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Combustion duration influence on hydrogen-ethanol dual fueled engine emissions: An experimental analysis

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Abstract

The research presented in this article expresses experimental results of combustion duration effect on a dual fueled engine. In particular, the research was focused on the emissions occurred specifically from a hydrogen-ethanol dual fueled engine. This study was performed on a compression ignition engine that was converted to run and act as a spark ignition engine. This modified engine was fueled by hydrogen–ethanol with various percentage substitutions of hydrogen. The substitution was altered from 20 to 80% at a constant speed of 1500 rpm. The various engine emission characteristics such as CO, Hydrocarbon, and NO_x were experimentally determined. This study resulted that at a compression ratio of 11:1 and combustion duration of 25°CA, the best operating conditions of the engine were shown. Moreover, the optimum fuel combination was established at 60 to 80% of hydrogen substitution to ethanol. The experimental results also revealed that at 100% load and at compression ratios 7, 9, and 11; the CO and HC emissions have decreased while NO_x increased and followed with the increase in the percentage of hydrogen addition and combustion duration. It was concluded that the retarding combustion duration was preferred for NOx emission control in the engine.

Keywords: combustion duration; compression ratio; dual fuel engine; alternative fuels; compression ignition; spark timing.

I. Introduction

There are various alternative fuels which have been emerged in the energy sector. Among those alternative fuels, hydrogen and alcohol substances are attractively developed due to their practical importance. However, some disadvantages have occurred from the operation with ethanol in order to reduce the power output. This resulted in a misfire which reduces engine performance and wastes the existing fuel. Some researches show that mixing hydrogen with ethanol has properly reduced this drawback. While the hydrogen emerges a low ignition energy limit, along with elevated burning speed, the hydrogen-ethanol mixture was coming as an easier substitution to ignite, reduces misfire, and by this means reduces the released emissions [1].

Wang C *et al.* [2] conducted performance and emission studies on a passenger car that run by the hydrogen–gasoline engine. Previous experimental results showed that when the engine was started with only hydrogen and fueled with the gasoline, the hydrocarbons (HC) and carbon monoxide (CO) emissions content were condensed by 64.1% and 62.1%, respectively.

Park *et al.* [3] studied the hydrogen ratio and exhaust gas recirculation (EGR), especially on its effect on combustion and emission characteristics of hydrogen and diesel dual-fuel premixed charged compression ignition (PCCI) engine. They have found that implementing hydrogen or diesel dual-fuel PCCI mode could decrease the HC, CO, and nitrogen oxides (NO_x) emissions.

Huang *et al.* [4] studied characteristics on combustion which were implemented on a direct-injection spark-ignited engine under lean mixture conditions at various ignition time fueled by hydrogen and natural gas combinations. Their research has revealed that the ignition time has affected the emissions, and they found that the HC was decreased while NO_x was increased by escalating the ignition

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timing whereas the CO was slightly varied under different ignition timings.

Moreno *et al.* [5] conducted the experiments at different speeds and equivalence ratios. For each speed, the ignition time could be preserved independently for its equivalence ratio and blend used. It was observed that at the chosen ignition time, the hydrogen addition to the blend had improved the combustion. Moreover, they have found that due to the increase in the combustion temperature of hydrogen, the NO_x emissions at stoichiometric conditions were higher.

Hamdan *et al.* [6] have studied a compression ignition (CI) engine. The performance and emission characteristics of the CI engine were observed while inducting the hydrogen in its inlet manifold. The exhaust temperature along with NO_x emissions was determined while varying the ignition time, engine speed, and hydrogen content. The results revealed that for the same diesel mass flow and with hydrogen content increased, the thermal efficiency of the engine has increased.

Karagoz *et al.* [7] have evaluated the emission features from a hydrogen supplemented diesel engine. At full loads with hydrogen addition, a great improvement on CO, carbon dioxide (CO_2), and smoke emissions with an increase in NO_x emissions were found from his experimental studies.

