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Effect of combustion duration on the emission characteristics of a hydrogen-ethanol dual fuelled engine

Syed Yousufuddin

Assistant Professor, Department of Mechanical Engineering, Jubail University College,
Royal Commission for Jubail and Yanbu,
Jubail Industrial City-31961,
P.O Box - 10074
Kingdom of Saudi Arabia
E-mail: yousufuddins@ucj.edu.sa, syedyousufuddin@rediffmail.com

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ABSTRACT

This paper focuses the results of the effect of combustion duration on the emission characteristics. A spark ignition engine is modified as compression ignition engine and employed with dual fuel mode of hydrogen-ethanol. It is observed with a compression ratio of 11:1 and at 1500 rpm with 25^0CA using hydrogen substitution to ethanol the optimal condition are found. The various engine emission characteristics like CO, Hydrocarbon, NO_X and exhaust gas temperature effects were studied. In the present investigation at various compression ratios the combination of fuel mode are taken up in order to study the emission and knock control.

Nomenclature

BTDC	before top dead centre
CA	crank angle
CI	compression ignition
CR	compression ratio
DC	direct current
MBT	maximum brake torque
SI	spark ignition
TDC	top dead centre

1. INTRODUCTION

Motor vehicles emit large quantities of carbon monoxide, hydrocarbons, nitrogen oxides and such toxic substances like fine particles. Each one of these can cause adverse effects on human health and environment. The exponential growth and usage of fossil fuel vehicles air pollution increased asymptotically. Initially, these problems were limited to city centers; but, today lakes, streams and even remote forests are also experiencing significant degradation. To counter this problem hydrogen and alcohol are substituted but resulted in reduction of brake power. While conventional energy sources such as natural gas and oil are non-renewable, hydrogen and alcohol can be coupled to act as renewable energy sources. Ethanol has a higher octane rating, is considered a renewable fuel and the engine needs to be only slightly modified. Lean operation of ethanol fuelled engines has additional drawbacks. Lean mixtures are hard to ignite, despite the mixture being above the low fire (point) limit of the fuel. Hydrogen can be used in conjunction with ethanol provided it is stored separately. Mixing hydrogen with oxygenated hydrocarbon fuel like ethanol reduces all of these drawbacks. The reduction of emissions and misfire are found with hydrogen-ethanol mixture [1].

Wang C et al. [2] experimented with hydrogen-gasoline the reductions of emissions are reduced in the range of 62.1 to 64.1%. The vehicle emissions performance could be improved from the Euro-II emissions standard of the original vehicle to the Euro-IV emissions standard of the hybrid hydrogen–gasoline engine-powered vehicle.

Park et al. [3] investigated the effects of hydrogen ratio and exhaust gas recirculation (EGR) on combustion and emissions in a hydrogen/diesel dual-fuel premixed charge compression ignition (PCCI). They found that the control of combustion phasing could be improved using hydrogen enrichment and EGR due to the retarded combustion phasing with a higher hydrogen ratio. Also, they found that Hydrocarbon (HC) and carbon monoxide (CO) emissions were reduced significantly in a hydrogen/diesel dual-fuel PCCI mode with a similar NO_x emissions level as that of the diesel PCCI mode.

The investigations of Zuohua Huang et al. [4] on spark ignition engine with natural gas hydrogen blends observed that HC concentration in the exhaust decreased while the NO_x rate increased.

Moreno et al. [5] studied at various speeds and loads with independent fuel blends. The NO_x emissions has been found to be high at stoichiometric conditions.

Hamdan et al. [6] focused the behavior with hydrogen ignition timing speed. The results showed the increase of thermal efficiency with hydrogen content. The effect of hydrogen supplement on engine efficiency is more pronounced at low engine speed and part-load. The hydrogen supplement causes an increase in NOx emissions which is attributed to the increase in the combustion temperature and as a result, lower smoke opacity numbers are attained.

