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Emission Formation Comparison of Spark Ignition Engines Using Different Fuels

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Abstract

Alternative fuels are a fun renewable resource that can help minimize particle pollution from internal combustion engines. At a constant engine speed of 2500 rpm, a comparative numerical analysis was undertaken to analyze the impacts of four alternative fuels (ethanol, hydrogen, gasoline, and liquefied petroleum gas (LPG)) on exhaust gas emissions. Carbon monoxide, nitrogen oxide, and unburned hydrocarbons are all monitored as exhaust gases. According to this study, using fuels including ethanol and hydrogen can significantly reduce emissions. With hydrogen, the majority of hazardous contaminants in exhaust gas are significantly decreased. In comparison to gasoline, hydrogen contains relatively clean unburned hydrocarbons. Ethanol and hydrogen are clean fuels that do not contribute to increase in net emissions from engines. The findings showed that ethanol fuel emits less carbon monoxide than regular gasoline, but LPG emits more CO. Furthermore, ethanol fuel burns cleaner and produces less CO than gasoline. In comparison to LPG fuel engines, NOx emissions were greater for gasoline fuel engines. Nonetheless, ethanol-fueled engines created less NOx than gasoline-fueled engines. When working in lean conditions, the NOx emission of the hydrogen-fueled engine was about ten times lower than that of a gasoline-fueled engine. The studies also demonstrated that hydrogen fuel engines emit less HC pollution than gasoline fuel engines, but gasoline fuel engines emit more than ethanol fuel engines.

Keywords: Emissions, Fuel, Ethanol fuel, Hydrogen Fuel, Spark Ignition Engine.

1. Introduction

In regional and global operations for both industry and transportation, internal combustion engines are presently the most reliable source of power and the most efficient energy conversion systems [1,2]. Exhaust gas emissions such as HC, CO, and NOx, which are hazardous to human health, the atmosphere, and the environment, have resulted from the over usage of internal combustion engines.

In an industrialized culture, maintaining a clean environment has also become a major concern. Automobile and motorcycle pollution is a significant environmental issue that must be addressed. Internal combustion engines with alternative energy sources within environmentally friendly fuels have become one of the most important subjects for researchers [3].

CNG, HCNG, LPG, LNG, biodiesel, biogas, hydrogen, ethanol, methanol, dimethyl ether, producer gas, and P-series have all been tested [4]. Where it is derived from non-petrochemical sources. These fuels have the advantage of emitting fewer pollutants into the atmosphere than gasoline, and most of them are more economically viable than oil and renewable [5].

Alcohols (methanol and ethanol) and LPG have some advantages over gasoline as a fuel for spark-ignition engines, such as superior anti-knock characteristics and lower CO and unburned HC emissions [6]. Suppliers are increasingly interested in investigating LPG as a transportation fuel from an environmental standpoint. Due to its composition and CO2 emission levels, it was discovered that liquid petroleum gas, which is generally a blend of propane and butane, provides an advantage in terms of harmful hydrocarbon emissions and ozone production [7]. Because alcohol contains oxygen atoms, it can be classified as a partially oxidized fuel [8,9]. Ethanol is mostly made from renewable resources like biomass and agricultural feedstock. As a result, ethanol is commonly employed as a substitute fuel in internal combustion engines. The octane number of ethanol exceeds the octane number of gasoline. Because of ethanol's high octane number, it can be used as a fuel in a SI engine with a greater compression ratio. The ethanol's latent vaporization heat increases the cooling effect in the cylinder, which increases volumetric efficiency. Ethanol is cleaner to burn than gasoline, producing less CO, CO2, and NOx. Hydrogen also has several particular advantages as an energy source, such as high efficiency, ease of storage, transportation, and conversion. Hydrogen has a substantially higher flammability limit than methane, propane, or gasoline, and its minimum ignition energy is an order of magnitude lower [10,11]. The ignition delay period, flame development length, quick-burning duration, and overall burning angle of hydrogen fuel are significantly shorter than those of gasoline and diesel engines [12] due to its exceptional ignitability and high adiabatic flame temperature. In fact, hydrogen and gasoline can be burned together in a variety of air-fuel ratios, resulting in great thermal efficiency and lower pollutant emissions [13]. The effects of employing four different fuels (gasoline-ethanol-hydrogen and LPG) on exhaust emissions in spark-ignition engines at a constant engine speed of 2500 rpm were investigated using MATLAB in this study.

