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Fuel temperature influence on spray and combustion characteristics in a constant volume combustion chamber (CVCC) under simulated engine operating conditions

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HIGHLIGHTS

- Cold diesel fuel exhibited deteriorated vaporization characteristics.
- Flame luminosity with cold diesel fuel was lower than warm diesel fuel.
- Cold diesel fuel showed lower in-chamber pressure and longer ignition delay.
- Ambient condition had more dominant effect than fuel temperature on combustion.

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ABSTRACT

High amount of unburned hydrocarbon emission and combustion instability are serious problems in diesel engines during cold starting. In order to solve these troubles, the effects of fuel temperature on spray and combustion should be understood. In this study, macroscopic spray and combustion experiments were carried out over a wide range of fuel temperatures from 243 to 313 K. The tests were performed under simulated low temperature cold start condition. In-chamber pressure analysis and high speed imaging were combined in a constant-volume combustion chamber (CVCC). The diesel fuel was injected into the CVCC under simulated engine operating conditions with an injection pressure of 35 MPa. The cold diesel fuel showed a longer liquid penetration length and a narrower spray angle in macroscopic spray imaging. The reasons for the deteriorated spray characteristics were revealed to be the attenuation of the fuel evaporation and ambient air entrainment. In combustion imaging, partial misfires of the diesel spray were detected under cold start condition. On the other hand, all of spray plumes were successfully ignited under hot start condition. The peaks of in-chamber pressure and flame luminosity were decreased with cold fuel because of the poor air–fuel mixture preparation during the ignition delay period.

1. Introduction

Although many technical improvements have been made to diesel engines, a serious problem still remains for starting at low ambient temperatures. In cold conditions, the low ambient air temperature results in a low peak compression temperature. The cylinder head and the engine block absorb most of the heat during the compression stroke, so the peak pressure also decreases [1]. In addition to the thermal conditions of the engine, the deterioration of fuel properties affects the mixture preparation during ignition delay period. Such conditions cause misfires with a high amount of hydrocarbon (HC), carbon monoxide (CO) and smoke emissions by poor air fuel mixing process [2]. However, in this situation, the cold start problem is getting worse because current emission regulations force the compression ratio of diesel engines to be further reduced [3–6]. To improve the cold startability, air temperature within the combustion chamber should be raised by using ignition aids, such as intake heaters or glow plugs [7,8]. Current automobile diesel engines require these aids for the ambient temperatures below 262 K [9].

With respect to the cold startability, most researches have focused on improving ignition by using various combustion strategies, such as applications of high pressure injection, multiple

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Nomenclature and Abbreviations

d_o	nozzle hole diameter (m)	V	mean injection flow velocity (m/s)
I	intensity of a pixel	x	axial distance from the orifice (m)
$\dot{m}_a$	entrained gas mass flow rate (kg/s)	μ	the dynamic viscosity (kg/m s)
$\dot{m}_f$	injected fuel mass flow rate (kg/s)	τ_{yx}	shear stress in the fluid (N/m^2)
N	pixel number	θ	spreading angle of the spray (Radian)
$P_{w\ fuel\ spray}$	chamber pressure with fuel spray (MPa)	bTDC	before top dead center
$P_{w/o\ fuel\ spray}$	chamber pressure without fuel spray (MPa)	CAD	crank angle degree
Re	Reynolds number	CO	carbon monoxide
ρ_{amb}	ambient density (kg/m^3)	CVCC	constant-volume combustion chamber
ρ_{fuel}	fuel density (kg/m^3)	HC	hydrocarbon
T_{amb}	ambient temperature (K)	LOL	flame lift of length
T_f	fuel temperature (K)	NO_x	nitrogen oxides
u_{eff}	effective velocity at the exit of the orifice (m/s)	PM	particulate matters
$\frac{du}{dy}$	the derivative of the velocity (1/s)		