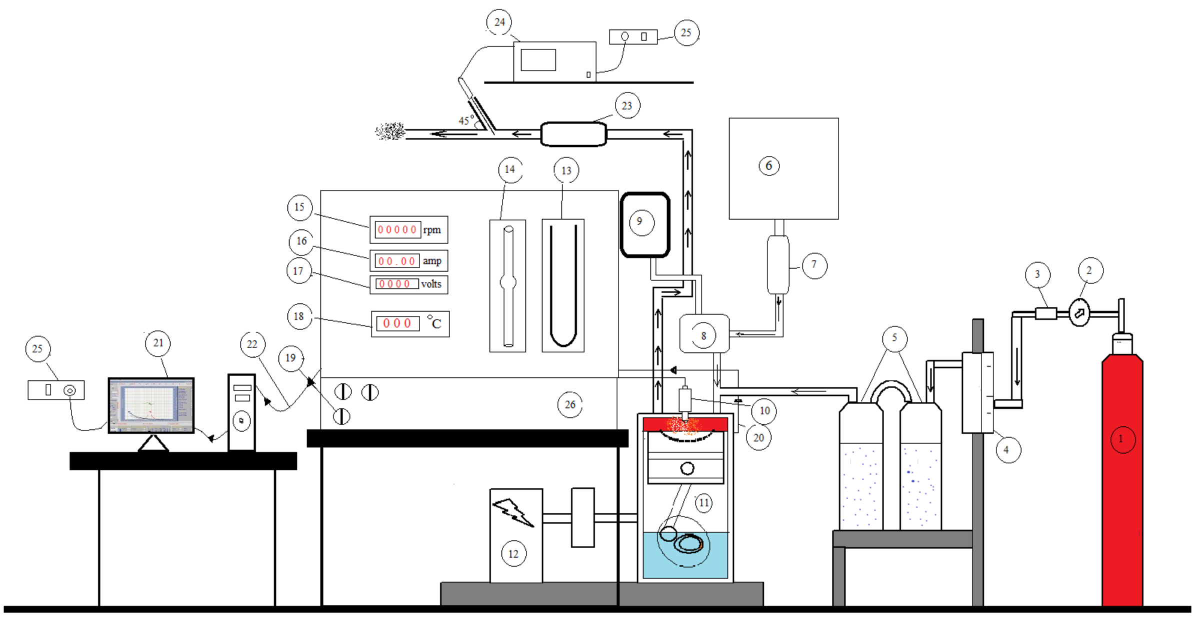
Karagoz [7] in his paper discusses the effect of engine load on performance of an H_2 enriched diesel engine. The hydrogen assisted diesel combustion was experimentally investigated on a CI engine. With hydrogen enrichment in diesel found that reduction in CO and CO_2. Also, a dramatic increase on NO_x emissions with H_2 addition at full loads was obtained. An important reduction on NO_x was achieved with H_2 addition at partial loads.

Combustion duration, which is a very significant operating parameter that affects S.I engine emissions and not much earlier work was made on hydrogen–ethanol operating on dual fuel engine under actual operating conditions, therefore this study concentrates on the effect of combustion duration (which was varied by varying the equivalence ratio) on emission characteristics like CO, Hydrocarbon, and NO_X emissions effects of a hydrogen-ethanol dual-fuel proportion with different percentage substitutions of hydrogen (i.e. 0-80% with an increase of 20% by volume) at three different compression ratios of 7:1, 9:1 and 11:1. These experimental works is carried out to study the effect of combustion duration on the engine emission characteristics to know the interaction between these parameters.

2 EXPERIMENTAL PROCEDURE

In the current investigation a single cylinder direct injection diesel engine works at low compression ratios with a provision of hydrogen inductment is employed as shown in Fig.1. An eddy current dynamometer is coupled to record the brake power. The specifications are enlisted in Table 1. For a given quantity and quality of the mixture under a given load setting the timing which gave the maximum speed is taken as the MBT spark timing. The contact breaker points and the condenser of the ignition circuit are fixed on a bakelite disc. The disc is mounted on the engine camshaft over which a small cam is made to operate the contact breaker points. The angular position of the contact breaker points with respect to the cam decides the spark timing and it could be altered at will by a suitably designed linkage which is provided on the engine test rig. The special software facilitates a data acquisition and analysis. The engine electronic control system provided access to all calibration parameters allowing the user to set a desired equivalence ratio (by adjusting fuel flow rate), combustion duration and ignition timing. The test rig equipped with thermocouples in conjunction with the digital temperature indicators. The K-type of thermocouples (Table 2) arranged at various points enable to record temperature of inlet, exhaust, cooling water, engine head, lubricating oil etc. A non-dispersive infrared gas analyzer is employed for measuring exhaust emissions. The NO_X and HC are measured in ppm while CO emissions by volume.

Various compression ratios are employed and the results are recorded at constant speed of 1500 rpm and at full load. The hydrogen and ethanol flow rates are so adjusted appropriately during experimentation.