2. Modelling Analysis

The Vibe 2-Zone Model is used to assess the combustion process of an AVL BOOST port manifold injection four-stroke SI engine. NOx emissions were computed in the model using the Pattas and Haftner calculation techniques, which involve considering and extending six Zeldovich equations. CO emissions were calculated using the Onorati approach, which is extensively used in zero-dimensional (0D) and one-dimensional (1D) software. The D'errico model, which is the most often used model in SI engines, was used to determine HC emissions. Crevice and HC absorption contributions, desorption mechanisms, and partial/incomplete combustion effects were all considered in the generation of HC. This model was set up to run on four different fuels: gasoline, ethanol, hydrogen, and LPG. To calculate combustion kinetics and intermediate processes during combustion, as well as emissions, MATLAB software was employed. Table1 shows the engine specifications (1).

Table 1 Engine specification (1).

Particulars	Specifications
Manufacturer	Korea
Engine Model	KIA, 16 Valves
Combustion system	MPI system
Number of cylinders	4 cylinders
Bore	86 mm
Stroke	86 mm
Compression ratio (CR)	10.5:1 (-)

3. Emissions Analysis

The amount of CO is estimated following 2 reactions based on Onorati et al. [14, 16] in Table 2.

Table 2 Two reactions to predict CO production [14, 16].

	Stoichiometry	Rate
R1	$CO+OH= CO_2+H$	$r_1= 6.76.10^{10} . e^{\left(\frac{T}{1102.0}\right)} . C_{CO}\ C_{OH}$
R2	$CO+O_2=CO_2+O$	$r_2= 2.51.10^{12} . e^{\left(\frac{-24055.0}{T}\right)} . C_{CO}\ C_{O2}$

The final rate of CO production/destruction in [mol/cm^3] is calculated as:

$$R_{co} = C_{const} . (r_1+r_2) . (1-\alpha) \quad (1)$$

$$\text{Where} \quad \alpha = \frac{C_{CO,act}}{C_{CO,equ}} \quad (2)$$

Pattas and Hafner's [15] NOx formation model in AVL Boost utilizes the well-known Zeldovich process [14]. Table 3 shows the rate of NOx production for six reactions.

Table 3 Reactions in NO_x formation mechanism [14].

	Stoichiometry	Rate $K_i=k_{0,i}\ T^a\ e^{\left(\frac{-TA}{T}\right)}$	K_0 [cm^3 mol s]	a [-]	T_A [K]
R_1	$N_2+O=NO+N$	$R_1=K_1 . C_{N2}\ C_O$	4.98E13	0.0472	38048.01
R_2	$O_2+N=NO+N$	$R_2=K_2 . C_{O2}\ C_N$	1.48E08	1.5	2859.01
R_3	$N+OH=NO+H$	$R_3=K_3 . C_N\ C_{OH}$	4.22E13	0.0	0.0
R_4	$N_2O+O=NO+NO$	$R_4=K_4 . C_{N2O}\ C_O$	4.58E13	0.0	12130.6
R_5	$O_2+N_2=N_2O+O$	$R_5=K_5 . C_{O2}\ C_{N2}$	2.25E10	0.825	50569.7
R_6	$OH+N_2=N_2O+H$	$R_6=K_6 . C_{OH}\ C_{N2}$	9.14E07	1.148	36190.66

The concentrations (Ci) are molar concentrations under equilibrium conditions with units [mol/cm^3] for all reactions rates ri. The concentration of N2O is computed using the following formula [14].

$$C_{N2O} = 1.1802.10^{-6} . T^{0.6120} . e^{\frac{9471.6}{T}} . C_{N2} . \sqrt{P_{O2}} \quad (3)$$

The final rate of NO production-destruction is estimated as [mol/cm^3]

$$r_{NO} = C_{PostProcMulti} . C_{Kinetic\ Multi}\ 2.0 . (1-\alpha^2) . \frac{r1}{1+\alpha . AK_2} \frac{r2}{1+AK_4} \quad (4)$$

