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Ignition and combustion characteristics of various biodiesel fuels (BDFs)

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HIGHLIGHTS

- Ignition and combustion characteristics strongly depend on the properties of fuel.
- We examine ignition delays under different ambient pressure conditions.
- Lower viscosity fuel CME indicated the faster evaporation and ignited well.
- Significant longer ignition delay was found under lower ambient pressure condition.

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ABSTRACT

The fundamental data of ignition and combustion characteristics of various biodiesel fuels (BDFs) are exhibited for finding the optimal condition in diesel engines. The experimental research has been conducted in a constant-volume vessel with the pre-burn system under diesel-engine conditions. The ignition delays and heat release rates were investigated under different ambient temperatures and pressures. This study used diesel oil and various BDFs such as jatropha methyl ester (JME), coconut methyl ester (CME), soybean methyl ester (SME) and palm methyl ester (PME). The experimental results on fuel-spray development and combustion characteristics were affected by the properties of biodiesel fuels (BDFs), which may support potentially the optimal design of diesel engine fueled with BDFs. Evaporation and mixing are promoted at the tip of fuel jet with lower distillation temperature and lower viscosity, resulting in a shorter length dense region in the spray. These properties may disturb the mixture formation of BDFs at spray tip although the penetration lengths are almost same. The ambient temperature (T_i) and ambient pressure (p_i) strongly influenced the ignition and combustion processes of BDF and diesel oil. Though ignition delays of all BDFs are shorter than that of diesel oil in the whole temperature range from 600 K to 1200 K, CME exhibits the significant shortest delay, suggesting a dominant effect of physical properties of mixing process. At the ambient temperature 800 K and 4 MPa, all of BDFs and diesel oil predict the similar histories of heat release rate. The pre-mixture combustion with longer ignition delay dominates the combustion process at 700 K, but its period is almost constant irrespective of BDF. Ignition delay becomes longer than the injection period for high density and viscosity tested fuels, resulting in a very slow combustion.

1. Introduction

Diesel from petroleum is the main energy source for internal combustion engines. Biodiesel has been considered to be an alternative fuel to diesel in order to reduce the use of petroleum fuels. Researchers have tried to use vegetable oils to produce biodiesel fuel (BDF). BDF offers a lot of advantages such as it is renewable, biodegradable and carbon neutral [1,2]. Soybean oil is one of the

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popular vegetable oils in United States, whereas, some others are found in Asian countries such as palm oil in Malaysia and coconut oil in the Philippines. The used cooking oils from general households, restaurants, and cafeterias have been collected and extensively used to produce biodiesel in Japan [3]. The use of biodiesel fuel (BDF) has many advantages like the regular diesel that are mostly used for transportation and power generation [4]. Biodiesel is composed of alkyl esters of fatty acids produced from vegetable oils, animal fats and used cooking oil. It can be produced by the transesterification process [5–11]. The direct use of vegetable oil and its blend in diesel engine has caused many difficult situations because of high viscosity and high phosphorus content. The transesterification reaction can successfully convert the straight vegetable oils into vegetable oil esters called Fatty Acid Methyl Esters (FAME) or biodiesel fuel (BDF). Biodiesel fuels (BDFs) have been directly used in the conventional diesel engine without modification [8–13]. Many researchers have started to develop the methods to investigate diesel combustion mechanisms in order to provide information to engine manufacturers. Diesel engines primarily operate on the principle of compression ignition.

The combustion phenomenon is generally composed of two combustion phases namely a premixed phase and a diffusion phase. The emission of diesel engine related with combustion processes of BDF has been described to have lower emissions of smoke, particulate matter (PM), carbon monoxide (CO) and hydrocarbon (HC) as compared using diesel oil, while the engine performance is almost unchanged or improved [14–17]. The targets of numerous researchers are extensively using BDFs to reduce CO_2 emission and the pollutant emissions to the environment and also to overcome the problem of NO_x emission [2–10,13–18]. However, very few researches have the fundamental data of ignition and combustion characteristics of BDF which are strongly affected by the properties of fuel. In particular, ignition delay and heat release rate are the important fundamental parameters in the investigation of the ignition and combustion characteristics in compression–ignition engines. Shahabuddin et al. [14] investigated the combustion characteristics of biodiesel based on the different varying conditions such as fuel injection timing, injection pressure, engine loads and compression ratio. The results showed that the potential of shorter ignition delay and lower heat-release rate is obtained by using higher cetane number and lower volatile fuels. The higher cetane number fuels generally depicted the shorter ignition delay and better fuel–air mixing [18]. Biodiesel intends to give better ignition quality though it has slightly lower cetane number than diesel oil. On the other hand, the high injection pressure and small nozzle-hole size provide smaller fuel droplets and faster fuel evaporation in the spray combustion process of liquid fuel, which corresponds to optimize the engine design [18,19]. The present study demonstrates the fuel spray development that is related with the ignition and combustion characteristics. The lower distillation temperature fuels exhibited the faster evaporation and easily mixed with air in the chamber [18]. The high speed fuel spray can capture both of the fuel combustion processes and the fuel injection system which are the important parts of fuel spray combustion. Combined with spray evaporation, the temporal evolution of the autoignition process determine the duration of the ignition delay.

