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Effects of heated ethanol on retrofit single-hole gasoline injector performance

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ABSTRACT

The main aim of this work is to explore the injector performance in terms of fuel mass flow rate and discharge coefficient when ethanol is in use with gasoline injectors at elevated temperatures. The operating fuel injection was at the pressures between 0.2 and 0.4 MPa and the temperatures in a range of 40–80 °C. A fuel injector test cell with electronic control for injection pulse, timing and pressure was set to 120 Hz and 60 min injection duration to drive three single-hole 0.34 mm nozzle diameter injectors. The fuels were injected into a known volume flask at quiescence atmospheric pressure and weighed to attain the fuel mass flow rates. By this manner, the discharge coefficient can be calculated by the assumptions of quasi steady, incompressible and one dimensional flow through each injector. When operating at 40 °C injection temperature, ethanol delivered greater fuel amounts than gasoline resulting in higher discharge coefficients. The temperatures of the injected fuels are shown to affect the fuel flow rates and the discharge coefficients.

1. Introduction

Nowadays, fuel injection systems for gasoline engines such as port fuel injection and direct injection have been widely used with electronic control unit due to its feedback control to conform to worldwide emission regulations [1]. Some car owners require their obsolete car models to use with current alternative fuels such as alcohol-gasoline blends e.g. E85 (85% ethanol and 15% gasoline). Up to date, pure ethanol has been introduced to the market that necessitates advanced technologies for fueling at a cost. Therefore, some retrofit cars require further calibration for using these alcohol based fuels. In addition, surrounding heat nearby the intake manifold can affect alcohol based fuels prior to inducting into the engine combustion chamber. Extensive studies are therefore focusing on injection characteristics of neat alcohol or alcohol-gasoline blended fuels.

Zhang and Hung [2] investigated the transient fuel spray characteristics from a multi-hole injector by analyzing dimensionless parameters. The temporal development of spray penetration and cone angle of ethanol, methanol and gasoline were analyzed using a Planar Mie scattering to generate spray images. In the first stage, the spray penetration increases linearly with time after the start of injection. During the developed stage, the effect of aerodynamic forces becomes more influential on the spray penetration.

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For gasoline direct injection engines, Chen and Nishida [3] studied the spray evaporation and combustion of ethanol-gasoline blends (E0, E85, and E100) injected by hole-type nozzle. The tests in a high-temperature and high-pressure quiescent constant volume vessel equipped with a dual-wavelength laser absorption scattering technique were investigated. Ethanol evaporates faster than gasoline while the combustion becomes more vigorous due to the oxygen content in ethanol. Furthermore, the ethanol-gasoline blends improved combustion stability particularly when advancing the ignition timing.

Under hot fuel conditions, Aleiferis and van Romunde [4] analyzed the spray development of iso-octane, n-pentane, gasoline, ethanol and n-butanol from a high-pressure multi-hole injector for direct-injection spark-ignition engines. This work used an optical high-speed imaging and droplet sizing investigation to outline the effects of fuel properties, temperature and pressure on spray formation. The tests were at 20, 50, 90 and 120 °C injector body temperatures for ambient pressures of 0.5 bar and 1.0 bar. Some key physical properties were obtained from their analysis.

Anand et al. [5] reported the measured spray structure and droplet size distributions of ethanol-gasoline blends for a low-pressure multi-hole port fuel injector. Specimens i.e. gasoline, ethanol, and their blends were studied at 0.25 MPa and 0.6 MPa using laser backlight imaging. The development and droplet sizes of gasoline and ethanol sprays have similar characteristics. Interaction of multiple fuel jets is insensitive to the viscosity.

Subsequently, there are some other aspects that have not been studied concerning ethanol injection with elevated temperature. The main aim of this work is to study the injection characteristics when injecting the heated ethanol in terms of mass fuel flow rate and discharge coefficient under the fuel temperature range of 40–80 °C with injection pressure variation in the range of 0.2–0.4 MPa.