With

$$\alpha = \frac{C_{NO,act}}{C_{NO,equ}} . \frac{1}{C_{PostProcMulti}} \quad (5)$$

$$AK_2 = \frac{r1}{r2+r3} \quad (6)$$

$$AK_4 = \frac{r4}{r5+r6} \quad (7)$$

The hydrocarbon emission level described by the equation below [14] depends strongly on mass in the crevices through two first mechanisms

$$m_{crevice} = \frac{PVcrevice\ .M}{RTpiston} \quad (8)$$

The total hydrocarbons released into the exhaust gases undergo a complex mechanism of oxidation due to the existing high temperature in the chamber. To predict the oxidation speed of the amount of HC, the Arrhenius equation is used [14, 17]:

$$\frac{dC_{HC}}{dt} = -F_{OX}\,.\,A_{OX}.\exp\left(\frac{-T_{OX}}{T}\right).\,C_{O_2}.\,C_{HC} \quad (9)$$

$$\frac{\partial w_F}{\partial t} - D\ \frac{\partial^2 w_F}{\partial r^2} = 0 \quad (10)$$

4. Results and Discussions

In this section, carbon monoxide emissions, NOx Emissions, HC Emissions, HC Creation of Oil and HC formation of Crevice will be researched at an engine speed of 2500 rpm under diverse fuels gasoline, hydrogen, LPG, and ethanol fuels.

4.1 Carbon Monoxide Emissions

Incomplete combustion produces carbon monoxide. This happens when there is not enough oxygen near the fuel (hydrocarbon) for complete combustion or when combustion is quenched near the cylinder's cold surface.

Figure 1 shows the carbon monoxide levels for various fuels at a 2500 rpm engine speed. The numerical results show that ethanol fuel produces less carbon monoxide than baseline gasoline, however, LPG produces more CO than gasoline. The differences in the chemical and physical properties of different fuels could explain the disparity in results. Similarly, Selim [6] discovered that when engines run on ethanol, carbon monoxide levels drop. Ethanol also burns cleaner and produces less CO than gasoline. It has a low diffusivity and is difficult to ignite at low temperatures, hence combustion does not take place. C2H5OH is the chemical formula for ethanol. Ethanol has a higher hydrogen content than gasoline. On the other hand, because hydrogen engines release extremely low amounts of CO as a result of burning some lubrication oil particles, it is assumed that CO concentrations will be absent in well-maintained engines. Due to its molecular structure, CO emissions from gasoline fuel remain higher than those from hydrogen and ethanol fuel.