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.Manometer 14.Burrete 15.Speed indicator 16.Current indicator 17.Voltage indicator 18.Temperature indicator 19.Loading unit 20.Pysoelectric 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.

Figure 1 Experimental Test Rig with necessary instrumentation

Table 1 Engine specifications

Engine specification	Data
Bore (mm)	80
Stroke (mm)	110
Cylinder Capacity (cm^3)	552.64 cc
Compression ratio (made available)	7:1 – 11:1
Ignition source	Spark plug
Combustion Chamber	Disk-shaped combustion (with a flat piston and chamber celing)

Orifice diameter (mm)	15
Rated power (kW)	3.7
Rated speed (rpm)	1500

Table 2 Engine Instrumentation

PARTICULARS	SPECIFICATIONS	UNCERTAINTY
Temperature sensor	Radix, Type RTD, PT100 measures the temperature of water inlet & outlet for Engine and Calorimeter. Range 0-250 ºC	±1%
	Radix, Thermocouple type "K" measures the temperature of Exhaust gases before and after Calorimeter. Range 0-400 ºC	±0.8%
Load sensor	Sensortronics, Model No 60001.	±0.2%
Piezo Sensors	PCB Piezotronics, Model SM111A22 Range 0-350 bar	±0.1%
Exhaust gas analyzer	MN-05multi gas analyser.	CO % vol ± 1.18% O_2 % vol ± 0.7% NOx (ppm) ± 0.2%
Dynamometer	Saj Test Plant Pvt. Ltd, Model No AG10.Maximum Speed of 10000 rpm and Torque of 11.5 N-m	Speed ±1% and torque ±0.4%

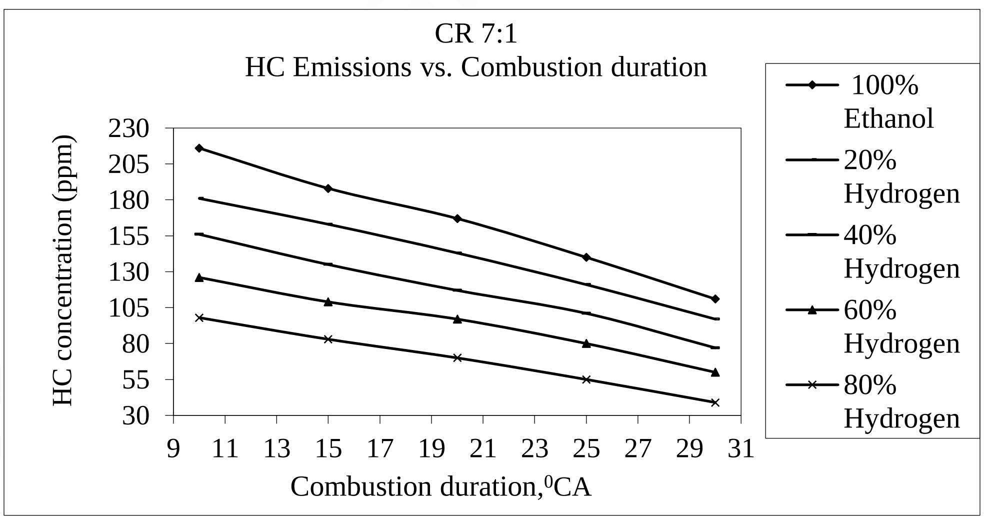


Figure 2 Variation of HC concentration with combustion duration at CR 7:1 and 1500 rpm

3. RESULTS AND DISCUSSION

3.1. Effect of Combustion duration on engine exhaust HC concentration

The engine exhaust HC concentration decreases linearly advancing the combustion duration. The variation in combustion duration will affect the mixture stratification and increase the fraction of lean mixture and decrease combustion temperature. Another reason for the decrease in HC emissions could be explained based on the surface to volume ratio, which increases as the spark is advanced and this reduces the HC emissions. This resulted in the increase of HC concentration with postponing the ignition timings. It is also revealed from Figs. 2, 3 and 4 that HC concentration decrease linearly with shortening the time interval from the ending of fuel admission to the ignition start regardless of hydrogen fractions.

