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Effects of injection pressure on ignition and combustion characteristics of impinging diesel spray

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HIGHLIGHTS

- Ignition delay of an impinging spray flame is longer at higher injection pressures.
- The ignition location is in the air at low injection pressures.
- The ignition location is on the wall surface at high injection pressures.
- Combustion duration and TINL are shortened with increased injection pressure.
- The variation rates of AF and SINL are faster at higher injection pressures.

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ABSTRACT

The constant injection mass is a criterion for measuring the thermal efficiency of diesel engines. In this study, the effects of the injection pressure on the ignition and combustion characteristics of an impinging diesel spray are investigated for a constant injection mass. Experiments are performed in a constant volume combustion chamber including a high-pressure common-rail injector with a single-hole nozzle. A high-speed camera is used to capture the ignition and combustion behavior. Variation laws for the ignition delay, ignition location, combustion duration, flame area, spatially integrated natural luminosity, and time integrated natural luminosity are obtained by analyzing the images captured in these experiments.

1. Introduction

The phenomenon of spray-wall impingement can seriously affect in-cylinder combustion processes. It increases the amount of fuel deposited on the piston head, which leads to a longer combustion duration, and thus higher hydrocarbon (HC), carbon monoxide (CO), and soot emissions [1,2]. In high-pressure direct-injection diesel engines with a small bore, the spray-wall impingement phenomenon is inevitable owing to the limit of the combustion chamber geometry and the distance between the injector and piston [3]. The spray-wall impingement phenomenon is more likely to occur in cold-start processes. The decrease in ambient temperature causes an increase in the liquid penetration length [4,5]. Many studies on impinging spray have been performed in the past few years. The injection pressure is one of the most important injection parameters, and it exerts a significant influence on the fuel evaporation, mixture formation, combustion process, and emissions [6,7]. On one hand, increasing the injection pressure increases the penetration rate and the possibility of spray-wall impingement. On the other hand, increasing the injection pressure is an effective way to improve economic performance, enhance combustion efficiency, and achieve lower emissions by decreasing soot formation in diesel engines [8,9]. Therefore, it is vitally important to investigate the ignition and combustion characteristics of impinging diesel spray at different injection pressures, as this is beneficial for improving engine performance and reducing emissions.

Many studies have investigated ignition and combustion characteristics under different injection pressures. Liu et al. investigated the effects of injection pressure on the ignition characteristics of a diesel jet under cold-start conditions. They found that the injection pressure does not significantly affect the ignition delay or flame lift-off length, but a higher pressure can result in a lower ignition success rate due to over-mixing of the air and fuel [10]. Yao et al. conducted experiments on the ignition and combustion characteristics of diesel in an air atmosphere, and determined that with increasing injection pressure, the flame lift-off length increases, while the ignition delay and combustion duration are shortened. In addition, the moments at which the maximum combustion pressure occurs and the apparent heat release rate starts to rise are advanced. Both the spatially integrated natural luminosity (SINL)

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and time integrated natural luminosity (TINL) are significantly reduced [11]. Agarwal et al. experimentally analyzed the effects of varying fuel injection pressures (500 and 1000 bar) on engine combustion and performance in a single cylinder research engine, and their results indicate that the cylinder pressure and heat release rate are higher at lower injection pressures. The engine performance is improved at low injection pressures, leading to lower brake specific fuel consumption (BSFC) and higher brake thermal efficiency (BTE) at all engine loads [12]. Jain et al. investigated the combustion, performance, and emission characteristics of a partially premixed charge compression ignition (PCCI) engine by varying the fuel injection pressure (FIP) from 400 to 1000 bar. They reported that PCCI combustion improves with increasing FIP (up to 700 bar) as a result of improved fuel atomization. However, further increasing the FIP deteriorates the combustion and engine performance as a result of intense knocking. Thus, the most suitable FIP is a medium FIP (700 bar) [13]. Pandian et al. investigated the effects of injection pressure on the performance and emission characteristics of a twin cylinder compression ignition direct injection engine, and concluded that increasing the injection pressure results in improved BTE; lower BSFC; reduced CO, HC, and smoke emissions; and higher NOx. However, if the injection pressure is too high, the results are negated [14]. Wang et al. investigated the effects of ultra-high injection pressure (300 MPa) on the flame structure and soot formation of an impinging diesel spray. Their results demonstrate that ultra-high injection pressures generate appreciably larger flame structures and lower soot levels [15]. Gao et al. investigated the flame structure of wall-impinging diesel sprays injected with group-hole nozzles in a constant-volume combustion vessel. They observed that the ignition delay for the impinging spray flame is shortened with increasing injection pressure owing to improved spray atomization and an enhanced fuel-air mixing rate [16]. Kannan et al. studied the effects of metal-based additives on the performance, emissions, and combustion characteristics of a diesel engine fueled by biodiesel. They noted that the observed reduction in BSFC and improvement in BTE is due to the proper mixing of fuel and air at higher injection pressures. Furthermore, advancing fuel injection results in better combustion [17]. Kegl investigated the influence of biodiesel on engine combustion characteristics, and determined that the higher injection pressure results in lower smoke and CO emissions, but in slightly higher HC emissions [18]. Agarwal et al. investigated the effect of varying fuel injection pressures on the particulate size distribution and spray characteristics. They reported that higher fuel injection pressures result in longer spray tip penetration and a larger spray area. The number of larger size particulates in the exhaust and the average particulate size decreased with increasing injection pressure as a result of improved air–fuel mixing [19]. Payri et al. carried out measurements of the ignition delay and lift-off length in a constant-pressure flow facility. They found that increasing the injection pressure reduces ignition delay and increases lift-off length [20]. Han et al. studied the effects of the air–fuel mixing quality on combustion characteristics, and observed that a higher injection pressure reduces CO, HC, and soot emissions [21].

