Fuel 105 (2013) 425–431

Contents lists available at SciVerse ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Primary investigation to leveraging effect of using ethanol fuel on reducing gasoline fuel consumption

Yuan Zhuang *, Guang Hong

School of Electrical, Mechanical and Mechatronic Systems, Faculty of Engineering and Information Technology, University of Technology, Sydney, Australia

HIGHLIGHTS

- ▶ Gasoline fuel could be leveraged by ethanol fuel using ethanol direct injection plus gasoline port injection (EDI + GPI).
- ▶ Brake mean effective pressure and volumetric efficiency increased with the increase of ethanol/gasoline energy percentage.
- ▶ The NO emission was decreased by enhanced charge cooling effect and reduced in-cylinder peak temperature in EDI + GPI.
- ▶ CO and HC emissions increased with the increase of ethanol/gasoline energy percentage.

ARTICLE INFO

Article history:
Received 20 February 2012
Received in revised form 27 August 2012
Accepted 5 September 2012
Available online 27 September 2012

Keywords:
Ethanol direct injection
Gasoline port injection
Single cylinder spark ignition engine
Leveraging effect

ABSTRACT

Ethanol has been used as an alternative fuel or fuel addicts in spark ignition (SI) engines for years. However, the existing methods of using ethanol fuel, such as blending gasoline and ethanol, pure ethanol and by-fuel of ethanol or gasoline do not make the best use of ethanol's potentials in improving engine performance. Compared with gasoline fuel, ethanol fuel possesses greater octane number and latent heat of vaporization, which allow higher compression ratio and consequently lead to the increased thermal efficiency. Ethanol fuel's higher combustion velocity could also help increase the combustion efficiency and minimize the energy loss. This paper reports our preliminary investigation to the leveraging effect of using ethanol direct injection plus gasoline port injection (EDI + GPI) on reducing the consumption of gasoline fuel. Experiments were conducted on a YBR250 engine which was a single cylinder SI engine modified to be equipped with EDI + GPI. At each of the four designated engine speeds, the engine load was set to be either medium or light and the ethanol/gasoline energy ratio (EER) was varied from 0% to 60.1%. The rate of the total heating energy of two fuels was kept constant in one of the two engine load conditions. Experimental results were analyzed and discussed in terms of engine performance, in-cylinder combustion characteristics and engine emissions. They showed certain leveraging effect of using ethanol fuel by the increased BMEP, volumetric efficiency and thermal efficiency and reduced NO with the increase of EER.

1. Introduction

The degradation of the global environment and the foreseeable future depletion of worldwide fossil fuel reserves have been the driving force to searching alternative fuels that are sustainable and environmental friendly. Ethanol fuel is one of the renewable fuels for addressing these issues. The potential of ethanol fuel in improving the performance of internal combustion engines has been extensively investigated. Park et al. and Huang et al. found that adding ethanol fuel to gasoline could improve the mixture burnt rate and combustion efficiency due to its high combustion velocity [1,2]. Nakata et al. and Szybist et al. pointed out that charge cooling effect, high heating value of a stoichiometric mixture for ethanol blends (per unit mass of air), additional thermodynamic effects on the ratio of specific heats (γ) and mole multiplier effect could all attribute to the increase of thermal efficiency when a SI engine was fueled with ethanol or ethanol/gasoline blended [3,4]. Caton et al. and Ayala et al. showed that by taking the advantages of ethanol's anti-knock ability enhanced by its high octane

Abbreviations: ATDC, after top dead center; AFR, air fuel ratio; BTDC, before top dead center; BMEP, brake mean effective pressure; BSFC, brake specific fuel consumption; BSEC, brake specific energy consumption; CAD, crank angle degree; CA50, crank angle at which the mass burnt fraction is 50%; DI, direct injeciton; EDI, ethanol fuel direct injection; ECU, electronic control unit; EER, ethanol/gasoline energy ratio; GPI, gasoline port injection; IMEP, indicated mean effective pressure; HE, heating energy; PI, port injection.

* Corresponding author. Address: PO Box 123, NSW 2007, Australia. Tel.: +61 0433020876.

E-mail addresses: Yuan.Zhuang-1@student.uts.edu.au (Y. Zhuang), guang.hong@uts.edu.au (G. Hong).

0016-2361/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2012.09.013

number and high latent heat of vaporization, engine compression ratio was increased and this consequently improved the engine thermal efficiency [5,6].

However, when ethanol fuel is blended with the gasoline fuel prior to fueling in a spark ignition (SI) engine, the engine uses a constant ratio of ethanol to gasoline, no matter how engine operating condition changes. In this case, ethanol's greater ability to suppress engine knock and to reduce pollutant emissions has no chance to show, but its disadvantages such as low heating value and low flashing temperature may degrade the engine performance. The advantages of the ethanol fuel should be implemented and the problems associated with using ethanol as a renewable fuel should be resolved. As the octane number of the ethanol fuel is greater than that of gasoline fuel, this allows the engine to have a greater compression ratio without engine knock. With increased compression ratio, the engine thermodynamic efficiency will be increased. It was predicted that, due to its latent heat greater than that of gasoline fuel, ethanol fuel's evaporation would reduce the peak temperature during combustion and consequently allow the increase of compression ratio. This has led to a new idea of ethanol direct injection plus gasoline port injection (EDI + GPI) which is expected to use the ethanol fuel in a more effective and efficient way and to reduce or avoid the problems associated with the currently used blended ethanol and gasoline fuel.