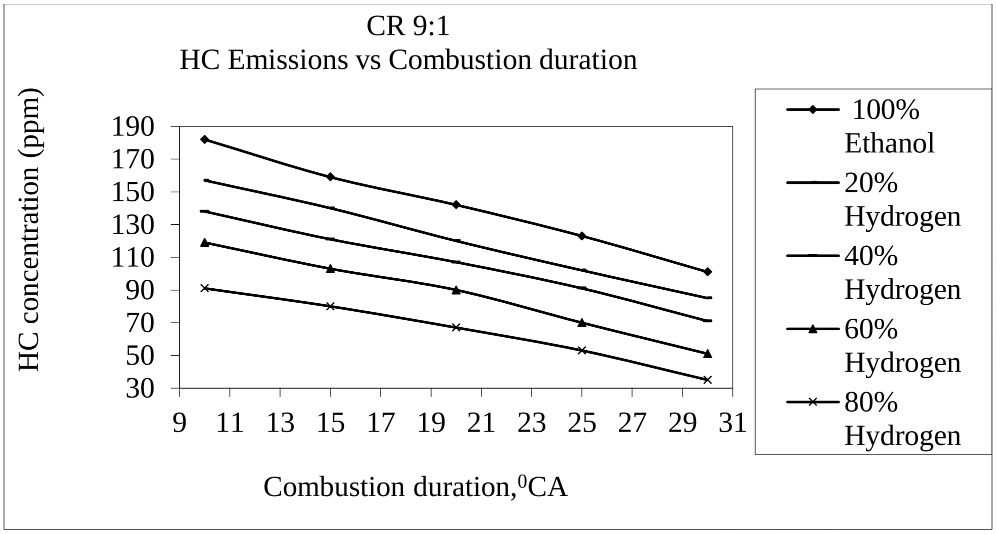


Figure 3 Variation of HC concentration with combustion duration at CR 9:1 and 1500 rpm

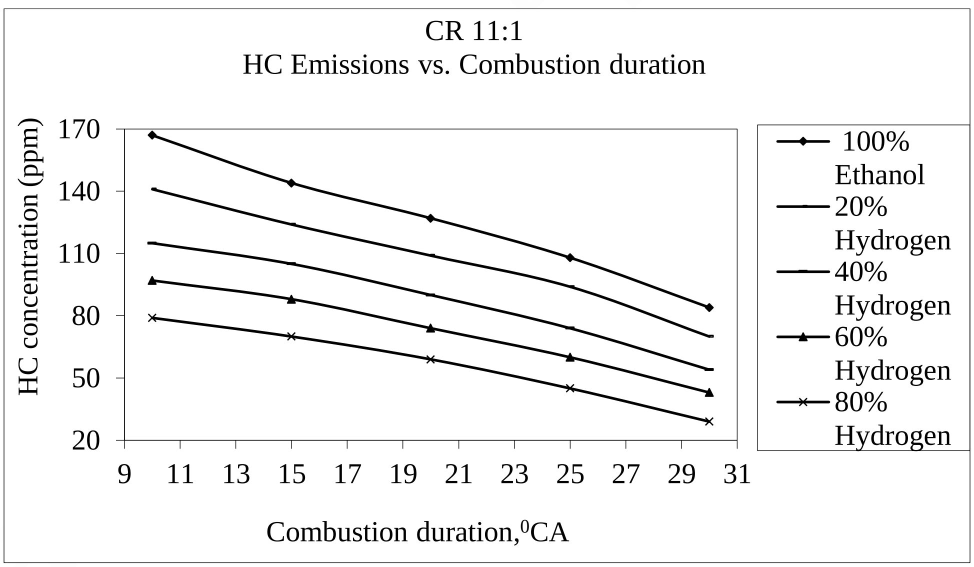


Figure 4 Variation of HC concentration with combustion duration at CR 11:1 and 1500 rpm

3.2 Effect of Combustion duration on engine exhaust carbon monoxide concentration

CO concentration (Figs.5, 6 and 7) remains low value for both ethanol combustion and ethanol–hydrogen dual fuel combustion and this is as mainly due to the reduction in carbon atoms concentration in the blended fuel and the high molecular diffusivity of hydrogen which improves mixing process and hence combustion efficiency.

As the percentage hydrogen substitution is varied from zero to 80% the CO emissions were reduced by 72.72, 77.6 and 79.9% for 7, 9, 11 C.R respectively. It was also found that when the compression ratio when changed from 7:1 to 11:1 for the equal change in percentage substitution caused a reduction of CO by 30.4%. The experimental tests also revealed that at 100 % loadCO concentration decreased with the increase in percentage of hydrogen addition for all compression ratios.