Teng Su *et al.* [8] have developed a rotary engine which has a provision at the port to inject n-butanol and hydrogen. Their main aim was studying the emissions and the combustion characteristics of a rotary engine fueled by hydrogen-blended n-butanol. This research has developed a self-developed hybrid electronic control unit to regulate the injection duration of a mixture of hydrogen and n-butanol. The research has shown that the HC emissions were reduced by 54.5% while the hydrogen volume fraction was increased from 0 to 6.3%. In addition, CO_2 and CO emissions were also reduced with a substantial increase in hydrogen blending fraction. The last result was about NO_x emissions that found to be increased because of the increasing of the chamber temperature.

Fanbo Meng *et al.* [9] have studied the emission characteristics of hydrogen and n-butanol fueled engine. The hydrogen addition fractions of 0%, 2.5%, and 5% were used under spark timings of 10°, 15°, 20°, 25°, and 30° crank angle before top dead center CA BTDC. The obtained results showed that CO and HC emissions were decreased while the NO_x emissions were increased along with the hydrogen escalation.

Sridhara Reddy *et al.* [10] have studied the effect of compression ratios (CR) on the performance and the emissions of a diesel-CNG dual fuel engine by adding hydrogen fraction as a combustion booster. Their results revealed that the addition of hydrogen in CNG had given better results than diesel-CNG dual fuel operation.

Yasin Karagoz *et al.* [11] investigated how the hydrogen addition variation affects engine performance, emissions, and combustion characteristics. It was found from their study that with hydrogen induction by 25 and 50% of total charge energy, there was a decrease in smoke emissions with an increase in nitrogen oxides. After increasing the hydrogen content, an increase was observed in HC although the CO_2 and CO gaseous emissions were significantly reduced.

This research discusses the effect of combustion duration on emission characteristics such as CO, HC, and NO_x emissions. The research focus was particularly on hydrogen-ethanol dual fuel implementation on three different compression ratios. The compression ratio has been set at 7:1, 9:1, and 11:1. Thereafter, experimental studies were conducted to define the effect of combustion duration on the emission characteristics. The main goal was to get an updated understanding on the interaction between combustion duration and emission characteristic.

II. Materials and methods

A. Research engine and experimental setup

This work was implementing a single cylinder direct injection diesel engine (Figure 1) which was installed using the specifications mentioned in Table 1. This engine was converted by changing the diesel fuel system with a carburetor in order to be able to operate in petrol. The carburetor was later attached to the air intake manifold of the engine, and a spark plug was mounted in place of the diesel injector. A suitable provision was provided to admit hydrogen in the inlet manifold [12]. The different spacers were arranged between the cylinder and the cylinder head to vary compression ratio. The compression will be modified from 7 to 11 ratio. The Eddy current dynamometer was connected to the engine. A varying timing arrangement is applied to the engine to operate the engine under spark timing. The spark timing could be adjusted by altering this arrangement mechanically [13]. A specific software then analyzes the combustion duration period within various degrees and the rate of the released heat [14]. Detail specification of the instruments is described in Table 2. The temperature was recorded using K-type thermocouples positioned at several engine points (i.e., inlet, exhaust of the engine, engine head, cooling water inlet, and cooling water outlet). To measure engine exhaust emissions, an advanced AVL five-gas analyzer was used.

B. Research testing

The final test was performed to observe the engine emission on finding the effect of combustion duration on the various engine emission characteristics (i.e., CO,

Table 1.
Engine specifications

Engine Specifications	Value
Cylinder diameter	80 mm
Cylinder capacity	552.64 cc
Stroke length	110 mm
Orifice diameter	15 mm
Rated power	3.7 kW
Rated speed	1500 rpm
Ignition source	Spark plug
Compression ratio	7:1 to 11:1
Combustion chamber	Disk shaped