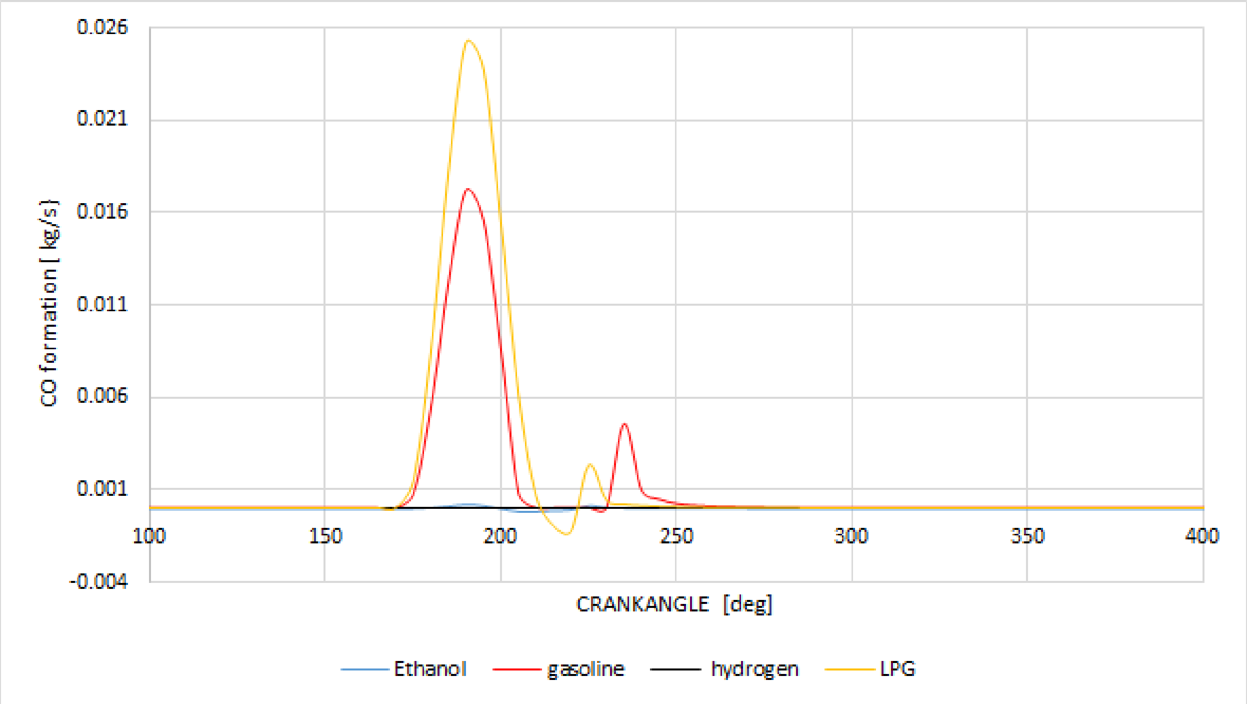

Figure 1 Variation in CO emission formation with crank angle

4.2 NOx Emissions

The reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures, produces NOx emissions.

Hydrogen fuel is classified as a clean fuel with a high mass-energy density, according to its features. Furthermore, hydrogen's fast-burning properties enable high-speed engines to run with less heat loss than gasoline. Figure 2 shows that a hydrogen-fueled engine emits around ten times less NOx than a gasoline-fueled engine while operating in lean circumstances. Because of its low ignition energy and volume energy density, hydrogen has significant drawbacks. In addition, as compared to LPG fuel engines, gasoline fuel engines emit the most NOx. This is because gasoline has fast flame propagation and combustion duration, as well as a rapid rise in-cylinder temperature, which is favorable for the production of nitrous oxide.

It can be seen from the graph that an ethanol-fueled engine creates less NOx than a gasoline-fueled engine. This statistic relates to ethanol fuel's cleaner combustion.

Furthermore, the reduction in the heating value and high evaporation heat of ethanol minimize temperature, resulting in a drop in-cylinder temperature. In comparison to hydrogen engines, ethanol engines have a lower adiabatic flame temperature, which minimizes NOx generation.

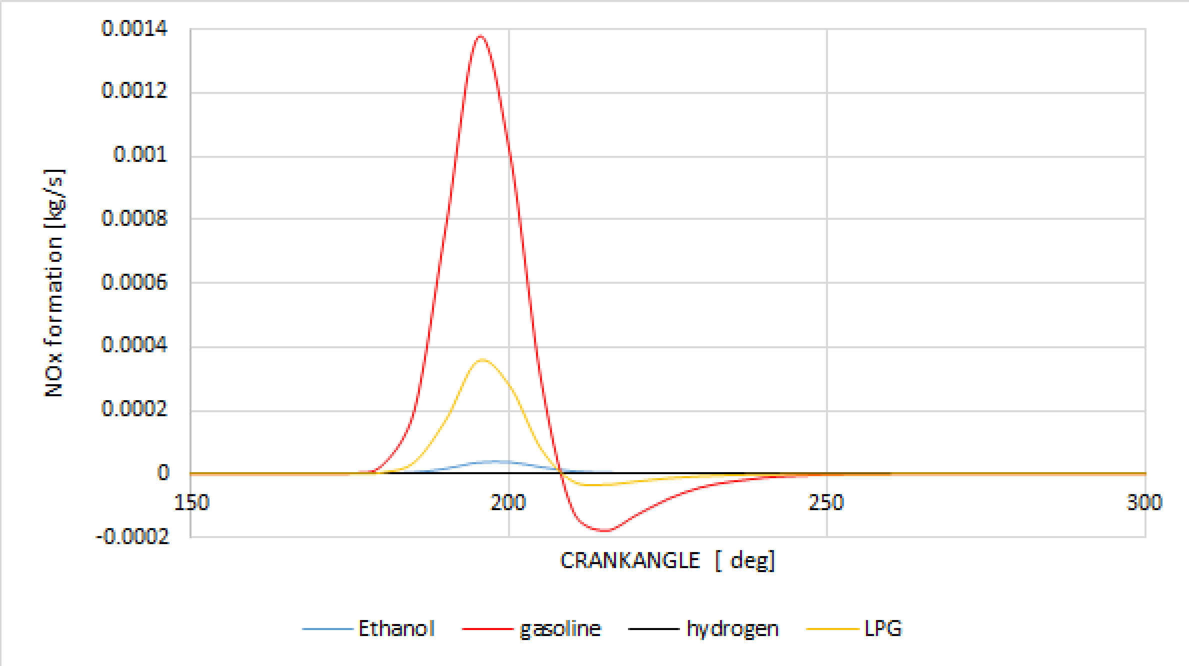

Figure 2 Variation in NOx emissions formation with crank angle.

