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Research Paper

Experimental study on sparking ignition engine performance for optimal mixing ratio of ethanol–gasoline blended fuels

S. Phuangwongtrakul [a], W. Wechsatol [a,*], T. Sethaput [b], K. Suktang [a], S. Wongwises [a]

[a] Faculty of Engineering, Department of Mechanical Engineering, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand
[b] Sirindhorn International Institute of Technology, Mechanical Engineering Program, Thammasat University, Pathum Thani 12121, Thailand

HIGHLIGHTS

- The optimal mixing ratio of ethanol–gasoline blended fuels is proposed.
- At low speed, the optimal mixing ratio will increase torque output significantly.
- E40 and E50 fuels provide the highest brake thermal efficiency.
- E20–E40 fuels provide the highest maximum brake torque.

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ABSTRACT

The purpose of this study is to experimentally determine the optimal blend rate of ethanol–gasoline fuels in order to maximize the brake thermal efficiency of a commercial SI engine. In this study, the engine performance, in terms of brake torque and brake specific fuel consumption, has been investigated with variation of volumetric mixing ratio between 87.5-octane gasoline and 99.5%-purity ethanol (E10, E20, E30, E40, E50, E60, E70, E85, and E100). The experiment has been conducted at different engine speeds and percentages of intake-throttle opening. The tests were performed at a constant compression ratio. The relative air–fuel ratio was tuned to unity and the ignition timing was tuned for maximum engine torque. The experimental results indicated that the appropriate ethanol–gasoline mixing ratio can enhance engine torque output, especially at low engine speed. The brake thermal efficiency is maximum when the engine operates at 58–73% of WOT with an engine speed of 2000–2500 rpm, using E40 and E50 fuels. This paper also provides a guideline for a suitable ethanol–gasoline blend rate at a certain engine load and speed.

1. Introduction

To reduce fossil fuel dependency and increase the share of renewable energy, ethanol has been introduced, with a dramatic increase of production over the past decades. The significant increment of ethanol output has been driven by governmental policies across the world [1]. Ethanol is used for various applications: as fuel for direct combustion for electricity production [2], as fuel in fuel cells [3], and as a working fluid in refrigeration systems [4]. Generally, ethanol is most widely used as an alternative transportation fuel by commonly blending with gasoline in constant percent ethanol. However, the constant concentration of ethanol blended with gasoline might not be suitable for providing optimal efficiency. Compared to gasoline, ethanol provides a higher octane number, which provides better antiknock capabilities. The higher octane of ethanol allows higher compression ratio in an internal combustion engine and leads to an increase in engine efficiency [5,6]. Ethanol also has a higher latent heat of vaporization. These bring about a lower temperature of the air intake manifold, and increase the density of air, which allows more air-intake into the cylinder to improve the volumetric efficiency. In contrast, the heat of combustion (heating value) of gasoline is higher than that of ethanol. The lower heating value of ethanol leads to higher fuel consumption [7].

Many researchers have studied the effect of using ethanol–gasoline blended fuels on engine performance and exhaust emission in SI engines. Yüksel and Yüksel [8] experimentally investigated the SI engine performance and the fuel consumption using E60 fuel. They found that E60 fuels provide slightly increased specific fuel consumption compared to gasoline. Bayraktar [9] performed an experimental investigation using gasoline–ethanol blends (1.5–12% volume of ethanol, with an increment of 1.5%) for SI engine performance and exhaust emissions. The test results indicated that increasing ethanol content increases effective power and efficiency due to combustion improvement.

* Corresponding author. Tel.: +66 2 470 9123; fax: +66 2 470 9111.
E-mail address: wishsanuruk.wec@kmutt.ac.th (W. Wechsatol).

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Al-Hasan [10] investigated the effect of ethanol–gasoline blended fuels ranging from 0% and 25% ethanol, with an increment of 2.5%. Experiments were conducted with a four cylinder SI engine (Toyota, Tercel-3A) at three-fourths throttle opening position and variable engine speed, ranging from 1000 to 4000 rpm. The results showed that ethanol addition can improve about 8.3% of brake power, 7% of volumetric efficiency, 9% of thermal efficiency, and 5.7% of fuel consumption. Ethanol additions also reduce the brake specific fuel consumption by 2.4% and equivalence air–fuel ratio by 3.7%. The experiment also concluded that ethanol–gasoline blended fuels with 20% ethanol provide the best result when both engine performance and exhaust emission are considered. Hsieh et al. [7] investigated ethanol–gasoline blended fuels with 0%, 5%, 10%, 20%, and 30% ethanol on the performance and emission of a commercial engine (Nissan Sentra GA16DE). The experiments were conducted by varying the engine speeds (range of 1000–4000 rpm) and throttle valve opening in the range of 0%–100% with 20% increments. Hsieh et al. found that a higher percent ethanol brings about a reduction in the heating value of fuels. The ethanol–gasoline blend provides a marginal increase in torque output and specific consumption, compared to gasoline. Using ethanol–gasoline blended fuels can significantly restrict pollutant emissions of CO and hydrocarbons. Since ethanol content accommodates complete combustion, the CO_2 emission is increased; NO_X emission is not dependent on the ethanol content. By using an identical engine, Wu et al. [11] investigated the relationship between ethanol–gasoline blended fuels and air–fuel equivalence ratios in SI engine performance. The experiment were conducted under different air–fuel equivalence ratios ranging from –25% to 25% of the original (around 0.9), with an increment of 5%. The tests were conducted based on the following conditions: five fuels (E0, E5, E10, E20, and E30), two engine speeds (3000 and 4000 rpm), and six throttle valve openings ranging from 0% to 100%, with an increment of 20%. The results indicated that the highest torque output and the lowest brake specific heat consumption are obtained when the air–fuel ratio is slightly smaller than one. Increasing ethanol content slightly increases the torque output, especially at a small throttle valve opening.