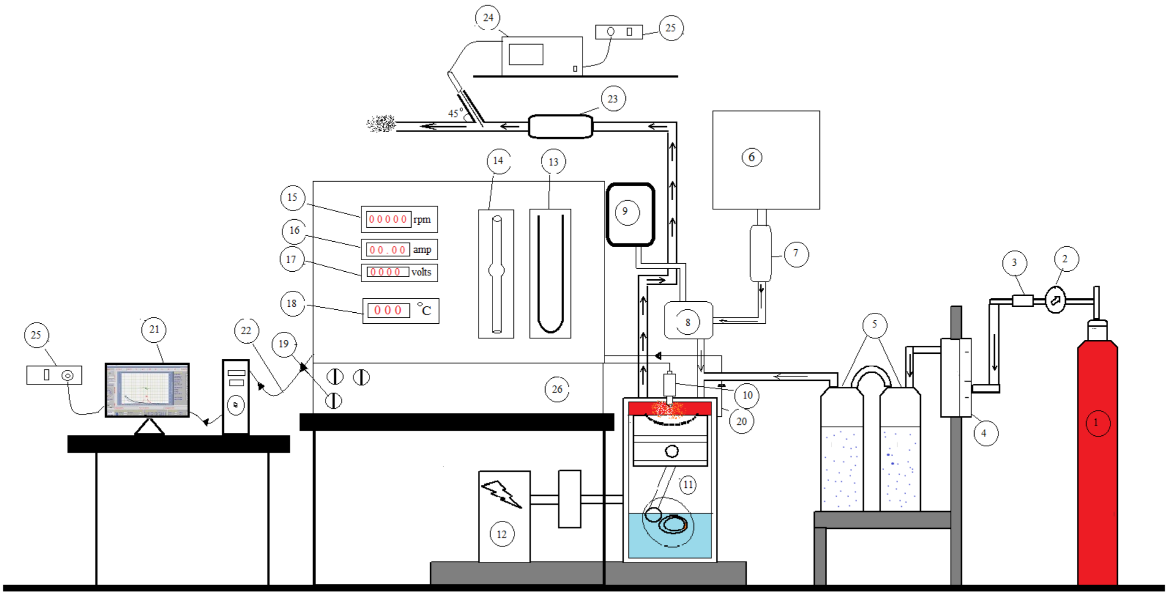

Figure 1. Experimental setup; (1) hydrogen gas cylinder; (2) pressure gauge; (3) flash back arrestor; (4) hydrogen gas flow controller; (5) flame arrestor; (6) air tank; (7) inlet air heating unit; (8) carburetor; (9) fuel (ethanol) tank connected to carburetor; (10) spark plug; (11) variable compression ratio (VCR) engine; (12) Eddy current dynamometer; (13) manomater; (14) burrete; (15) speed indicator; (16) current indicator; (17) voltage indicator; (18) temperature indicator; (19) loading unit; (20) piezoelectric sensor; (21) computer interfaced with VCR engine; (22) cable connecting the sensor to computer; (23) calorimeter; (24) exhaust gas analyzer; (25) power supply; (26) control panel

Table 2.
Instrumentation specifications

Particulars	Specifications	Uncertainty
Temperature sensor	Radix, type RTD	±1.1%
	Radix, thermocouple type "K" measures the temperature of exhaust gases before and after calorimeter. Range 0 to 400°C	±0.7%
Piezo sensors	PCB piezotronics	±0.1%
Load sensor	Sensortronics	±0.1%
Exhaust gas analyzer	MN-05 multi gas analyser.	CO % vol ±1.15% O_2 % vol ±0.5% NO_x (ppm) ± 0.1%
Dynamometer	10000 rpm maximum speed and 12.5 N-m torque	Speed ±1.2% and torque ±0.5%

HC, and NO_x). The tests were directed using three designated compression ratios (7, 9, and 11) and the speed was constantly set at 1500 rpm for each ratio. The set on the throttle was varied while the load was kept persistent at 100% in kW. Within this set, the hydrogen and ethanol flow rate were controlled to keep the speed at a constant state. This control process was conducted by adjusting the volume of hydrogen substitutions with a specific increment (20% increment for 0 to 80% hydrogen substitution). Moreover, to achieve the best torque, an adjustment was made to the spark timing.