Aiming to leverage the effect of the available ethanol in reducing the consumption of gasoline fuel, Cohen et al. first proposed direct injection of ethanol fuel in developing a small turbocharged SI engine which should match the performance of a much larger existing engine [7]. In their report, they estimated ethanol's energy value increased by the leveraging effect on increasing the efficiency of using gasoline fuel. This leveraging effect was assessed experimentally on a Ford 'EcoBoost' which was a 3.5 L gasoline turbocharged direct injection (GTDI) engine with direct fuel injection of E85 and port fuel injection of gasoline (E85 DI + Gasoline PI) [8]. The compression ratio of the GTDI engine was 9.8:1. It was increased to 12:1 for E85 DI + Gasoline PI. Their experimental results showed that the engine thermal efficiency could be improved and the ethanol fuel could be used to conserve gasoline usage. This verified the estimation of leveraging effect of ethanol fuel in reducing the consumption of gasoline fuel proposed by Bromberg et al. [9].

Investigation to dual-injection strategies applied to SI engines has been reported in the past 2 years [12,13]. To investigate the flexibility of dual-injection strategies, Wu et al. [12] conducted experiments on a single-cylinder SI engine with port injection of gasoline fuel and direct injection of one of the three fuels: gasoline, ethanol and 2.5-dimethylfuran (DMF). In their experiments, the port injected and the directly injected fuels were tested at five different ratios. The spark timing was fixed at the knock-limited maximum brake toque. Their results showed that the indicated mean effective pressure (IMEP) increased with the decreased PI mass fraction, independent which fuel was directly injected. When ethanol fuel was directly injected, the indicated efficiency increased and the HC, NO_x and CO_2 emissions reduced. Zhu et al. [13] investigated the combustion characteristics of the dual-injection system on a single-cylinder SI engine. They conducted experiments in light and heavy load conditions only but with three different combinations of PI and DI injections of gasoline and ethanol fuels. Their results showed that, at light load, the IMEP increased by 2% when the ethanol fuel was directly injected and the gasoline fuel was port injected but decreased in other combinations of dual-fuel injection. Also in light load condition, the percentage of the ethanol fuel affected the combustion characteristics significantly. However, at heavy load, the percentage of the fuel directly injected played a more important role in affecting the combustion characteristics.

The leveraged effect of ethanol fuel blended with gasoline fuel at different ratios on the performance of DI gasoline engines has also been demonstrated in the investigation to blended ethanol/gasoline fuel. To study the feasibility of using ethanol fuel in direct injection (DI) gasoline engines, E0 (100% gasoline) and E100 (100% ethanol) fuels were tested on a V6 3-L DI gasoline engine [10]. The compression ratio for E100 was 13:1 and for E0 11.5:1. The engine's full load performance with these two fuels was compared. The engine torque with E100 was well above that with E0 over the full range of engine speed. The maximum torque with E100 was 7.6% greater than that with E0. Their results showed that the E100 fuel was leveraged effectively on this DI gasoline engine with increased engine torque when the amount of the ethanol fuel injected was equivalent to that of the gasoline fuel based on heating values. The torque increment was partially explained as due to the increase of burned gas mole fraction. The effect of different blending ratios of ethanol/gasoline was also investigated through experiments conducted on a single-cylinder 4-stroke DI gasoline engine with varied spark timing [11]. It was analyzed based on combustion performance, regulated emissions and engine efficiency. Their results showed that, with the ethanol/gasoline blend ratio increased from 0% to 100%, the engine efficiency increased and the emissions of CO and NO_x reduced or remained.

This paper reports our preliminary results of investigating the leverage effect of using ethanol fuel on reducing the consumption of gasoline fuel and on improving engine performance of a single cylinder research engine equipped with EDI + GPI. The results include the effect of ethanol fuel energy ratio on the engine performance such as BMEP, volumetric efficiency, fuel consumption, in-cylinder pressure indicated thermal efficiency and emissions.

2. Experimental setup

2.1. Test engine and instrumentation

The experiments were performed on a research engine which was modified from a four-stroke single-cylinder SI engine for Yamaha motorcycle YBR250. The specifications of the engine are shown in Table 1. Fig. 1 is the schematic diagram of the engine testing set up. As shown in Fig. 1, the research engine is equipped with an electronic control unit (ECU), a direct injection system (9,10,14) for ethanol fuel and a port injection system (16) for gasoline fuel. The port fuel injection pressure is 250 kPa and the pressure in the common rail for direct ethanol fuel injection can be adjusted to be a fixed value in a range of 3–13 MPa. The ethanol direct injector is mounted on the same side as the spark plug opposite the sprocket of camshaft to avoid interference. There is a slope angle of 15° between the axis of the injector and the horizontal surface which is the interior surface of the cylinder head and 12° between the axis of the injector and the vertical surface. The tip of the injector is placed between the intake valve seat and the spark plug, attempted to use the tumble flow to form richer mixture adjacent to the spark plug. Both port and direct fuel injections are controlled by the ECU.

As shown in Fig. 1, the engine is coupled to a DC dynamometer (2). The in-cylinder pressure was measured using a Kistler 6115B measuring spark plug pressure transducer (15). During the engine testing, the temperature of the engine body was between 250 °C and 270 °C. The temperature of the lubricating oil was maintained between 85 °C and 95 °C. The temperature was measured through *K*-type thermocouples (8,13,18). A 80 L intake buffer tank (19), with a volume approximately 320 times the engine's displacement volume, was used to stabilize the intake flow. A Bosch wide-band lambda (12) sensor was mounted in the exhaust pipe. It measures the equivalence ratio (λ), when engine is operated with gasoline fuel only. The exhaust gas emissions were measured using a Horiba MEXA-584 L gas analyzer (5). Exhaust gas samples were taken at a