Yücesu et al. [12] experimentally analyzed the effect of ethanol-unleaded gasoline blends (E10, E20, E40 and E60) on engine brake torque and brake specific fuel consumption (BSFC). The experiments were performed by varying compression ratios (5:1–13:1), ignition timing (10–36 °CA, BTDC), and relative air–fuel ratios (0.8–1.2) at a constant speed of 2000 rpm and WOT. Experimental results of engine performance showed that at retarded ignition timing, usage of ethanol blends provides higher brake torque, compared to unleaded gasoline. However, there is no significant difference in maximum brake torque ignition timing between gasoline and ethanol blends under all compression ratio conditions. In the rich operation region (above stoichiometric air–fuel ratio), ethanol content addition increases the engine torque. Ethanol content addition also increases the BSFC. A similar experimental investigation performed by Topgül et al. [13] showed that usage of ethanol blends allows compression ratios of engines to increase without knocking. Koç et al. [14] experimentally studied the effects of unleaded gasoline (E0) and unleaded gasoline–ethanol blends (E50 and E85) on brake torque and BSFC. The experiments were performed at variable engine speed (1500–5000 rpm with 500 rpm increments), at 10:1 and 11:1 compression ratios and wide open throttle. The results showed that engine torque provided by ethanol blended fuels (E50 and E85) is visibly higher than that by E0 at all engine speeds and both compression ratio conditions. Compared to base gasoline (E0), E50 and E85 can increase BSFC by 20.3% and 45.6%, respectively, at 10:1 compression ratio and 16.1% and 36.4%, respectively, at 11:1 compression ratio. Costa and Sodré [15] experimentally investigated the influence of compression ratio (10:1, 11:1, and 12:1) on the performance of an SI engine by using E22 and E100. The tests were conducted under fully opened throttle conditions at variable engine speeds ranging from 1500 to 6500 rpm. The result showed that increasing compression ratios improved engine torque and power output for both fuels. E100 provides a major decrease in specific fuel consumption and an increase in thermal efficiency with increased compression ratios. The influence of compression ratio (8:1, 8.5:1, 9:1, and 9.5:1) on an SI engine's performance was experimentally investigated by Balki and Sayin [16]. Three different fuels (unleaded gasoline, pure ethanol and methanol) were used as fuel. The tests were conducted with constant WOT, engine speed, and ignition timing. The experimental results can be summarized that ethanol provides better brake thermal efficiency and volumetric efficiency compared to pure gasoline. At 8.5:1 compression ratio, the use of ethanol also increases BSFC by 58.9% compared to gasoline. Balki et al. [17] observed that with variable engine speeds, the use of ethanol typically provides higher brake thermal efficiency than that of gasoline for the entire range of engine speed. Especially, at high engine speed, there was a significant difference in brake thermal efficiency between ethanol and gasoline usage. Abdel-Rahman and Osman [18] studied the effect of varying the compression ratio (8:1–13:1) on SI engine performance, using different ethanol–gasoline blended fuels (E10, E20, E30, and E40) with a fully opened throttle. The test results concluded that an increasing compression ratio increases the indicated power when the percentage addition of ethanol is above 20%. Also, the optimum compression ratios (which provide maximum indicated power) were 8:1 for E10, 10:1 for E20 and 12:1 for E30 and E40. Celik [19] initially determined the effect of a ethanol–gasoline blend rate on engine power and specific fuel consumption using E0, E25, E50, E75, and E100 fuels. The tests were run at a constant speed of 2000 rpm, with full throttle opening and an air excess ratio of 1.0. The experimental results showed that E25, E50, and E75 fuels provide 3%, 6%, and 2% higher engine power, respectively, than E0. However, E100 reduce power by 4% compared to E0. E25, E50, E75, and E100 increase specific fuel consumption by 10%, 19%, 37%, and 56%, respectively, compared to E0. The researcher concluded that E50 is the most suitable fuel in terms of engine performance and exhaust emission. Afterward, the second test were performed by varying compression ratios (6:1, 8:1 and 10:1) and engine speed in the range of 1500–4000 rpm using E0 and E50. The result showed that increases of compression ratio give higher engine power and lower specific fuel consumption. At a high compression ratio (10:1), an increase of about 29% in engine power was observed when running with E50, compared to E10.

From the literature review, the relationship among engine speed, throttle position (% WOT), and percentage of ethanol by volume of fuel, which affect the performance of an SI engine, has not been exhaustively studied. Hence, in this study, an experiment has been conducted with variable engine speed and partially opened throttle (% WOT). The engine performance in terms of brake torque and brake specific fuel consumption has been investigated under various volumetric mixing ratios between 87.5-octane gasoline and 99.5%-purity ethanol. Also, an optimal mixing ratio based on the thermal efficiency of engine has been determined.

2. Experimental apparatus and procedure

2.1. Experimental setup and apparatus

Fuel property testing of different ethanol-blended gasolines was conducted, based on the testing equipment as shown in Table 1.

In this study, 9 types of ethanol fuel mixtures were prepared based on the variable mixing ratio between 87.5-octane gasoline and 99.5%-purity ethanol by volume, as shown in Table 2.

The main components of the experimental setup consist of a spark-ignition gasoline engine, an engine control unit (ECU), an engine performance testing unit, an air flow meter, an air–fuel ratio