2. Materials and methods

2.1. Injector test cell

The injector test cell is schematically depicted in Fig. 1. The fuel injection control module from Motorscan model Ultra Sound 2500 was used to supply pulse and speed signals by electronic control to injectors. The fuel under controllable pressure was injected through a liquid-to-liquid heat exchanger immersed in a water bath Lauda model Ecoline 011 with temperature controller from Lauda model E200. The temperature of the fuel flow was controlled within the range ± 0.1 °C of the set temperatures. The subsequent fuel flowed through a header of four injectors and was injected through three single-hole 0.34 mm nozzle diameter injectors to a known volume flask at quiescence atmospheric pressure. The resistance of the injector was 11.8 Ω and the maximum flow rate of the injector was by 260 cc/min. Fig. 2 shows the measured dimensions in mm of the test injector with ± 0.1 mm tolerance and its main components. Results from these three injectors were average and are used as representative values for analysis. The fuel mass from each injector was weighed by CST balance model CDR-6 with accuracy of ± 0.05 g. The flow rate of the fuel mass was then calculated over a constant time.

2.2. Fuel

There were two types of fuel used in the test, ethanol and gasoline. General properties of the two fuels are listed in Table 1 [6].

2.3. Test conditions

The injection tests were conducted under steady-state conditions using ethanol and gasoline, respectively, at the constant injection pressures of 0.2, 0.3, and 0.4 MPa with variations in the fuel temperatures 40, 60, and 80 °C. The fuel injector test cell composed of electronic control for injection pulse, timing and pressure previously described in Section 2.1 was employed and controlled at 120 Hz and 60 min injection duration.

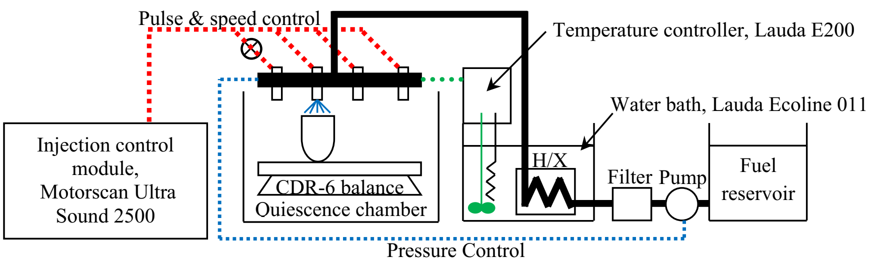

Fig. 1. Fuel injector test cell.

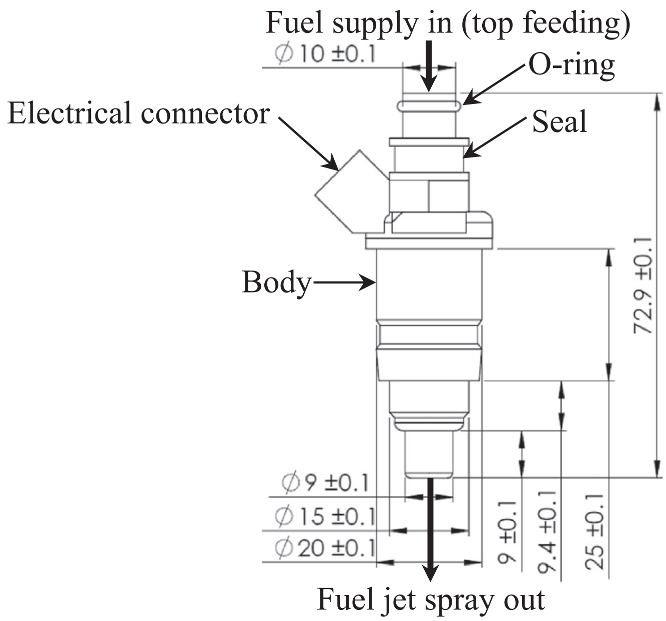

Fig. 2. The test injector main dimensions and components (unit: mm).

Table 1
Fuel properties [6].