4.3 HC Emissions

Part of the fuel inducted into the engine escapes combustion, resulting in unburned hydrocarbon (HC) emissions. Many mechanisms contribute to HC emission, including fuel adsorption and desorption in the oil layer, flame quenching, fuel escaping into fissures, and fuel accumulating in engine deposits among others.

Fig. (3) shows that hydrogen fuel engines emit less HC pollution than gasoline engines. This relates to the fact that hydrogen has a higher flammability limit than gasoline. Furthermore, HC emissions are reduced due to enhanced combustion and a lower hydrocarbon component in hydrogen fuel compared to gasoline fuel. Ethanol emission from the SI engine also follows the same principle as HC emission. The ethanol exhaust is unburned ethanol fuel. As a result of the crevice mechanism, most ethanol emissions can be classified as part of HC emissions. Because of the leaning effect generated by the ethanol fuel, the emissions of gasoline fuel engines are higher than those of ethanol fuel engines.

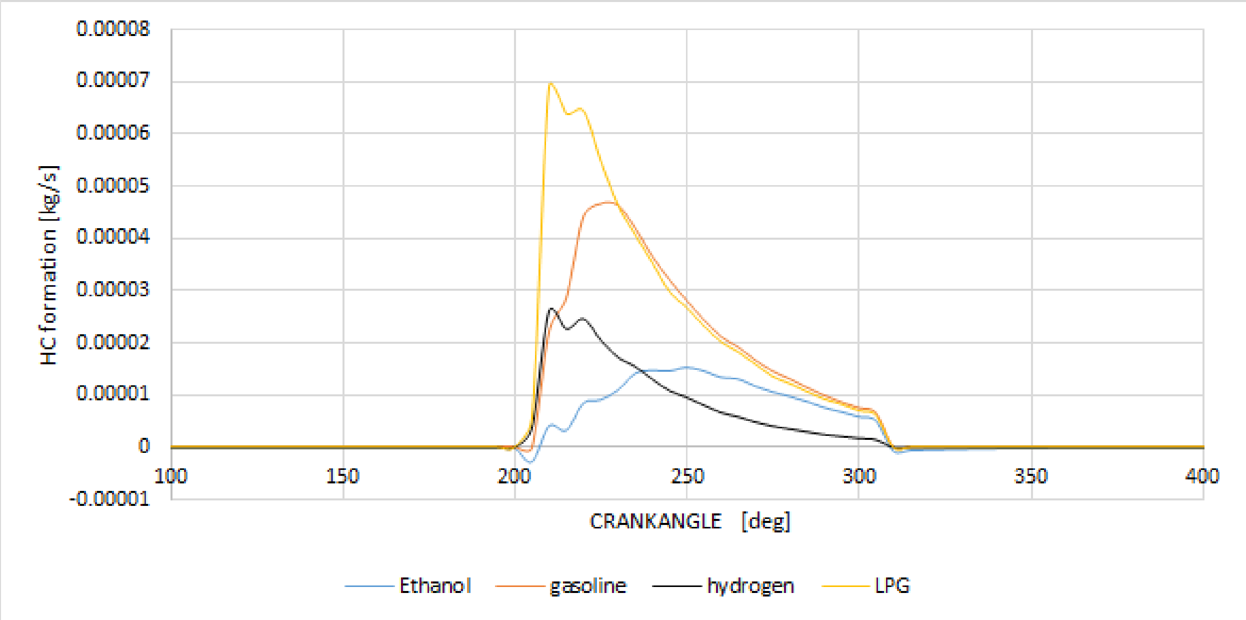

Figure 3 Variation in HC emission formation with crank angle.

4.4 HC Formation of Oil

Oil, also known as petroleum, is a hydrocarbon that is a readily combustible fossil fuel made primarily of carbon and hydrogen. Oil takes a long time to produce, with the first traces of it appearing millions of years ago. Figure 4 depicts the variation in HC generation of oil as a function of crank angle for various fuel types. The HC formation of oil for gasoline is higher than ethanol and LPG, which emit less hydrogen.