The main purpose of this work is to exhibit the fundamental data of ignition and combustion characteristics of various BDFs and then simultaneously compare with the standard diesel oil data. This study investigated the ignition and combustion data of various biodiesel fuels (BDFs) by using constant-volume vessel at different temperature and pressure condition. Two types of conditions are considered depending on the properties of fuels. The base condition in the chamber is set at ambient pressure of 4 MPa and ambient temperature of 750 K, whereas the pressure is reduced to 2 MPa in the final condition. The high-speed shadowgraph photos were applied to analyze the spray penetration and flame development during the combustion phenomena of these fuels. Based on the results, the authors have investigated the mechanism of ignition and combustion for these fuels to emphasize on the formation of fuel–air mixture and heat release rate.

2. Experimental setup

The injection system of pressure-storage type is setup to inject BDF into the combustion chamber as shown in Fig. 1. A common rail system has been applied to introduce BDF to the combustion chamber [18,20]. A modified version of common-rail injection system of Denso was used to operate and manage the injected fuel in this work. The fuel was injected at pressure of 80 MPa. A piezoelectric pressure-transducer (Kistler 6052A) was used to trace the pressure in the constant-volume combustion chamber and this enable us to determine the ignition delay. Pressure pick-up was connected to a charge-amp and an A/D converter and they were channeled to a computer for recording all experimental data. Fuel-spray penetration and flame developments were visualized and recorded with high-speed shadowgraph using digital camera with a speed of 10,000 fps.

2.1. Constant-volume vessel

The combustion characteristics of fuels are investigated using the pre-burn system with a constant-volume combustion vessel. An intake and exhaust valve, an injector, a spark plug, a stirrer and a pressure transducer are the important parts in this constant-volume vessel for diesel engine combustion conditions. A circular combustion chamber with volume approximately 150 cm^3 has a dimension of 80 mm in diameter and 30 mm in depth. The quartz windows are equipped in this chamber to facilitate full optical access. The initial combustible premixed gases are charged and manually adjusted by the intake valve while an exhaust valve is mounted to eliminate the exhaust gases. A conventional spark ignition system is used to burn the premixed gas, meanwhile the temperature distribution before fuel injection is controlled by the stirrer which is kept constant over 8000 rpm. At the top of the vessel, there is a single shot injector which is 0.22 mm in diameter to inject the fuel. Like diesel-engine combustion, this chamber has been used to produce a high temperature and high pressure condition [18].

2.2. Optical diagnostics

The technique of shadowgraph is used to visualize the liquid spray penetration and development of flame. Shadowgraph is

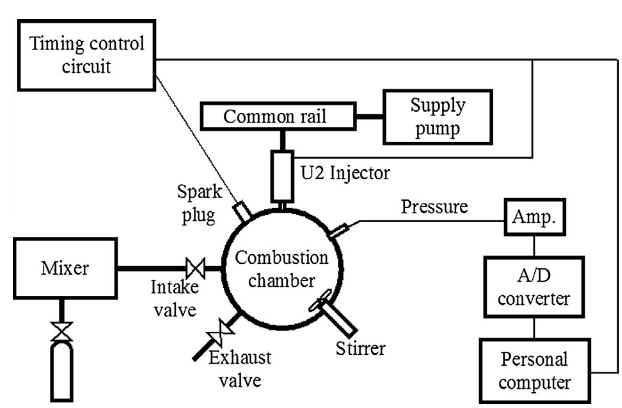

Fig. 1. Schematic diagram of experimental setup.