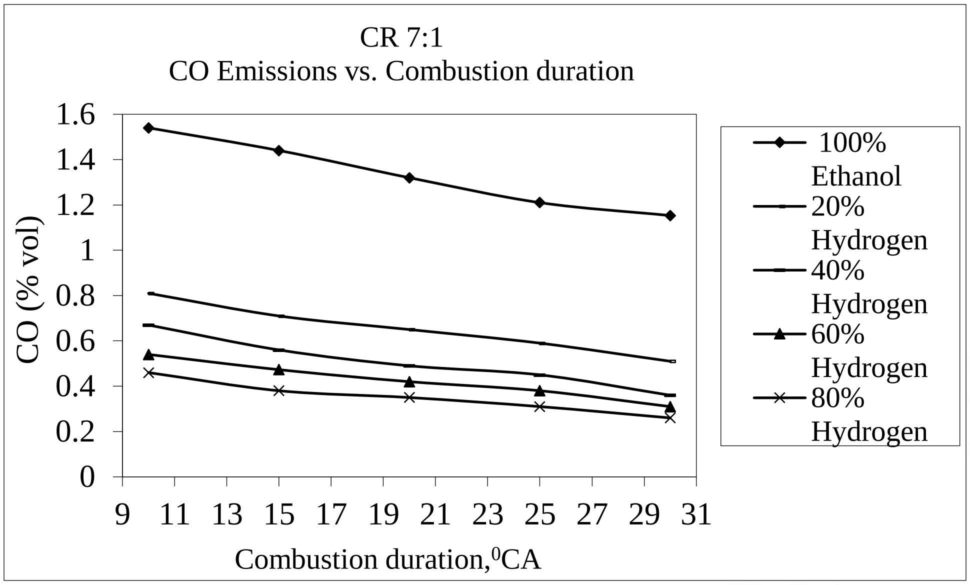


Figure 5 Variation of CO emissions with combustion duration at CR 7:1 and 1500 rpm.

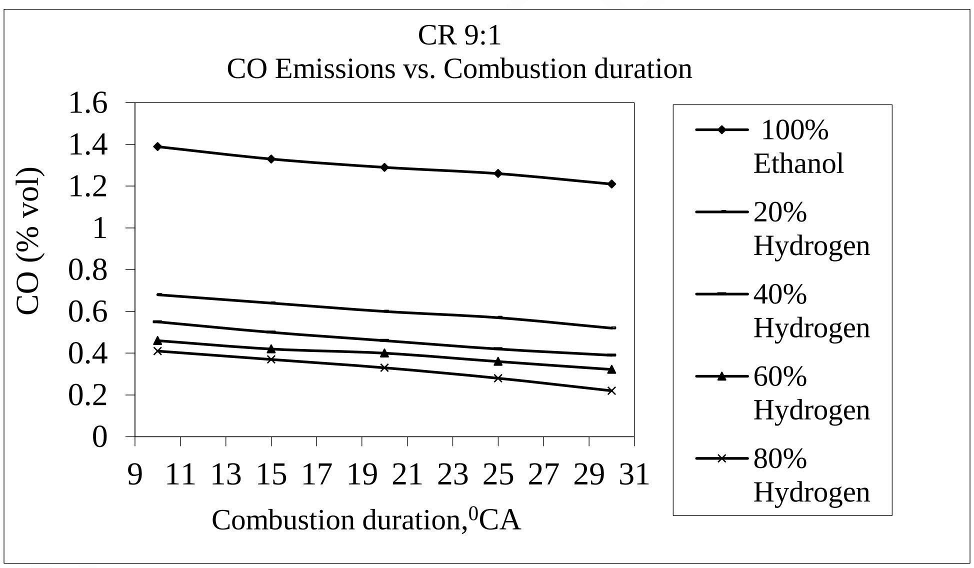


Figure 6 Variation of CO emissions with combustion duration at CR 9:1 and 1500 rpm.

