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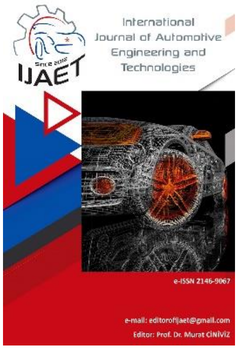

Original Research Article

Simulation analysis of cycle skipping strategy in SI engine fueled with ethanol gasoline mixture

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ABSTRACT

Researches are carried out with different methods to reduce the emissions emitted by conventional fuel engines. In addition to using alternative fuels, especially ethanol, in gasoline engines, fuel injection, and combustion controls are applied in various strategies. In this study, the effects of various cycle skipping strategies on emissions were analyzed through a numerical model of a single-cylinder naturally aspirated spark ignition (SI) engine. The validated model was fueled with an ethanol gasoline blend with 30% ethanol content. The model engine was operated at partial load and 1500 rpm constant engine speed under Normal (N), 1N1S, 2N1S and 3N1S cycle skip strategies. NOx emission increased with all strategies due to increased in-cylinder temperature with more fuel depletion in ignition cycles. The BSFC decreased by 9.93%, 13.67% and 5.93% in the 1N1S, 2N1S and 3N1S cycle skipping strategies, respectively. CO and HC emissions decreased with all cycle skipping strategies compared to the normal cycle.

Keywords: Cycle skipping, Spark ignition engine, ethanol blend, emissions, gasoline fuel.

1. Introduction

In recent years, interest in electric vehicles has been increasing rapidly in order to overcome the handicaps brought by conventional fuel vehicles. While vehicle manufacturers produce new models of electric motor and hybrid vehicles, they continue to produce vehicles with internal combustion engines. Many researchers aim to improve performance and emissions by providing combustion control with alternative fuels, fuel injection strategies and different cycle and control strategies. Alternative fuels that are widely used in spark ignition engines are ethanol mixtures. Ethanol has the characteristics of low viscosity, poor lubricity and long-term mixing with conventional petroleum fuels [1]. Ethanol gasoline blends are alternative fuels that reduce hydrocarbon emissions and carbon monoxide emissions [2 - 4]. Alcohol-gasoline blends such as ethanol can significantly reduce air pollution and the use of fossil fuels, as they provide significant improvements in HC, NOx, and smoke emissions [5, 6]. The skip fire strategy relies on disabling spark plug ignition or fuel delivery from the injector to disable the cylinder [7]. In addition, the intake air can be cut off to skip the cycle [8]. Lower fuel consumption can be achieved with different cycle skipping applications [9]. Less fuel consumption can be achieved by reducing the pumping losses and by skipping the cycle at partial loads [10]. In addition, turning the camshaft forward or backward has a very important effect on fuel consumption, which is applied earlier or later on valve opening and closing [11, 12]. Although the skipping cycle strategy contributes significantly to the reduction of fuel consumption, NOx emissions may increase due to the increase in the average cylinder temperature [13]. In addition, HC emission may increase due to the increase in oil entry from the crankcase into the cylinder or the increase in the flame extinguishing effect of the cylinder walls [14, 15].

Kutlar et al. In their study on a single-cylinder gasoline engine, they found that brake specific fuel consumption decreased by approximately 11% at partial loads [16]. Dogru et al. numerically examined the loop skipping application. They found that NOx emissions varied by about 39.4% [12]. Ritzmann et al. investigated the cylinder deactivation and restart function. They found that cylinder deactivation and re-activation increased fuel consumption [17]. Erdal et al. investigated the effects of electronically controlled cycle skipping strategy on emissions in a natural gas gasoline engine. They found significant improvements in HC and CO emissions, but an increase in NOx emissions [18]. Mohammed et al. discovered that NOx HC and CO emissions were reduced as a result of the research conducted at different engine speeds with mixtures of ethanol in the range of 10-40% [19]. Dhande et al. tested blends of ethanol gasoline mixed at different ratios and at different engine speeds. As a result, they found a 25% increase in volumetric efficiency and a 20% increase in engine power [20]. Palini et al., in their study on the effects of mixing gasoline-ethanol at various ratios and engine speeds, stated that thermal efficiency increased, CO and HC emissions decreased, but NOx emissions increased [21]. Turner et al. after examining ethanol and methanol gasoline blends, concluded that alcohols could be used gradually due to the difficulty of mixing [22]. In the study in which Kul and Ciniviz examined the gasoline mixtures formed with ethanol which they obtained from waste bread and fabricated ethanol, it was observed that the heat release rates in both ethanol mixtures increased as the ethanol percentage in the mixture increased. As the mixing ratio of ethanol in gasoline increased, HC and CO emissions decreased. It has been determined that the ethanol obtained from the bread added to the mixture is cleaner in terms of HC and CO emissions compared to the fabricated ethanol [23].