III. Results and discussions

A. Combustion duration effect on HC concentration

The decreases of HC concentration on engine exhaust linearly advance the combustion duration. Delaying combustion duration shall increase the fraction implied on the unburned fuel, and also increase the fraction of lean mixture within the combustion chamber, and finally decreases the combustion temperature. This matter had triggered a reduction of HC post-flame oxidation especially throughout the expansion stroke. Another reason for the decrease in HC emission could be explained based on the surface to volume ratio, which increases as the spark is advanced and this reduces the HC emissions.

It is also revealed by Figure 2, Figure 3, and Figure 4 that because time interval reduction from the ending of fuel induction to the beginning of ignition there is a decrease in HC concentration linearly. With the variation of hydrogen percentage substitution from zero to 80%, the percentage reduction in the HC values is 68.2% at CR 7, 72.63% at CR 9, and 77.59% at CR 11, respectively. The effect of the changing on compression ratio from 7:1 to 11:1 for pure ethanol and 80 % of hydrogen substitutions is a reduction of HC by 15.6 and 40.58 % respectively. HC reduction up to 21.26% has

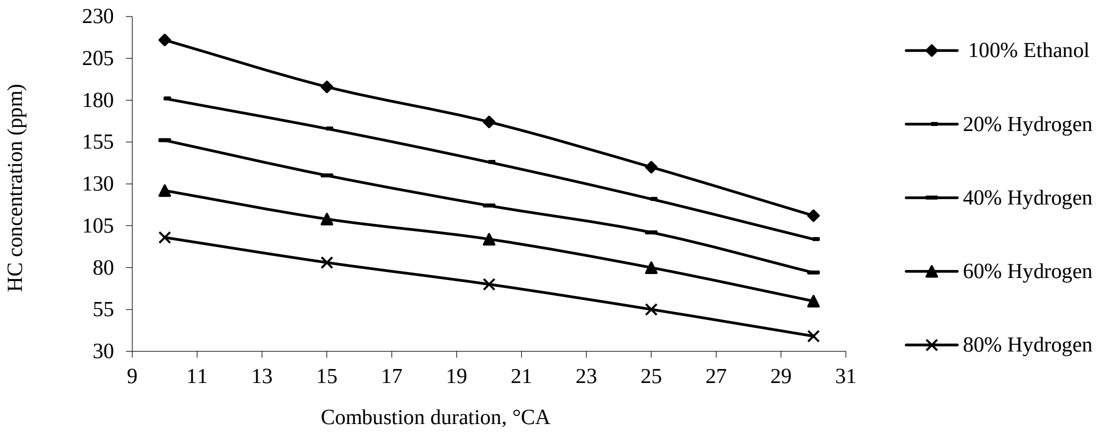

Figure 2. Variation of HC concentration with combustion duration at CR 7:1

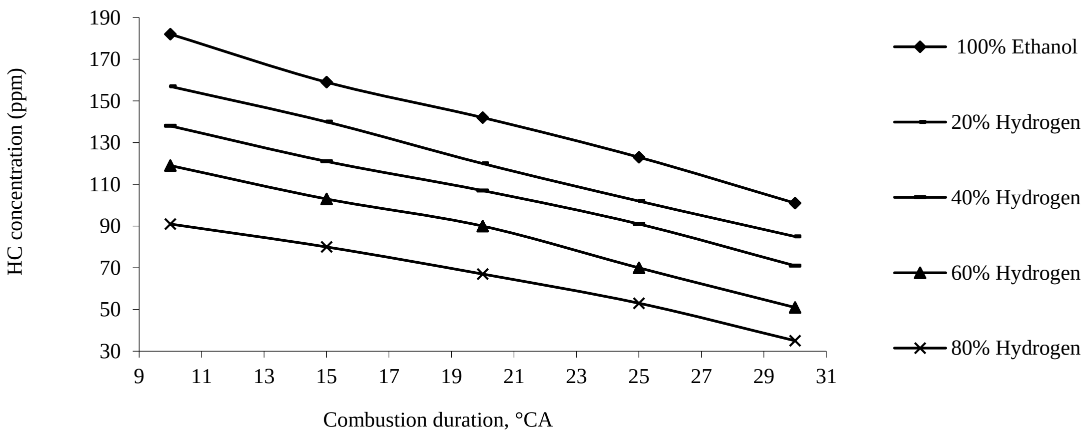

Figure 3. Variation of HC concentration with combustion duration at CR 9:1

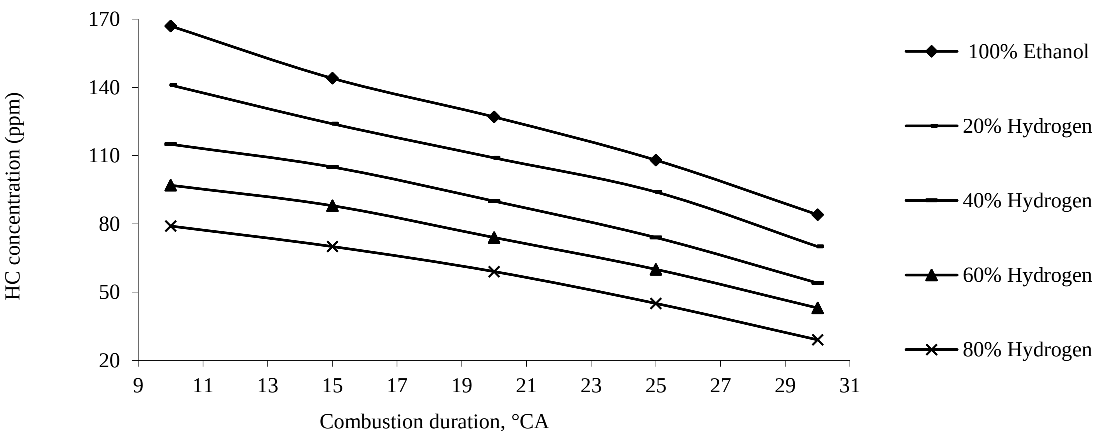

Figure 4. Variation of HC concentration with combustion duration at CR 11:1

been found as the effect of the variation of the compression ratio from 7:1 to 11:1. This CR alteration was made at the same change in substitution percentage. Figure 2 expresses the HC concentration variation within combustion duration at compression ratios 7:1. Figure 3 shows the similar variation of HC concentration at compression ratios 9:1. Finally, Figure 4 indicates the slight reduction when implemented at compression ratios 11:1.

B. Combustion duration effect on CO concentration

Low CO concentration can be seen in Figure 5, Figure 6, and Figure 7 for both ethanol combustion and ethanol–hydrogen dual fuel combustion. This is mainly because of the high diffusivity of hydrogen and reduction in carbon atoms for ethanol combustion and ethanol–hydrogen combustion.