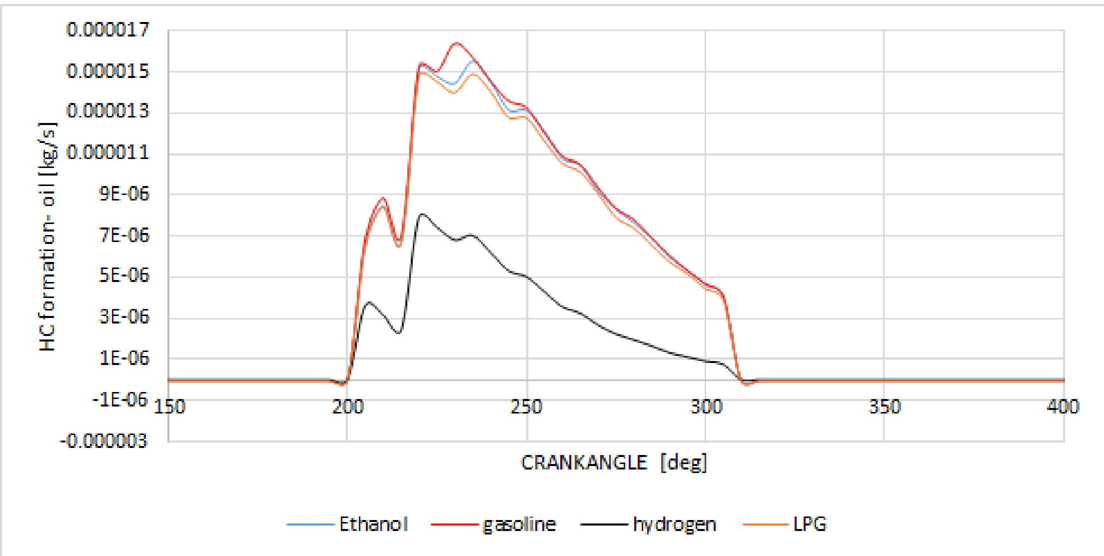

Figure 4 Variation in HC formation of oil with crank angle.

4.5 HC Formation of Crevice

The surface-to-volume ratio of crevices, or small spaces around the combustion chamber's surface, is high enough to inhibit flame spread. Crevices can be found between the piston head and the liner, between the engine head and the block's gasket joints, along with the seats of the intake and exhaust valves, and between the spark plug threads.

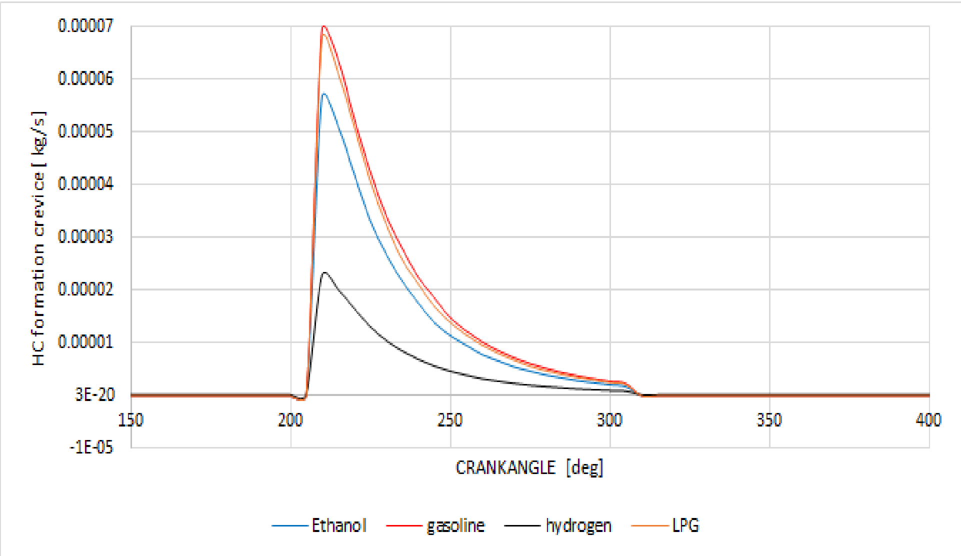

Figure 5 Variation in HC formation of crevice with crank angle.