This study was implemented by modeling a single-cylinder spark-ignition engine in AVL Boost software. Unlike the cycle skipping strategy studies in gasoline engines in the literature, ethanol-gasoline emulsion fuel was used in the model engine operated at partial loads. Thus, in this study, the effects of both the cycle skipping strategy and the ethanol-gasoline mixture on emissions and performance were evaluated together.

2. Materials and Method

This study was carried out by modeling the single-cylinder naturally aspirated Honda GX 270 SI engine with real experimental data in AVL Boost software. The specifications of the test engine are given in Table 1. The validation of the model engine was ensured by the compatibility of the experimental data with the simulation data and the overlapping of the data, as seen in our previous study [23]. As can be seen in Figure 1, the in-cylinder pressure data obtained experimentally and theoretically in 2000 rpm were largely matched to each other. The Mixing controlled combustion (MCC) module in the software library was used for the combustion model in the model engine. The cycle skipping strategies were controlled by the Engine İnterface (EI) element in the simulation software. This apparatus in the software can be used to control various scenarios.

Table 1. Engine specifications

Parameter	Specifications
Cylinder number	1
Bore x stroke [mm]	77 × 58
Swept volume [cm^3]	270
Aspiration method	Natural
Compression ratio	8.5 / 1
Net power [HP]	8.4 (3600rpm)
Net torque [Nm]	19.1 (2500rpm)

3. Cycle-Skipping Modes

The cycle skipping strategy was made by fueling a 30% ethanol gasoline mixture at a constant engine speed of 1500 rpm in a single-cylinder SI engine. All experiments were carried out at constant partial engine load, BMEP 2 bar. In the study, the most suitable ignition advance was selected for the model and kept constant in all cycle skip modes. The first study was performed as a normal study (N) without skipping. The second application was applied as 1 normal cycle and 1 skip cycle (1N1S). Another application was applied as 2 normal cycles and 1 skip cycle (2N1S). In the fourth application, 3 normal cycles and 1 skip cycle (3N1S) were applied. In Figure 2, in-cylinder pressure raw curves of N, 1N1S, 2N1S and 3N1S cycle skipping strategies are shown. As can be seen in the curves, the in-cylinder pressure values increase as the cycle skipping frequency increases.

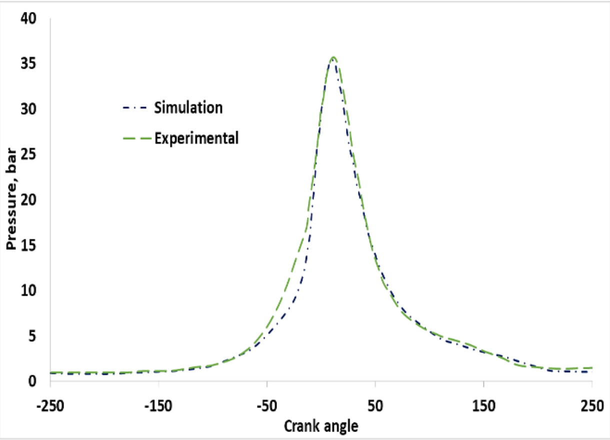

Figure 1 Pressure variations of experimental and theoretical results

4. Results

The effects of various cycle skipping strategies on fuel consumption and emissions of a single-cylinder SI engine fueled with a 30% ethanol-gasoline mixture in an AVL Boost numerical model engine were investigated. Experiments were carried out at 1500 rpm constant engine speed and BMEP 2 bar conditions.

Brake specific fuel consumption is shown in Figure 3. While the BSFC was in a decreasing trend with the 1N1S and 2N1S strategies, it started to increase again with the 3N1S strategy. Compared to the 30% ethanol gasoline blended normal engine, the BSFC decreased by 9.93%, 13.67% and 5.93% in the 1N1S, 2N1S and 3N1S cycles, respectively.

HC emission is shown in Figure 4. HC emission showed a significant increase in the 1N1S strategy. HC emission decreased with 2N1S and 3N1S strategies. Flame extinction is the most important cause of HC emission. With the extinguishing of the flames on the cylinder walls, the ratio of unburned HC increased.