3.3 Effect of Combustion duration on NO_x concentration

The Decrease in the time intervals among the ending of fuel admittance and combustion duration period will create high blend stratification and make a rapid combustion thus, increasing the combustion temperature and NO_x concentration. The NO_x concentration (Figs. 8, 9 and 10) increases almost exponentially with advancing the combustion duration. As mentioned the higher NO_x emissions at the advanced timings of the spark, 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 10 to 30^0 before TDC for 80 – 0% by volume with an decrement 20 % of hydrogen at CR 7:1 is found as 11.92, 8.1, 10.94, 12.63, and 13.8% respectively. At compression ratios in the range 9 to 11 operated under similar conditions it is found that NO_X level increases at various hydrogen substitutions of 0 – 80% by volume with an of increment 20 % is found as 23.3, 14.47, 12.31, 18, 8.74% and 31.33, 18.7, 17, 13.17, 8.62%. Thus, it is seen that by varying the combustion duration from 10 to 30^0 and compression ratio from 7:1 to 11:1 the minimum percentage increase in NO_x noticed was around 8.62% at CR of 11:1. The inlet temperatures could control the value of NO_X.

As can be seen from Figs. 8, 9 and 10, the NO_x formation was observed to be a very strong function of spark advance and combustion duration. Any small changes in spark timing resulted in a substantial change in NO_x emissions. It seems that the advanced combustion duration increased the temperature level in the burnt gases which in turn increased the NOx level. Therefore, from the results it is analyzed that the retardingcombustion duration is preferred for NO_xemission control and to avoid knock. The exhaust temperature is also affected by combustion duration.

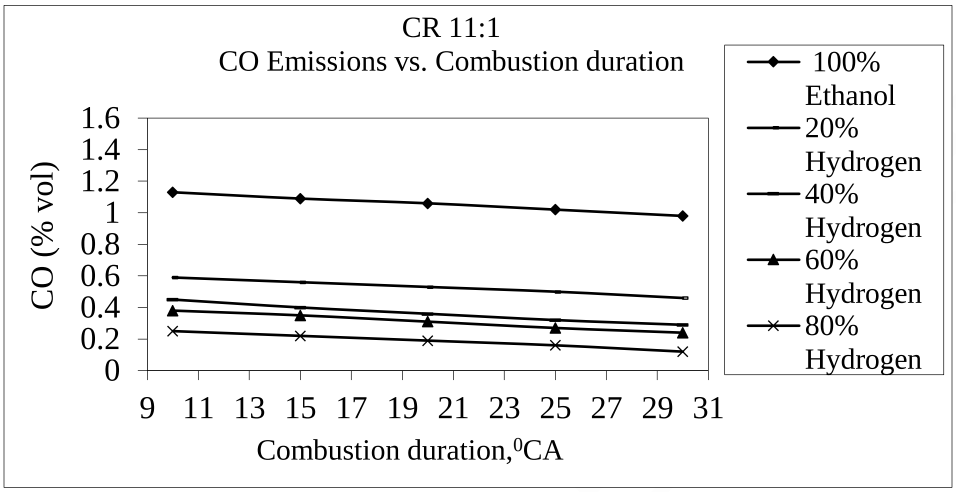


Figure 7 Variation of CO emissions with combustion duration at CR 11:1 and 1500 rpm.