injection and exhaust gas recirculation (EGR). Chartier et al. studied the effect of injection strategies on the cold start performance in an optical direct injection diesel engine at a very low ambient temperature down to 244 K [10]. They found that fuel evaporation was limited at a low temperature but the engine performance could be improved by using three pilot injections. Zhong et al. also investigated the impact of split injection on cold startability in a diesel engine [11]. In this research, 4-cylinder diesel engine was tested under ambient temperature of 273 K, 264 K and 254 K. The combustion and emission characteristics were compared between single and multiple injection cases. From the result, it was confirmed that split-main injection strategies could improve the cold startability by shortened cranking period and lowered engine speed overshoot. At the same time it reduced the injected fuel mass and unburned HC emissions by almost 50% during the cranking period. In terms of the spray experiments, Payri et al. examined internal nozzle flow and the macroscopic spray characteristics according to the temperature of the fuel [12]. They showed that the Reynolds number decreased as a result of the increased viscosity of the cold fuel. This flow characteristic resulted in poor atomization with a narrower spray angle and a shorter vapor penetration length. Research on the spray characteristics of the biodiesel fuel according to various fuel and ambient temperatures were conducted in a constant volume chamber [13]. The results indicated that the evaporation of the fuel was suppressed as the fuel temperature decreased from 360 to 300 K. These are presented in lengthened liquid penetration and a decreased vapor fuel mass.

In spite of these efforts, a comprehensive understanding of the spray and combustion characteristics of diesel fuel under various fuel temperature conditions has not yet been carried out. Most previous studies have concentrated on the engine performance and emission characteristics according to the atmospheric conditions. Therefore, this study presents visualizations of the macroscopic spray and combustion under wide range of fuel temperatures in a constant volume combustion chamber. In contrast with previous researches, the experiments were performed not only with different diesel fuel temperature but also under simulated engine operating conditions. To simulate cold and hot engine start conditions, different pre-ignition processes were carried out by adjusting reactant mixture. The diesel fuel was injected using a common-rail system with a temperature range from 243 to 313 K. The in-chamber pressure analyses, including a rise in pressure and the derivative of the in-chamber pressure were performed with high speed imaging.

2. Experimental setup and condition

2.1. Experimental equipment and test procedure

Fig. 1 shows a schematic diagram of the fuel injection system. The fuel tank was designed to control the fuel temperature within the range from 243 to 333 K by operating a refrigeration cycle and an electric heater. The coolant was circulated through cooling fins which are installed inside the fuel tank. On the other hand, the fuel temperature was also possible to be increased by electric heater which is located around the fuel tank. The precise fuel temperature control within ±0.1 K was available by proportional integral

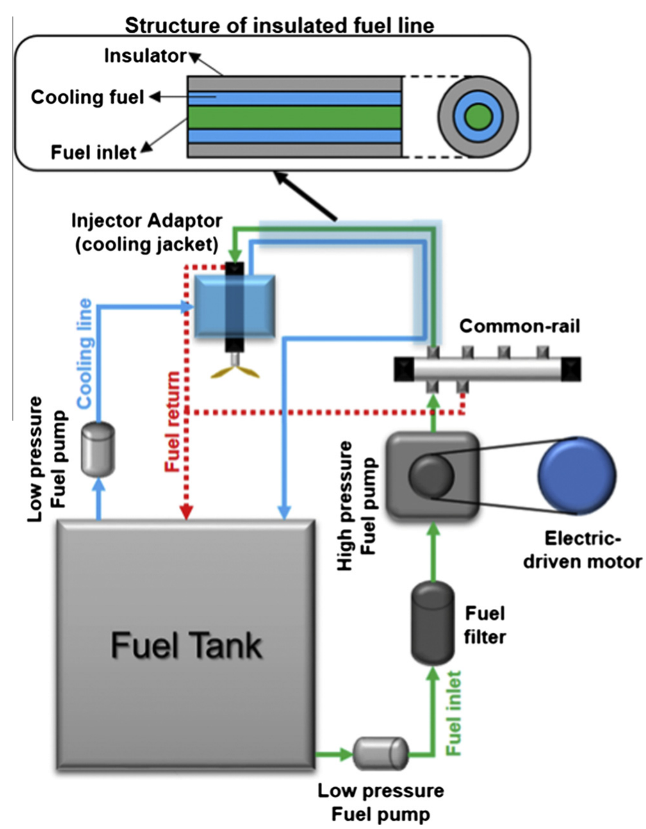

Fig. 1. Schematic diagram of fuel injection system.