Selected properties	Fuels	
	Ethanol	Gasoline
Research octane number	130	95.0
Density at 15 °C (kg/l)	0.792	0.743
Lower heating value (MJ/kg)	26.7	42.4
Reid Vapor Pressure at 37.8 °C (kPa)	54.0	59.4
Oxygen content (wt%)	34.7	1.1*
Theoretical air-to-fuel ratio	9.0	14.5

Remark: *6.0%vol. of methyl tert-butyl ether.

2.4. Studied parameters

If the pressure upstream of the injector nozzle is determined and measured, and assuming the flow through each nozzle is quasi steady, incompressible, and one dimensional, the mass flow rate of fuel injected through the nozzle $\dot{m}_f$ is given by [7]

$$\dot{m}_f = C_D A_n \sqrt{2\rho_f \Delta p} \quad (1)$$

where A_n is the nozzle minimum area, C_D is the discharge coefficient, ρ_f is the fuel density, and Δp is the pressure difference across the nozzle. During injection, the fuel injection pressure is set while the fuel is injected to atmospheric condition in the weighed flask on the balance. Therefore, the pressure drop across the injector nozzle in all cases will be the difference between the injection pressure and atmospheric pressure. By the use of Eq. (1), the discharge coefficient can be calculated by other known parameters and constants.

3. Results and discussion

3.1. Effects of pressure drop on fuel flow rate

At a temperature, fuel mass flow rate is dependent on pressure difference across the injector nozzle as shown in Fig. 3. The error bars represent 95% confidence. The fuel mass flow rate increased with the injection pressure. It is obviously seen from Fig. 3 that the relation between the fuel mass flow rate and the pressure drop follows $\dot{m}_f \propto \sqrt{\Delta p}$. With the same value of pressure drop, the injector delivered higher rate of ethanol than gasoline. This may be due to the difference in fuel density

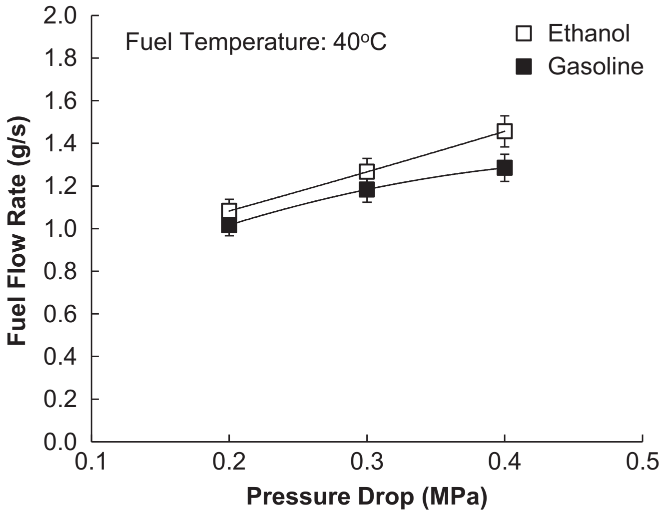

Fig. 3. Fuel mass flow rate dependency on pressure drop across injector nozzle at 40°C fuel temperature.

(see Table 1) while the setting of the injection duration was equally kept. In addition, these trends of the injection were also observed with other fuel injection temperatures; results are not shown.

3.2. Effects of temperature on fuel flow rate

Fuel mass flow rate is also dependent on injection temperature as shown in Fig. 4 for 0.4 MPa pressure drop across the injector nozzle. The variations in fuel mass flow rate were different for fuel type, depending on fuel temperatures. When elevating the fuel temperatures from 40 °C up to 60 °C, the injection of ethanol delivered greater fuel flow rate than gasoline. However, the increment of the fuel temperatures of up to 80°C caused the fuel mass flow rate declined for all type of fuels compared to those at 60 °C. This behavior can occur when ethanol absorbed external heat that changes the density of the fuel itself, causing the injector delivering lesser fuel throughout its nozzle.

