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Nozzle effects on the injection characteristics of diesel and gasoline blends on a common rail system

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ABSTRACT

In this study, the injection characteristics of diesel and blends of diesel and gasoline were investigated on a common rail injection system, using two nozzles with different orifice diameter and opening pressure. The volumetric injection rate curves, volumetric and mass cycle injection quantities and the coefficient of variances within a range of changed injection pressure and energizing time were investigated. It was found that increased gasoline proportion in fuel blends produced higher peak volumetric injection rates and volumetric cycle injection quantities than those of diesel, but comparative mass cycle injection quantities with diesel. The nozzle opening pressure and the orifice diameter also influenced the injection rate curve and cycle injection quantity, but the influential behavior depended on the energizing time and injection pressure, which might be attributed to different needle lifting motions. Higher peak injection rate and cycle injection quantity were found with increased orifice diameter, injection pressure and energizing duration. Cycle injection quantity variance was strongly related with the length of energizing time and injection pressure, but nozzle parameters and test fuels were not observed to significantly influence the injection quantity variance.

1. Introduction

The pursuit of high-efficiency and low-emissions internal combustion (IC) engines has been carried out for decades in the industrial and academia fields [1–3]. These efforts have significantly promoted the novel engine combustion strategies development such as homogenous charge compression ignition (HCCI) [4], stratified charge compression ignition (SCCI) [5] and premixed low temperature combustion (LTC) [6]. These novel combustion strategies could simultaneously reduce the NOx and soot emissions from IC engines while the thermal efficiency could be still maintained similar to conventional diesel engines. However, recent studies revealed that in advanced engine combustion strategies that are dominated by fuel oxidation chemistry, fixed fuel properties (e.g. ignitability and volatility) are not beneficial for the combustion and emissions control across the entire operational range. Instead of using one single fuel, fuel properties should be optimized according to the engine operational conditions. For example, the optimized fuel auto-ignition and volatility are proved to promote uniform mixture formation and contribute to soot emissions reduction in LTC [7]. Therefore, blends of diesel and gasoline instead of diesel were employed recently in advanced compression ignition (CI) engine combustion modes, and remarkable advantages in emissions control and fuel efficiency improvements were observed. Combining LTC mode with diesel and gasoline blends, an enhanced mixture charge was formed [8], and NOx and soot emissions were simultaneously reduced with moderate exhaust gas recirculation (EGR) introduction [9]. In addition, an intake boost strategy was proposed to broaden the LTC operation window [10]. In another study, Rezaei et al. [11] investigated the combustion and emissions on a partially premixed compression ignition (PPCI) engine fueled with diesel-gasoline fuel, and indicated that specific NOx emission and accumulation particulate concentration were reduced up to 59% and 90%, respectively. Also, an improvements of emission characteristics and thermal efficiency were found by Liu et al. [12] by fueling the engine with gasoline/diesel/PODEn blends. Kokjohn et al. [13] found that the reactivity controlled compression ignition (RCCI) concept was potential to achieve high thermal efficiency, near-zero NOx and soot emissions, compromising with acceptable in-cylinder pressure rise rate over a wide operation range. In a recent study by Torregrosa et al. [14], improved trade-off relationships between NOx and soot, efficiency and noise were

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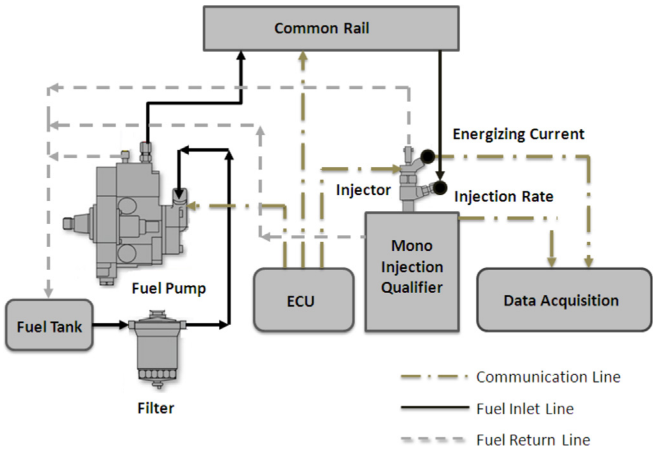

Fig. 1. Schematic of fuel injection test system.

obtained in a CI engine fueled with diesel and gasoline blends.