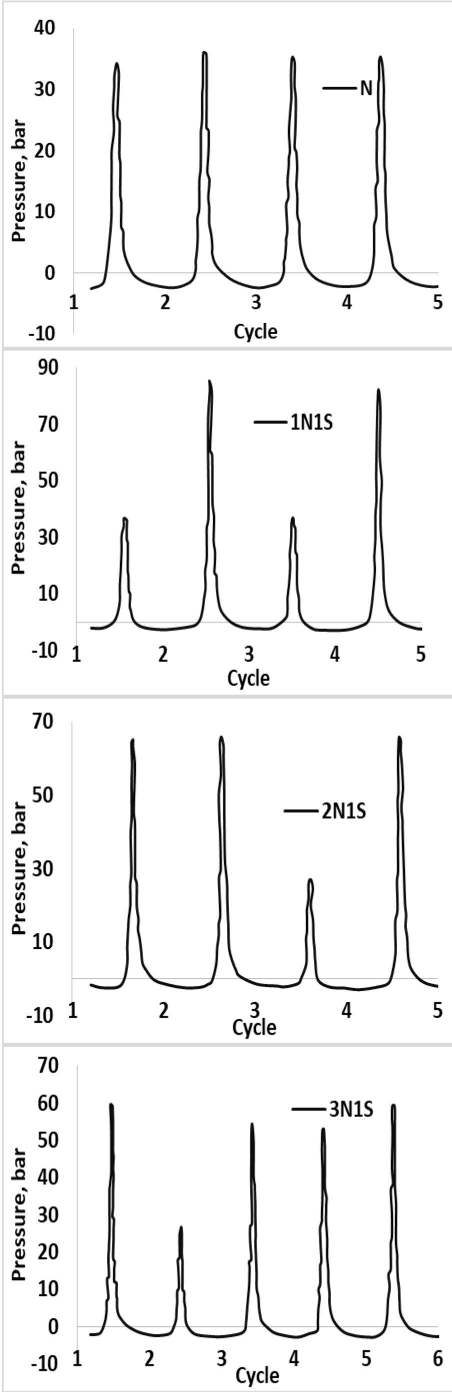

Figure 2 Pressures of skipping strategies

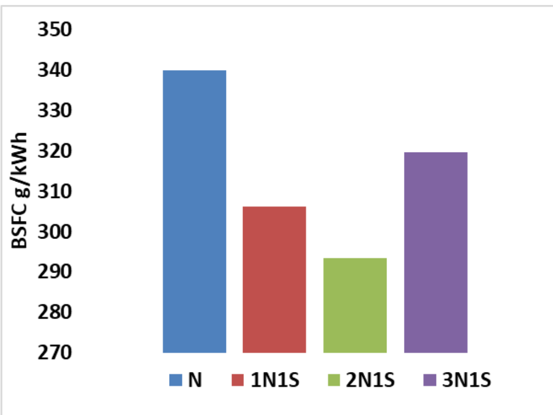

Figure 3 Comparison of brake specific fuel consumption of cycle skipping strategies

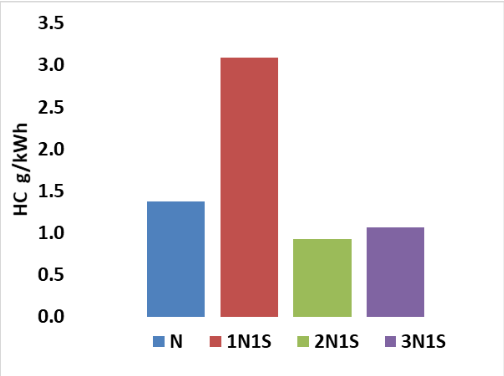

Figure 4 Comparison of HC emissions of cycle skipping strategies

In addition, the engine consumed more fuel to maintain its power, causing an increase in HC emissions. HC emission decreased by 32.76% and 22.31% in the 2N1S and 3N1S cycles, respectively, compared to the normal cycle.

NO_x emission is shown in Figure 5. NO_x emissions increased significantly with cycle skipping strategies. While in-cylinder exhaust gas is reduced in cycle skipping modes, more fuel is sent into the cylinder in ignition cycles to achieve the same engine power. Therefore, the increase in in-cylinder pressure and temperature with excess fuel caused serious increases in NO_x emissions. However, according to the 2N1S strategy, the NO_x emission has decreased by 54.65% in the 3N1S strategy.