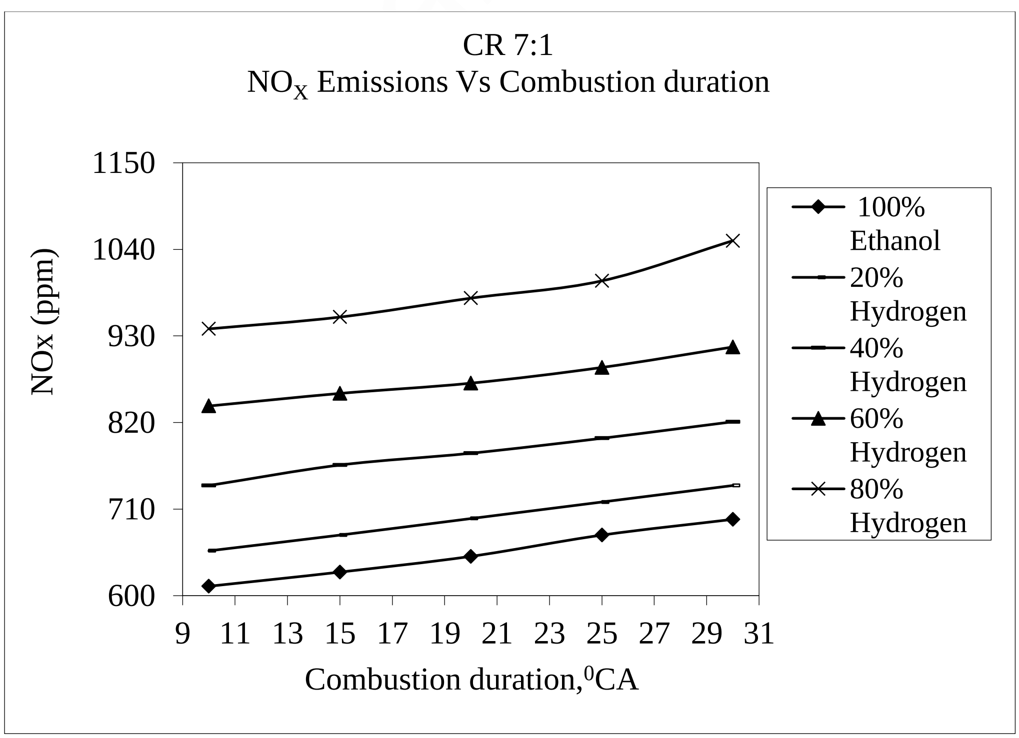


Figure 8 Variation of NO_X emissions with combustion duration at CR 7:1 and 1500 rpm

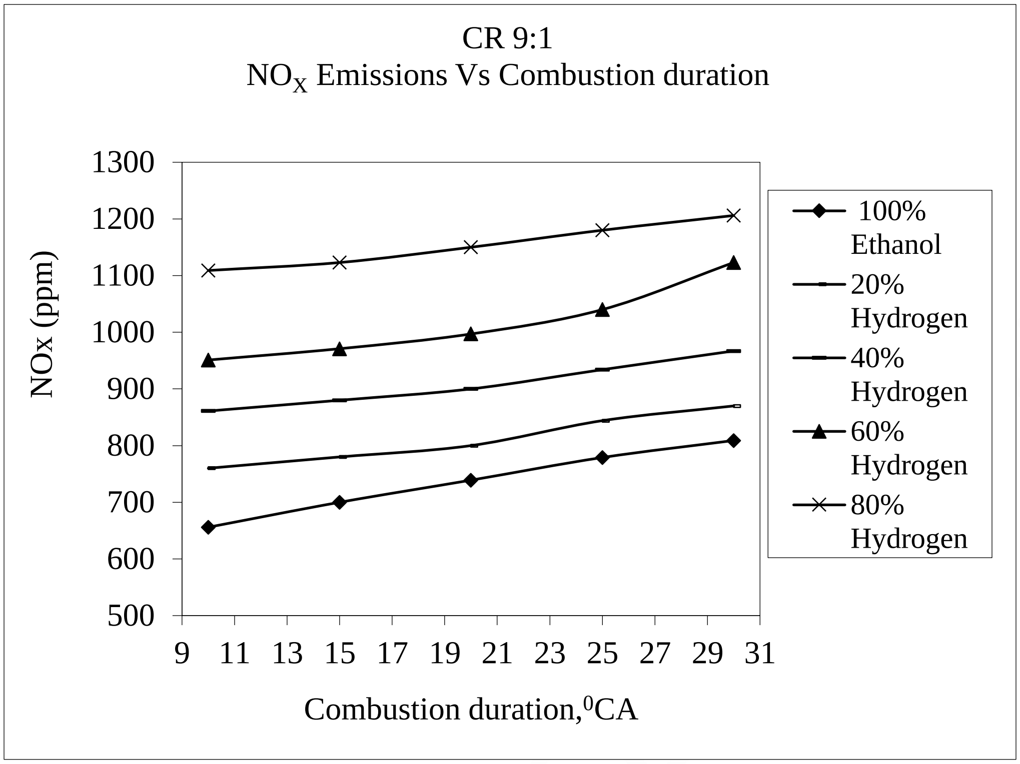


Figure 9 Variation of NO_X emissions with combustion duration at CR 9:1 and 1500 rpm

