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Effects of diesel fuel temperature on fuel flow and spray characteristics

Youngsoo Park [a], Joonsik Hwang [a], Choongsik Bae [a,*], Kihyun Kim [b], Jinwoo Lee [c], Soonchan Pyo [d]

[a] Korea Advanced Institute of Science and Technology, Republic of Korea
[b] Hyundai Heavy Industry, Republic of Korea
[c] Ulsan College, Republic of Korea
[d] Hyundai Motor Company, Republic of Korea

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ABSTRACT

The cold start issue has been a problem in diesel engines. Thus, in the present research, the diesel fuel flow and macroscopic spray characteristics over a wide fuel temperature range were investigated to provide valuable insights for solving the cold start problem. An injection system including a common-rail and a fuel supplier was designed to control the fuel temperature from 243 K to 313 K. For the fuel flow characteristics, the results showed that the injection quantity decreased by 50% as the fuel temperature decreased from 313 K to 243 K under the same energizing time. It was also confirmed that the real start of injection timing was retarded as the fuel temperature decreased. The reason is that increased fuel viscosity disturbed the injector needle motion and fuel flow in the nozzle. The spray test was performed under the simulated cold start condition using a constant-volume combustion chamber (CVCC). For the macroscopic spray characteristics, the liquid-phase fuel penetration increased and the spray angle decreased with cold fuel due to attenuated fuel evaporation process and interaction with ambient gas. These results could cause poor air–fuel mixing process under the cold starting.

1. Introduction

Diesel engines are recently receiving more attention in the passenger car market due to their high fuel efficiency and torque characteristics compared with gasoline engines. However, the cold start issue has made trouble in diesel engines especially, below-zero temperatures because combustion processes of diesel engines are governed by the air–fuel mixing process and compression heat [1,2]. Under very low ambient temperatures, the cylinder head and block absorb most of compression heat, thus preventing ignition [3]. Also, the low compression temperature suppresses fuel vaporization process, leading to incomplete combustion [4]. Changes in diesel fuel properties, such as density and viscosity, according to the lowered ambient temperature also affect the cold start [5]. In addition, emissions regulation, which is becoming increasingly stricter on nitrogen oxides (NO_x) and particulate matter (PM), is forcing the compression ratio of diesel engine to be lowered [6–9]. This trends deteriorate the cold start problem. The cold startability or start delay is defined as the ability of an engine to start within a specified time and continue to run without any malfunction [3]. If the cold startability is aggravated, unburned hydrocarbon (HC), PM and carbon monoxide (CO) would be increased during the cold start due to the incomplete combustion [3,10,11]. Stability in idling will also be worsened. With regard to the cold startability issues, several studies related to the fuel injection of diesel engine during the cold start have been conducted. A spilt injection strategy during the cold start is known to be an effective way to improve the cold startability [12–14]. Chartier et al. reported that the cold startability under the ambient temperature of 244 K could be improved by the application of three pilot injections [12]. Zhong et al. revealed that split-main injection strategies could improve the cold startability and, at the same time, reduce the injected fuel mass and unburned HC emissions by almost 50% [13]. Payri et al. also showed that multiple injection strategies could improve the idling stability after the cold start [14]. However, inaccurate injection quantity and timing may lead to a lower load and unstable combustion during the cold start. Research about spray characteristics of biodiesel fuel in various fuel and ambient temperature have been conducted [15]. The results showed that evaporation of injected fuel was suppressed as the fuel temperature decreased from 360 K to 300 K, which resulted in lengthened liquid fuel penetration and decreased vapor fuel mass.

From previous studies, it is known that the injection control according to the fuel/ambient temperature affected the cold startability of diesel engines significantly, indicating that precise injection control during the cold start is required. Thus, in this study, the effects of diesel fuel temperature on fuel flow and

* Corresponding author. Tel.: +82 42 350 3044; fax: +82 42 350 5044.
E-mail address: csbae@kaist.ac.kr (C. Bae).

