ketone, water, and pyrolytic lignin. This model enabled estimating the lifetime of a suspended degraded-biomass droplet. Hallett and Beauchamp-Kiss [18] also established an evaporation model for pure and denatured ethanol droplets, and activity coefficients were used to describe the behaviors of nonideal phase equilibrium. Previous studies have also asserted that the thermal conductivity of a bio-droplet is highly correlated with its evaporation rate [19] and the composition of its volatile substances [20–22].

Because of its complex composition, a multicomponent bio-droplet features multiple combustion stages. Wardana [23] conducted a combustion experiment on a *Jatropha* oil droplet and determined that it exhibited two combustion stages. The first and second stages involved the combustions of fatty acids and glycerol, respectively. Micro-explosions occurred before the second combustion stage, and the frequency of the micro-explosions increased with increasing temperature [24]. In addition, various sooting mechanisms were generated as the temperature increased [25–27]. Dissimilar ignition methods exert distinct effects on droplet combustion. A heating wire can be used to continuously increase the temperature of a droplet. A spark ignition method utilizes equilibrium thermal plasma discharge to convert ionized to even, cylindrical electrodes with 2000 K of spark temperature [28,29]. According to the aforementioned assertions, the spray combustion behaviors of a bio-oil are related to the combustion

characteristics of its single droplet. Because multicomponent droplets exhibit various evaporation stages under high temperature, applying bio-oils to power machinery can induce engine knock. In addition, multicomponent bio-droplets feature complex evaporation and combustion behaviors. Therefore, this study examined the combustion and chemical kinetic characteristics of multicomponent bio-oil droplets. Specifically, cedar wood was rapidly decomposed to produce an aqueous-phase bio-oil and oily-phase bio-oil, which were then mixed with kerosene to prepare multicomponent droplets. Analyses such as droplet diameter measurement and thermogravimetric analysis were conducted to discuss the chemical kinetic characteristics of the multicomponent bio-oil droplets with dissimilar compositions, thereby clarifying the application of bio-oils to power machinery.

2. Experimental methods

In this study, a suspended single-droplet combustion system was adopted to examine the combustion characteristics of multicomponent droplets. As shown in Fig. 1, the system incorporates a droplet generator, combustion chamber, electronic ignitor, and image capturing device. The droplet generator involves an ink-jet printing scheme. Specifically, when the direct-current pulse released from the digital delay generator initiates and deforms the piezoelectric wafer, a droplet of the oil stored in the droplet generator is squeezed out. Next, the droplet is fixated onto the 90° intersection of two 0.012 mm long ceramic fiber strands. The droplet diameter is approximately 0.6 mm. The size of the combustion chamber is 70, 60, and 80 mm in length, width, and height, respectively. The chamber is isolated with glass to exclude ambient air, thus preventing the droplet combustion from being affected by external air flows. The electronic ignitor includes two 1 mm long electrodes that are 4 mm apart from each other. The digital delay generator and electronic control are used to manage the amount of spark discharge. A constant ignition energy of 84 mJ was employed

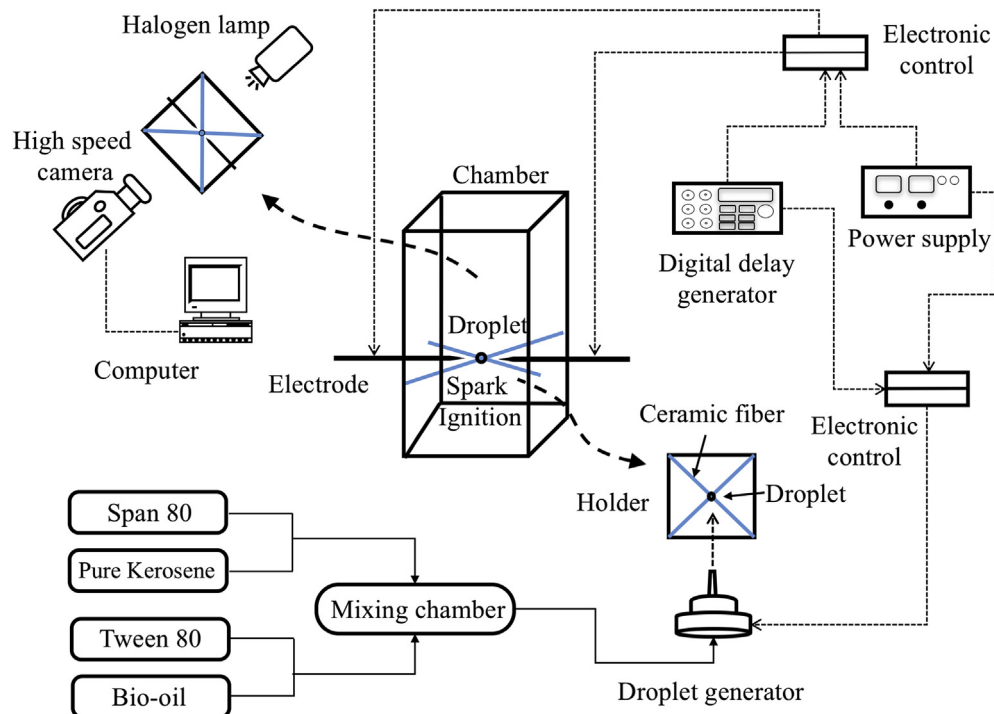


Fig. 1. Experimental setup.

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