As reviewed above, most previous studies have focused on the combustion characteristics of the injection process and a comparison at the same time. However, the effect of the injection pressure on the ignition and combustion characteristics of an impinging diesel spray with a constant injection mass have not been investigated. The condition of a constant injection mass is a criterion for measuring the thermal efficiency of a diesel engine. The injection duration also differs for different injection pressures under a constant injection mass, which can have different effects on the ignition and combustion characteristics. Therefore, this study focuses on the effects of injection pressure at a constant injection mass on the ignition and combustion characteristics after wall impingement through the whole combustion process. The experiments in this study were performed in a constant-volume combustion chamber. Flame images were first captured with a high-speed camera, and then processed using the self-encode procedure in MATLAB software. These images were used to determine and analyze variation laws for the ignition delay, ignition location, combustion duration, flame area (AF), spatially integrated natural luminosity (SINL), and time integrated natural luminosity (TINL).

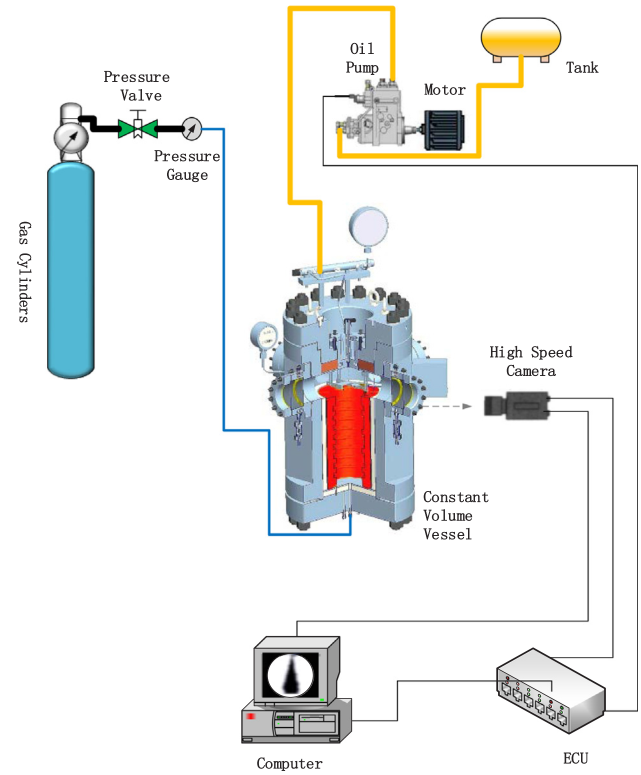

Fig. 1. General experimental layout.

2. Experimental setup

As shown in Fig. 1, the experimental setup includes a fuel injection system, constant-volume combustion chamber, wall impingement facility, and optical imaging system.

2.1. Fuel injection system

The fuel injection system consists of a high-pressure oil pump, a conventional rail with a pressure regulator, and an injector installed in a single-hole nozzle (0.18 mm diameter). The pump allows for a maximum injection pressure of 175 MPa. The injection pressure in the common rail is established by the high-pressure oil pump, which is driven by a variable-frequency motor. A Kistler pressure transducer is fixed inside the common rail to measure the injection pressure. The injector in this system could be opened with a pressure of 35 MPa. A single-hole axis nozzle is employed to avoid interference between the chamber walls and spray-spray interaction. All parts of the injection system are electronically controlled by a Kibox unit controller and corresponding control software.

2.2. High-pressure and high-temperature test rig

To mimic the in-cylinder thermodynamic conditions of a direct injection diesel engine, a constant-volume combustion chamber is used in these experiments. The test rig has three components: a constant-volume combustion chamber, gas intake and exhaust system, and a temperature control system. The test chamber section allows for a maximum ambient temperature of 1000 K and a maximum ambient pressure of 6 MPa. Four large windows (100 mm diameter) are located