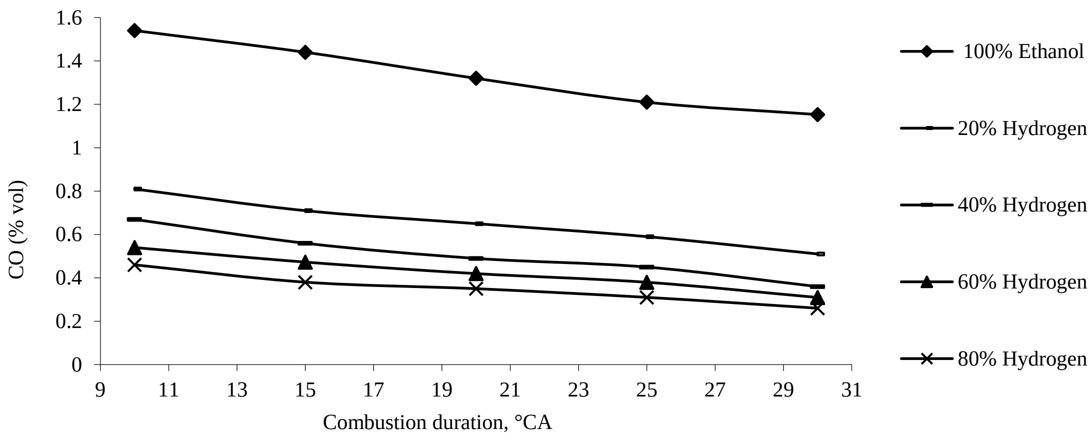

Figure 5. Variation of CO emissions with combustion duration at CR 7:1

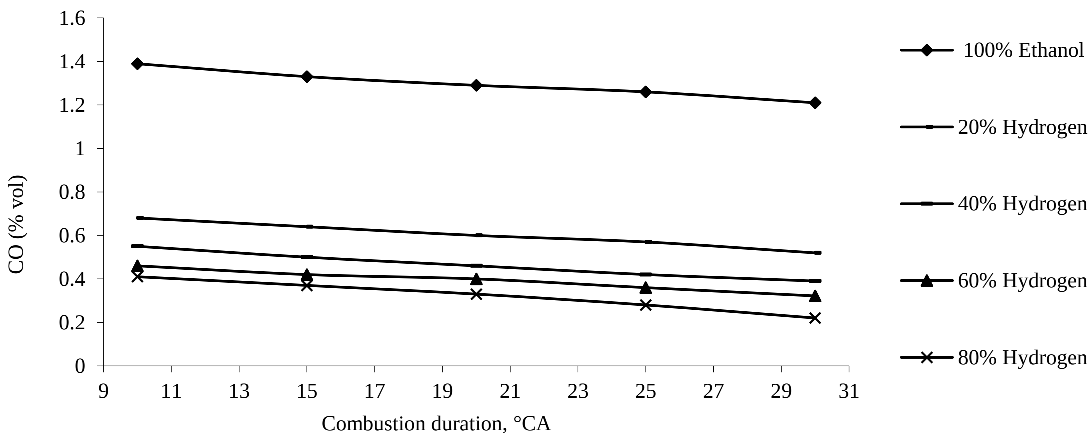

Figure 6. Variation of CO emissions with combustion duration at CR 9:1

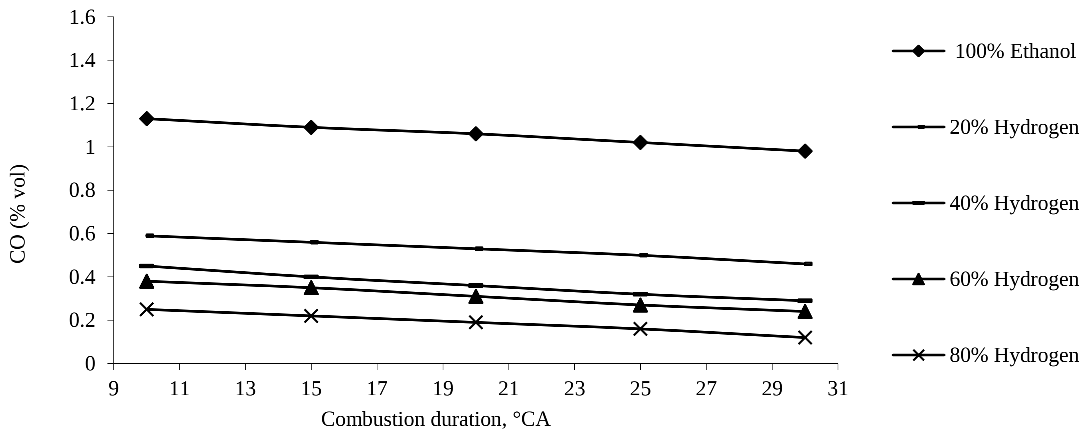

Figure 7. Variation of CO emissions with combustion duration at CR 11:1

Following the variation of the hydrogen substitution percentage from 0 to 80%, CO emissions reduction has occurred by 72.7%, 77.6%, and 79.9% for 7, 9, and 11 compression ratios respectively. It was also found that the reduction of CO by 30.4% had been found when the CR was altered from 7:1 to 11:1 at the same substitution percentage. The experimental tests also revealed that at 100% load CO concentration reduction happened at those three compression ratios.