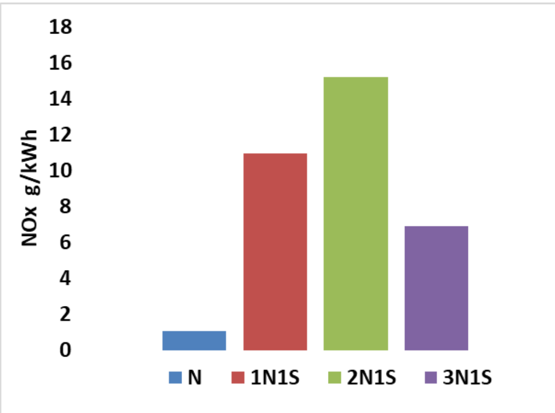

Figure 5 Comparison of NO_x emissions of cycle skipping strategies

CO emission is shown in Figure 6. CO emission was significantly reduced with the 1N1S and 2N1S strategies. However, with the 3N1S strategy, CO emissions tended to increase. According to the normal cycle strategy, the reason for the reduction of CO emissions in cycle skipping strategies can be explained as the reduction of residual gas in the cylinder in non-ignition cycles and better combustion. Because the exhaust gas remaining in the cylinder in the non-combustion cycle is almost completely removed, better combustion will occur with the increase in volumetric efficiency in combustion cycles. However, the slight increase in the 3N1S strategy can be explained by the increase in fuel taken into the cylinder and incomplete combustion. Compared to the normal cycle, CO emissions decreased by 53.32%, 63.09% and 58.64%, respectively, in 1N1S, 2N1S and 3N1S strategies.

The cylinder average pressure is shown in Figure 7. In-cylinder pressures increased as the number of cycle skipping increased. While the in-cylinder pressure was 33.91 bar in the normal cycle, it was 53.01 bar, 60.21 bar, and 69.30 bar in the 3N1S, 2N1S, and 1N1S strategies, respectively. The increase in pressure values as the number of cycle skips increases can be explained by the increase in the maximum heat release rate.

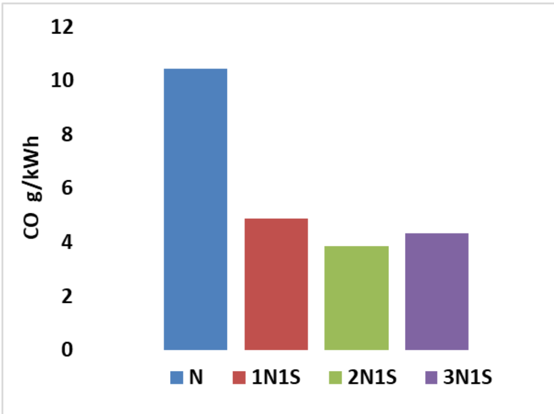

Figure 6 Comparison of CO emissions of cycle skipping strategies

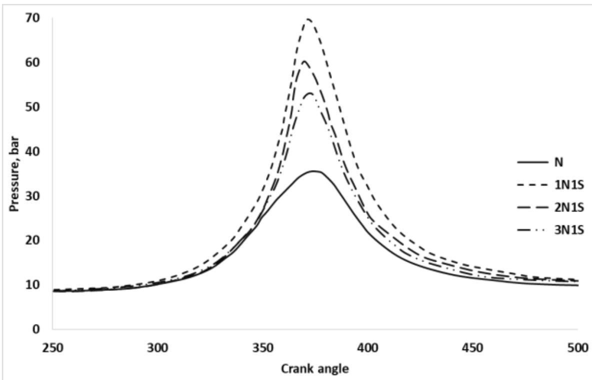

Figure 7 Comparison of cylinder pressure of cycle skipping strategies

The cylinder average pressure is shown in Figure 7. In-cylinder pressures increased as the number of cycle skipping increased. While the in-cylinder pressure was 33.91 bar in the normal cycle, it was 53.01 bar, 60.21 bar, and 69.30 bar in the 3N1S, 2N1S, and 1N1S strategies,

respectively. The increase in pressure values as the number of cycle skips increases can be explained by the increase in the maximum heat release rate.

5. Conclusion

Different cycle skipping strategies of a single-cylinder spark igniter engine fueled with ethanol gasoline mixture were investigated with AVL Boost simulation analysis software at partial load and 1500 rpm constant speed conditions. The main results of the analyzes can be summarized as follows:

- Brake specific fuel consumption in general decreased with cycle skipping strategies. The BSFC decreased by 9.93%, 13.67% and 5.93% in the 1N1S, 2N1S and 3N1S cycles, respectively.
- CO and HC emissions decreased with all cycle skipping strategies compared to the normal cycle. The highest reductions in CO and HC emissions were obtained with 2N1S, with the rates of 63.09% and 32.76%, respectively. HC emission tended to increase again with 3N1S.
- NOx emission increased with all strategies due to increase in-cylinder temperature with more fuel depletion in ignition cycles.
- As the cycle, which was skipped without combustion, became more frequent, the in-cylinder pressure peak value increased. The maximum cylinder pressure decreases as the cycle jump gap moves away from each other. The highest cylinder pressure was obtained with the 1N1S.
- As the number of cycle skipping applications increases, fuel consumption and emissions first improve and then worsen, depending on the intake of fresh air-fuel mixture, incomplete combustion and end-of-combustion temperature.

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