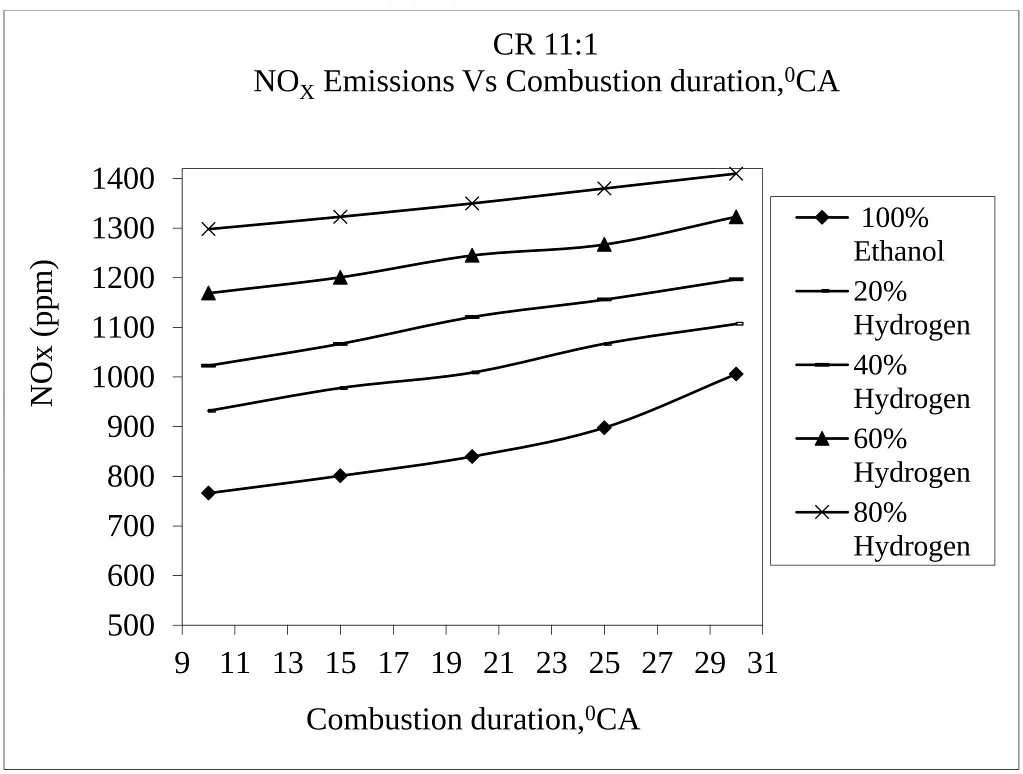


Figure 10 Variation of NO_X emissions with combustion duration at CR 11:1 and 1500 rpm

4. CONCLUSIONS

1. When the compression ratio changed from 7:1 to 11:1 the combustion duration decreased for 100% ethanol was 30.98% while the reduction was 17.8% with 80% hydrogen.
2. With the variation of percentage substitution of hydrogen from zero to 80% the percentage reduction in the HC values are 68.2, 72.63 and 77.59% for CRs of 7, 9 and 11 respectively.
3. The effect of C.R when changed 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.
4. The effect of compression ratio when changed from 7:1 to 11:1 for the equal change in percentage substitution is reduction of HC by 21.67%.
5. As the percentage hydrogen substitution is varied from zero to 80% the CO emissions were reduced by 72.72, 77.6 and 79.9% for 7, 9, 11 compression ratios respectively.
6. The effect of compression ratio when changed from 7:1 to 11:1 for the equal change in percentage substitution is reduction of CO by 30.4%.
7. CO concentration decreased with the increase in percentage of hydrogen addition for all compression ratios at 100 % load.
8. The reduction in HC and CO are attributed to reduction C/H ratio and combustion temperature.
9. CO concentration remains low for both ethanol combustion and ethanol–hydrogen dual fuel combustion and this is as mainly due to the reduction in carbon atoms concentration in the blended fuel and the high molecular diffusivity of hydrogen which improves mixing process and hence combustion efficiency.
10. By varying the combustion duration from 10 to 30^0 and compression ratio from 7:1 to 11:1 the minimum percentage increase in NO_x noticed was around 8.62% at CR of 11:1.
11. The NO_x formation observed to be a very strong function of spark advance. Any small changes in spark timing resulted in a substantial change in NO_x emissions. It seems that the advanced spark timing increased the temperature level in the burnt gases, which in turn increased the NOx level.
12. NO_x level was found to be higher with higher C.R and higher percentages of hydrogen substitutions.
13. At 100% load as the percentage of Hydrogen substitution was varied from zero to 80% it was found that the NO_X increased by 58.62, 59.3, 62.74% for 7, 9, 11 compression ratios respectively.
14. In the current investigation the optimum fuel combination is found to be 60-805 hydrogen substitution to ethanol at compression ratio of 11:1.
15. The optimum combustion duration for emissions reduction was found to be 25^0CA.
16. Therefore, from the results it is analyzed that the retarding combustion duration is preferred for NO_x emission control and to avoid knock.

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Conflicts of Interest: The authors declare no conflict of interest.

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