C. Combustion duration effect on NO_x concentration

The NO_x concentration increases almost exponentially by advancing the combustion duration (Figure 8, Figure 9, and Figure 10). As mentioned, the higher NO_x emissions at the advanced spark timings for all the hydrogen substitutions to ethanol are due to the higher peak temperatures realized at those timings. The increase of NO_x as the combustion duration varied from

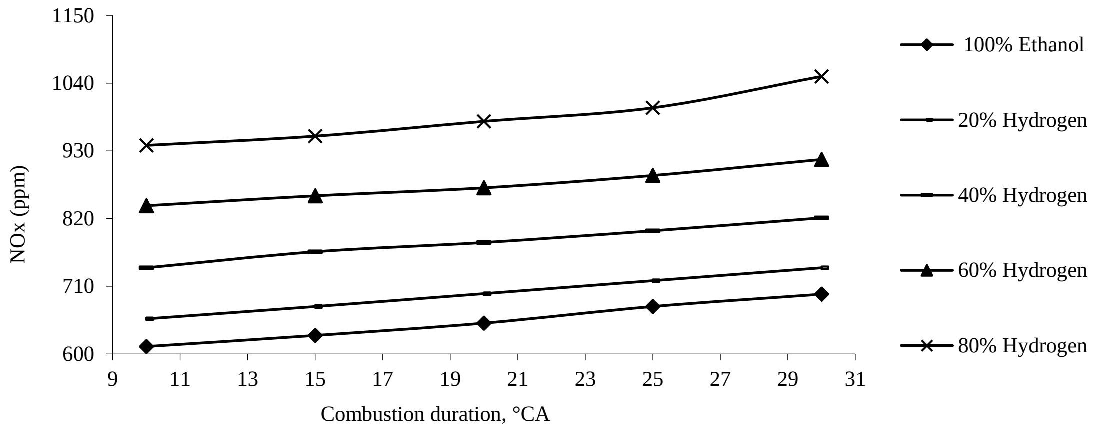

Figure 8. Variation of NO_X emissions with combustion duration at CR 7:1

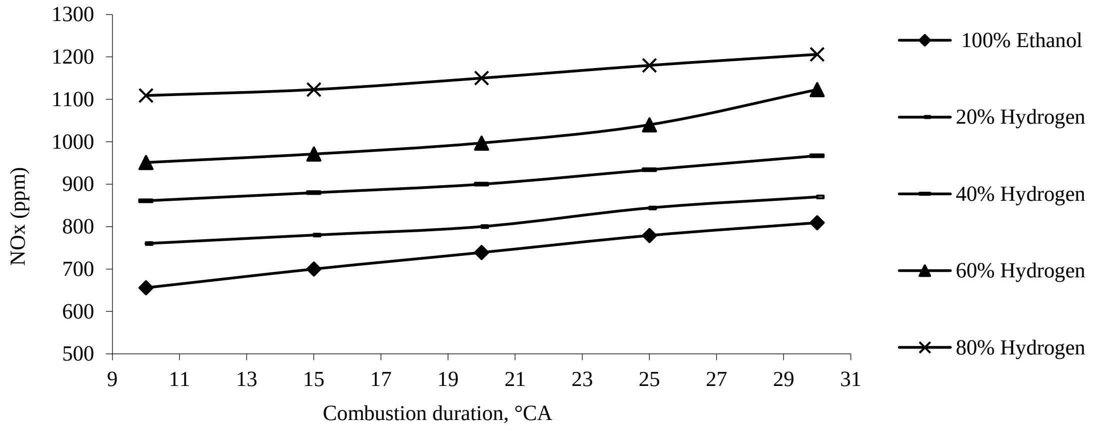

Figure 9. Variation of NO_X emissions with combustion duration at CR 9:1

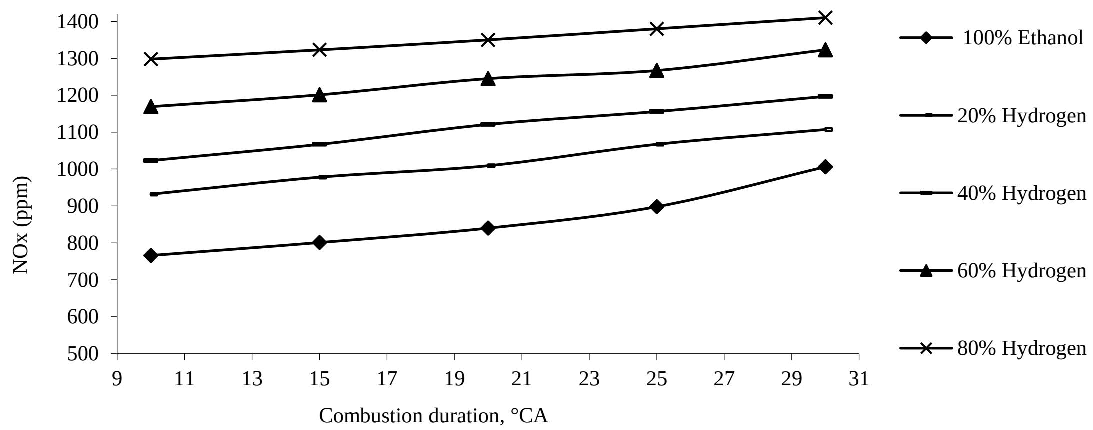

Figure 10. Variation of NO_X emissions with combustion duration at CR 11:1

10 to 30° before top dead center (TDC) of 80 to 0% by volume, and with a 20% hydrogen decrement at CR 7:1 is 11.92, 8.1, 10.94, 12.63, and 13.8% respectively. Whereas under similar conditions of operation at compression ratios 9 and 11, the increase of NO_x for different hydrogen substitutions is found as 23.3, 14.47, 12.31, 18, 8.74%, and 31.33, 18.7, 17, 13.17, 8.62%. Thus, it can be seen that by varying the combustion duration from 10 to 30° and compression ratio from 7:1 to 11:1, the minimum increment percentage in NO_x was around 8.62% at CR of 11:1. The NO_x levels were found to be higher because of the higher percentages of hydrogen substitutions used in the study. In place of the percentage of hydrogen, an addition was changed from 0 to 80%. It was found that for 7, 9, 11 compression ratios, the NO_x has increased by 58.62, 59.3, 62.74% respectively at 100% load that might be caused by increasing in chamber temperature [8].

As can be seen from Figure 8, Figure 9, and Figure 10, the NO_x formation is depends on combustion duration. Any small changes in combustion duration resulted in a change in NO_x emissions [15]. Therefore, from the results, it is analyzed that the retarding combustion duration is preferred for NO_x emission.

IV. Conclusion

The increasing of hydrogen substitution and the decreasing in carbon to hydrogen ratio are responsible for CO and HC reduction. Due to the high diffusivity of hydrogen and reduction in carbon atoms for ethanol combustion and ethanol–hydrogen combustion, the CO concentration remains low. The optimum fuel combination and the best operating conditions observed in the present study were 60 to 80% of hydrogen substitution and 11:1 compression ratio. The best combustion duration for emissions reduction was found to be 25°CA. Therefore, the result of this research mentioned that the retarding combustion duration was preferred for NO_x emission control in the engine. However, the engine operating parameters showed an effect on the combustion duration, and therefore, the designer has to consider these parameters carefully. Thus it can be conclude that combustion duration is needed to be carefully designed to attain a better performance and emission characteristics of the engine.

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