5. Conclusion

1. Ethanol fuel emits less carbon monoxide than regular gasoline; however, LPG emits more CO than gasoline.
2. When hydrogen is consumed, it creates only water and a small number of nitrogen oxides and emits no carbon dioxide. On the other side, fossil fuel combustion products such as CO, CO2, nitrogen oxides, and other air pollutants are dangerous to human health and the environment.
3. CO emissions from gasoline fuel remain higher than those from hydrogen and ethanol fuel due to its molecular structure.
4. Due to ethanol's leaning effect, gasoline engines produce more HC than ethanol engines.

Abbreviations

Symbol	Description	Symbol	Description
C_{PPM}	Post Processing multiplier	T	time [s]
C_{KM}	Kinetic Multiplier	C	Molar Concentration in Equilibrium
c	Molar Mass	ri	reactions rates based on the model
r_i	Zeldovich mechanism response rates		
R	gas constant (J/(kmol.K)		
T piston	piston temperature (K)		
P	cylinder pressure (Pa)		
V crevice	total crevice volume (m3)		
M	unburned molecular weight (kg/kmol)		
$M_{crevice}$	mass of unburned charge in the crevice (kg)		
C	Concentration of HC and O2 “[kmole/m3]		
F_{OX}	Tunable parameter		
T_{OX}	Activation temperature default = 18790.0 [k]		
A_{OX}	Frequency factor default = 7.7E12 [m3/kmole/s]		
w_F	Mass fraction of the fuel in the oil film		
R	radial position in the oil film (distance from the wall) [m]		
D	relative (fuel-oil) diffusion coefficient [m2/s]		

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مقارنة تكوين الانبعاث لمحركات الإشعال بالشرارة باستخدام أنواع مختلفة من الوقود

الخلاصة: *الوقود البديل هو مورد متجدد ممتع يمكن أن يساعد في تقليل تلوث الجسيمات من محركات الاحتراق الداخلي. عند سرعة ثابتة للمحرك تبلغ 2500 دورة في الدقيقة ، تم إجراء تحليل رقمي مقارن لتحليل تأثيرات أربعة أنواع من الوقود البديل (الإيثانول والهيدروجين والبنزين وغاز البترول المسال ((LPG) على انبعاثات غازات العادم. يتم مراقبة كل من أول أكسيد الكربون وأكسيد النيتروجين والهيدروكربونات غير المحترقة كغازات عادم. وفقًا لهذه الدراسة ، فإن استخدام الوقود بما في ذلك الإيثانول والهيدروجين يمكن أن يقلل بشكل كبير من الانبعاثات. مع الهيدروجين ، يتم تقليل غالبية الملوثات الخطرة في غاز العادم بشكل كبير. بالمقارنة مع البنزين ، يحتوي الهيدروجين على هيدروكربونات نظيفة نسبيًا غير محترقة. الإيثانول والهيدروجين وقودان نظيفان لا يساهمان في زيادة صافي الانبعاثات من المحركات. وأظهرت النتائج أن وقود الإيثانول ينبعث منه غاز أول أكسيد الكربون أقل من البنزين العادي ، ولكن غاز البترول المسال ينبعث منه المزيد من ثاني أكسيد الكربون. علاوة على ذلك ، يحترق وقود الإيثانول بشكل أنظف وينتج أقل من ثاني أكسيد الكربون من البنزين. بالمقارنة مع محركات وقود غاز البترول المسال ، كانت انبعاثات أكاسيد النيتروجين أكبر بالنسبة لمحركات وقود البنزين. ومع ذلك ، فإن المحركات التي تعمل بوقود الإيثانول تنتج أكاسيد النيتروجين أقل من المحركات التي تعمل بالبنزين. عند العمل في ظروف ضعيفة ، كان انبعاث أكاسيد النيتروجين من المحرك الذي يعمل بوقود الهيدروجين أقل بحوالي عشر مرات من انبعاثات المحرك الذي يعمل بالبنزين. "أظهرت الدراسات أيضًا أن محركات الوقود الهيدروجين تنبعث منها نسبة أقل من تلوث الهيدروجين من محركات وقود البنزين ، لكن محركات وقود البنزين تنبعث منها أكثر من محركات وقود الإيثانول.*