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Nomenclature

CVCC	constant-volume combustion chamber	N_2	nitrogen
NO_x	nitrogen oxides	O_2	oxygen
PM	particulate matter	P_{amb}	ambient pressure
HC	Hydrocarbon	T_{amb}	ambient temperature
CO	carbon monoxide	P_{inj}	injection pressure
C_2H_2	acetylene	Q_{inj}	injection quantity
H_2	hydrogen	ET	energizing time

macroscopic spray characteristics with a wide range of fuel temperature from 243 K to 313 K were investigated for more precise injection control. The experiments were conducted using a common-rail injection system and a constant-volume combustion chamber (CVCC) under the cold ambient condition. The correction factors for the injection quantity and timing were also derived according to the fuel temperature variation.

2. Experimental setup and conditions

2.1. Experimental setup

Fig. 1 shows a schematics of fuel injection system. A fuel tank was designed to control the fuel temperature with a range from 243 K to 313 K. The fuel tank has a refrigerator and an electric heater, thus the diesel fuel temperature can be controlled. A Bosch common-rail fuel injection system including a high pressure fuel pump driven by an electric motor and a solenoid type injector with seven-hole was utilized. To maintain the fuel temperature in the injector and the rail-to-injector fuel tube, the fuel in the tank was also circulated through the injector adaptor and the outer passage of rail-to-injector tube using an additional low pressure fuel pump. The detailed structure of the insulated fuel line is shown in Fig. 1. The fuel temperature at the near-nozzle tip was also monitored to measure the heat generated from the high-pressure fuel pump and transferred from the surrounding. The temperature difference between in the fuel tank and at the near-nozzle tip was shown in Table 3. The fuel

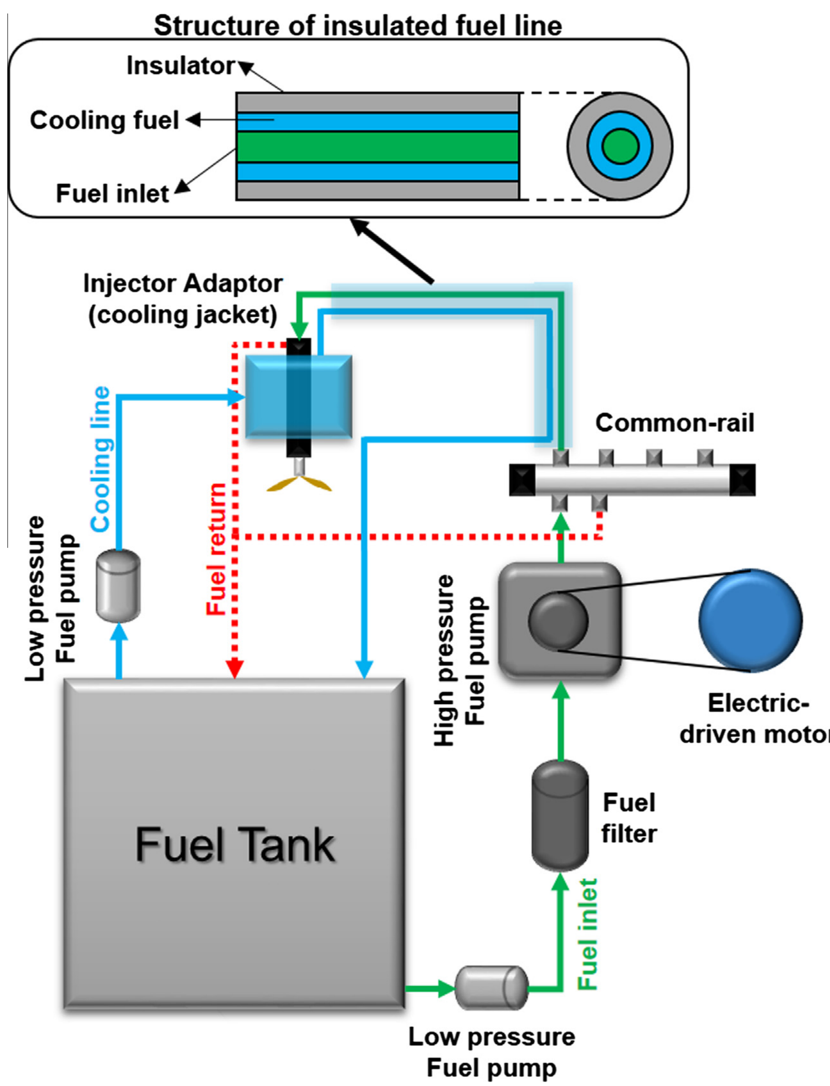

Fig. 1. Schematics of fuel injection system.