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Effect of compression ratio on the emission, performance and combustion characteristics of a gasoline engine fueled with iso-butanol/gasoline blends

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ABSTRACT

The study focuses on the effect of CR (compression ratio) on the emission, performance and, combustion characteristics of a gasoline engine fueled with iso-butanol (10%, 30% and 50%) blended gasoline fuel. The tests were conducted for three different CRs (9:1, 10:1 and 11:1) at 2600 rpm and wide-open throttle. The results indicate that the BSCF (brake specific fuel consumption), BTE (brake thermal efficiency) and the emissions of CO_2 (carbon dioxide) increased while UHC (unburned hydrocarbon) and CO (carbon monoxide) emissions decreased with the increase in the amount of iso-butanol in the fuel mixture at all CRs. The best results for BSFC, BTE, the emissions of CO and UHC were observed at increased the CR. Moreover, the ICP (in-cylinder pressure) generally increased with the increase in the amount of iso-butanol in the fuel mixture and the ICP and HRR (heat release rate) rose earlier than those values in gasoline.

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1. Introduction

Energy independence and reduction in pollutant emissions are a center of interest for researchers. Renewable fuels have gained in popularity because of their sustainability, low contributions to the carbon cycle, and in some cases lower amounts of greenhouses gases [1]. Moreover, energy diversification is also required by each country. One possible solution is the use of biofuels, especially the 2nd generation biofuels produced from biomass. Bio-fuels (methanol, ethanol, etc.) have been shown as good candidates as alternative fuels for vehicles because they are liquid, and have several physical and combustion properties similar to gasoline [2,3]. Alcohols have higher octane number and oxygen content. This allows the alcohol engines to have much higher CRs, and thus BTE (brake thermal efficiency) increased [4]. The most attractive feature of iso-butanol which is an isomer of n-butanol is its energy content which is higher than other alcohols such as methanol, ethanol, etc. Butanol not only can be produced with food, but also crop waste, wood waste, algae biomass, food processing waste, household waste, etc [5]. The major advantage of iso-butanol compared to fossil fuels is that it can significantly reduce CO_2 emissions because it is obtained from biomass. Iso-butanol has higher density than other alcohols such as ethanol and methanol etc [6,7]. Therefore, it can be mixed into gasoline in greater concentrations without exceeding imposed Reid vapor pressure limits [8]. The studies related to the iso-butanol usage in gasoline engines have been conducted by several researchers. In one study [9], the effect of iso-butanol/gasoline blends (with an alcohol concentration of 0%vol, 25%vol, 50%vol, 75%vol and 100%vol) on the exhaust emissions in a single cylinder port-fuel injection gasoline engine was investigated. It was observed that the addition of iso-butanol resulted in an increase of the fuel consumption of about 30% with iso-butanol and only slightly increased (about 2%) in CO_2 emissions. A strong decrease in UHC (unburned hydrocarbon) and NO_x (nitrogen oxides) emissions was obtained for iso-butanol. Deng et al. [10] experimentally and theoretically investigated the effect of using butanol-gasoline blend as fuel in gasoline engine on engine performance and exhaust emissions at different ignition and valve timing. They stated that the determination of the optimum ignition and valve timing for engine performance and exhaust emissions when used butanol/gasoline blend was important. ECU (engine control unit) must be also re-calibrated for blended fuel. Irimescu

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[8,11] experimentally analyzed the effects of blending isobutanol with gasoline on fuel conversion efficiency. According to the results obtained from chassis dynamometer, it was observed that fuel conversion efficiency generally decreased with pure isobutanol, and it increased slightly when 50% isobutanol compounded isobutanol-gasoline was used as engine fuel. Costagliola et al. [12] used ethanol-gasoline blend of 10%, 20%, 30%, and 85% ethanol and n-butanol/gasoline blend of 10% n-butanol in an SI (spark ignition) engine in order to examine the effects of these alcohol/gasoline blended fuels on combustion and regulated, unregulated organics and particulate emissions. The results demonstrated that the particulate emissions especially decreased between 60% and 90% when alcohol/gasoline blend for stoichiometric air fuel mixtures was used. Also, unregulated emissions such as benzene and benzo(a)pyrene reduced significantly. In the study [13], as the most suitable amounts of n-butanol/gasoline mixture (% by mass) based on emissions determined an SI engine having dual injection system at different operating conditions, they used n-butanol/gasoline blends as engine fuel. The experimental results demonstrated that NO and UHC emissions decreased considerably with increasing n-butanol ratio in blended fuels. This reduction occurred especially at 25%, 35% and 100% throttles. Venugopal and Ramesh [14] experimentally examined the effect of injection timing in a SI engine fueled with n-butanol, gasoline and n-butanol/gasoline blend. Experiments were carried out at different load and constant engine speed. According the test results, it was observed that neat butanol led higher engine torque and efficiency compare with gasoline and blended fuel at 60% throttle and suitable injection timing. In addition, CO_2 emission decreased compere to gasoline. The influence of iso-butanol addition to gasoline on BSFC, exhaust gas temperature, and BTE was experimentally investigated by Alasfour [15]. A hydra SI engine that had a single cylinder, spark ignition and fuel injection was used over a wide range of fuel/air equivalence ratio (from 0.8 to 1.3) for 30% volume iso-butanol/gasoline blend. The performance measurements were shown that BSFC increased when iso-butanol/gasoline blend was used. Furthermore, the BTE decreased when an iso-butanol/gasoline blend at an equivalence ratio of 1.0 as compared to those of unleaded gasoline. In the other study, it was examined the influence of pure ethanol and methanol in a gasoline engine on the combustion characteristics, engine performance and exhaust emissions with a wide open throttle and at the different CRs. The results illustrated that the use of pure ethanol and methanol fuels generally raised ICP (in-cylinder pressure), BSFC, BTE and brake mean effective pressure at all CRs [16].