However, changed fuel properties such as density, viscosity and bulk modulus of compressibility may potentially affect the injection characteristics such as discharge coefficients and mass flow rate during the injection events, as well as the spray and atomization characteristics, thus further influencing engine combustion processes. Dernotte et al. [15] examined the effects of physical fuel properties on the injection rate, and concluded that fuel viscosity posed significant impact on discharge coefficient at lower injection pressure condition while density remained the only property dominating the mass injection rate when increased the injection pressure up to 55 MPa. In a similar study conducted by Naser et al. [16], they indicated that fuel physical properties played key roles as injection timing was progressively postponed from premixed conditions, based on the mixture stratification analysis for fuels with different physical properties. Based on a numerical model, Boudy et al. [17] isolated effects of fuel properties on injection process and pointed out fuel density and bulk modulus of compressibility were dominant compared to fuel viscosity and highlighted that fuel property changes could lead to different injector opening processes and as such different injected fuel mass. In addition, Salvador et al. [18] found distinct differences between injector inlet pressures of biodiesel and diesel at low and high injection pressure conditions, and biodiesel produced a lower needle lifting process during opening phase due to its higher viscosity. To obtain a similar injection behavior as diesel they proposed a modification of nozzle geometry for biodiesel fuel. Both Han et al. [19] and Feng et al. [20] observed that an enhanced spray and atomization performance was induced by changing fuel physical properties, with increased proportion of gasoline in diesel-gasoline fuels.

On the other hand, injector nozzle design parameters, such as nozzle geometry, injector flow rate, are significant for engine injection, combustion and emissions control. Siebers found decreased nozzle orifice diameter produced longer spray penetration distance and intensified air entrainment into the fuel spray [21]. Benajes et al. indicated that conical nozzle produced higher discharge

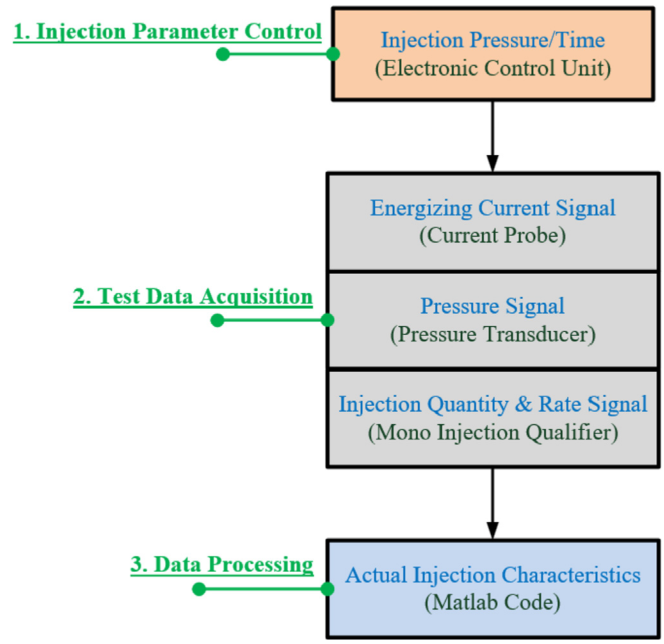

Fig. 2. Experimental procedure and data processing.

coefficient than cylindrical nozzle at high injection pressure, due to the easier formation of cavitation [22]. Hountalas et al. revealed that the variances in the nozzle geometry and the injector flow rate affect the fuel-air mixing process, thus shifting the trade-offs among NOx, soot emissions and fuel consumption rates [23]. Sharma and Murugan [24] found that at the full load condition, increased nozzle opening pressure from 20 to 22 MPa slightly increased the peak cylinder pressure and maximum heat release rate.

Due to the promising application potential of dieseline in CI engines, the injection characteristics of diesel and gasoline blends were investigated using two different nozzles on a common rail injection system in this study. The studied injection features for different fuels include volumetric injection rates, cycle injection quantities and injection quantity variances. In addition, the relationships between the abovementioned features and the injection operational parameters such as injection pressure and energizing pulse width were also established, providing experimental evidences for the injection calibration and optimization in advanced engine combustion strategies fueled with diesel and gasoline blends.

2. Experimental setup and test procedure

2.1. Experimental setup

The injection characteristics of diesel and dieseline were measured on a test rig as shown in Fig. 1. Fuel injection pressure up to 100 MPa was generated by a common rail system of 30 cm^3 rail volume. The rail pressure and injection pulse profile could be

Table 1
Some physical properties of test fuels.

	Density @ 313 K (g/mL)	Kinetic viscosity @ 313 K (mm^2/s)	Surface tension @ 298 K (mN/m)
G0	0.8045	2.3878	27.0630
G20	0.7895	1.6788	26.3767
G40	0.7765	1.1275	25.3117