3.3. Discharge coefficient

The temperatures of the injected fuels are shown to affect the discharge coefficients as shown in Fig. 5 for 0.4 MPa pressure drop across the nozzle. At the same pressure drop, the discharge coefficients for the injection of the ethanol were greater than gasoline. However, the variations in discharge coefficients were different for fuel type, depending on fuel temperatures. The greatest difference in discharge coefficient of up to 10% for ethanol compared to gasoline was observed at 40 °C. This is mainly derived from the larger fuel mass flow rate of ethanol than gasoline at 40 °C (see Fig. 4 for comparison).

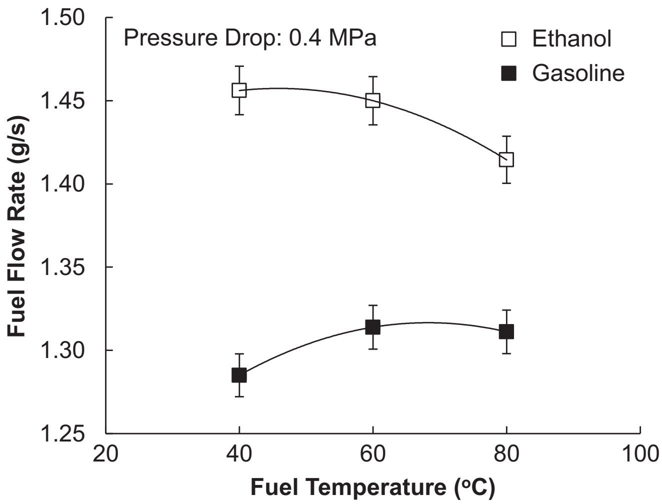

Fig. 4. Fuel mass flow rate dependency on fuel injection temperature at 0.4 MPa pressure drop.

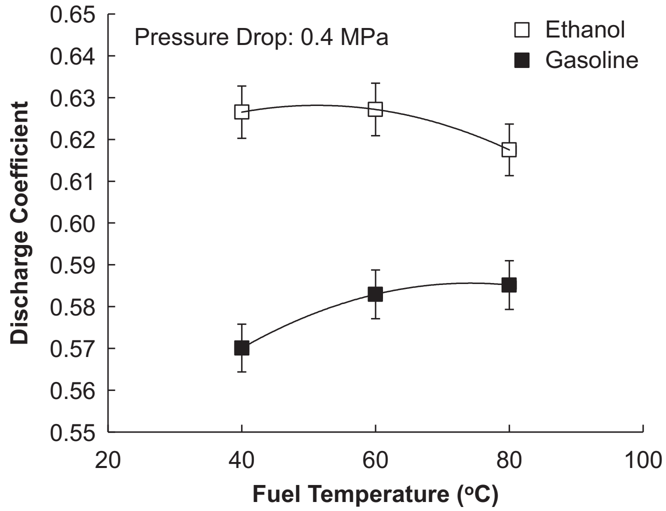

Fig. 5. Discharge coefficient variation with fuel injection temperature at 0.4 MPa pressure drop.

When the fuel temperatures were climbed up from 40 °C to 80°C, the discharge coefficients for the injection of ethanol were declined that contrasts to those of gasoline. This occurrence can be observed in parallel with the fuel mass flow rate depicted by Fig. 4.

4. Conclusion

The single-hole gasoline injector performance with retrofit use of ethanol at 0.2–0.4 MPa and 40–80 °C can be concluded as the followings, based on the assumption that the fuel flow was quasi steady, incompressible, and one dimensional.

- At constant fuel temperature, ethanol delivered greater fuel amounts than gasoline. Both fuels showed greater flow at higher pressure drop across the injector nozzle.
- Higher discharge coefficients were observed for ethanol. By the conditions used in the test, the heated ethanol up to 60 °C benefits for both terms of mass flow rate and discharge coefficient.

Calibrating fuel injection timing and duration, and adding fuel preheating element are recommended when an OEM gasoline injector has to be retrofit by ethanol fuel.

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