The CR (compression ratio) of an engine is the ratio of the cylinder volume to its combustion. However higher CRs make gasoline engines subject to engine knocking if lower octane number is used, also known as detonation [17]. Attard et al. [18] researched the effect of CR on the engine performance, emissions and combustion parameters. The tests were carried out on a double-cylinder, four-stroke, 430 cc, naturally aspirated, gasoline engine. Experimental results showed that the values of minimum BSFC and maximum BTE were obtained with an increasing CR. Another study [19] experimentally investigated the effects of the CR on the engine performance of a four-cylinder engine in which the water compounded ethanol and 22% ethanol compounded ethanol–gasoline blend were used as fuel. According to the results obtained, it was observed that in both fuel types, with the increase of the CR, the engine torque, exhaust gas temperature, BTE and engine power rose and volumetric efficiency decreased. The BSFC reduced with the increase of the CR and the biggest decrease was observed in the water compounded ethanol fuel study. Cooney et al. [20] examined the influence of two different ethanol–gasoline blends on the combustion characteristics with a constant load and speed, as well as at different CRs of 8, 10, 12, 14, and 16:1, in the experiments. Moreover, it was shown that even though the burning duration decreased with E20 (ethanol–gasoline blends of ethanol containing 20%), it was not affected by any further ethanol addition to the gasoline.

As seen in the literature review, iso-butanol/gasoline blend can effectively reduce the exhaust emissions. On the other hand, the influence of the CR on the engine performance, combustion and exhaust emissions using iso-butanol/gasoline blended fuel in the gasoline engines was not clearly studied. Therefore, in this study, both the effects of CR and iso-butanol blended gasoline fuel on the engine performance, combustion and exhaust emissions were experimentally investigated.

2. Material and methods

The tests were performed on a single-cylinder, four-stroke, KG-type, 389 cc and air-cooled, gasoline engine. The engine had a cylinder bore of 88 mm, a stroke of 64 mm, a CR of 9:1. The schematic diagram of experimental setup is showing in Fig 1. Experiments were conducted at steady states for constant engine speed (2600 rpm) which was engine speed being provided maximum engine torque with a wide-open throttle. In the tests, while static value of ignition timing, which is 24° BTDC (before top dead center), was used in studies conducted with the gasoline fuel, blended fuels operating were applied to minimum ignition timing for the best torque (MBT). The MBT ignition timing values obtained from the blended fueled studies are given in Table 1. In order to determine the engine torque, the shaft of the test engine was coupled to an electrical dynamometer, which was loaded by electrical resistance. A strain load sensor was employed to determine the load on the dynamometer. Fuel consumption was quantified by combined container method. Air consumption was measured by inclined manometer.

In all experimental studies, the manometer liquid moved throughout the inclined tube from the inclined manometer was recorded. To find the air-fuel ratio occurring during the experiments, Equation (1) and Equation (2) were used [16].

$$\dot{m}_a = C_d \cdot \rho_a \cdot \frac{\pi \cdot d^2}{4} \cdot \sqrt{\frac{2 \cdot \rho_f \cdot g \cdot \Delta_l \cdot sin\beta}{\rho_a}} \quad (1)$$

$$F/A = \frac{\dot{m}_f}{\dot{m}_a} \quad (2)$$

where, $\dot{m}_a$ is the air mass flow rate (kg/s), C_d is discharge coefficient, g is the acceleration of gravity (m/s^2), ρ_a is density of air (kg/m^3), ρ_f is density of fuel (kg/m^3), Δ_l is the reading data on the inclined tube scale (mmH_2O), d is orifice plate diameter (m), β is inclined tube at angle with the horizontal and F/A is the air-fuel ratio occurring during the experiments. Fuel mass flow rate ($\dot{m}_f$) value for both gasoline and iso-butanol blended fuel was calculated by finding out the time that a particular amount of fuel in the tank is consumed.

In the experimental studies, the equivalence ratio (ϕ) was calculated as F/A divided by the stoichiometric fuel/air ratio $(F/A)_{stc}$ as shown in Equation (3) [16].

$$\phi = \frac{F/A}{(F/A)_{stc}} \quad (3)$$

The equivalence ratio values obtained from all experiments are given in Table 2.

Exhaust emissions such as CO (carbon monoxide), CO_2 and UHC were measured with a Bilsa Mod 210 infrared gas analyzer. ICP was

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