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Effect of Electrode Plates on the Engine Performance and Gas Emissions of a Four-Stroke Petrol Engine

Mat Sazilin Ayub[1], Siti Nurul Akmal Yusof[2,*], Saiful Bahri Mohamed[2,♣], Mohd Sani Said[3], Yutaka Asako[4], Nor Azwadi Che Sidik[4], Mohd Shahir Kasim[5], Ahmad Tajuddin Mohamad[4]

[1] Kolej Komuniti Besut, Tingkat 3, Bangunan Baitul Ehsan, Jalan Besar, 22000 Jerteh, Terengganu, Malaysia
[2] Faculty of Innovative Design and Technology, Universiti Sultan Zainal Abidin, 21300 Terengganu, Malaysia
[3] Department of Polytechnic Education, Politeknik Kota Bharu, KM24, Kok Lanas, 16450 Ketereh, Kelantan, Malaysia
[4] Department of Mechanical Precision Engineering, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia
[5] Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Jalan Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

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ABSTRACT

The effectiveness generation of HHO gas depends on the characteristic of the electrode plates. This research aims to investigate the effect of the HHO gas generator produced through the water electrolysis technique. The effect of several controlled factors, such as the number, distance, and area of electrode plates used in the water electrolysis process to produce HHO gas, were studied and analyzed using a factorial full design approach (RBFAD). Stainless Steel of 1 mm thickness has been chosen as an electrode plate material. A single-cylinder four-stroke S.I. engine was used as the test engine. The engine was tested at 16 different setups where the engine speed and exhaust emission of carbon monoxide (CO) and hydrocarbon (HC) gasses were recorded. The statistical significance of these controlled factors contributing to the engine performance and exhaust emission has been established with the analysis of variance. It was found that the number of plates that interacted with a large area of electrode plate is a significant factor that caused an increase in engine speed on an average of 26%, an average reduction in CO by 43%, and a decrease in HC gas by 42%. In conclusion, the higher number of electrode plates and a higher electrode plate area produced more HHO gas that yields completed internal combustion. Thus, it can enhance the engine speed and reduces the CO and HC gas content in exhaust emissions.

1. Introduction

The alarming level of air pollution and increasing petrol price are the two major factors in transportation industries that have motivated the researchers to look for the alternative solution. Scientists from the Intergovernmental Panel on Climate Change recently predicted that global surface

* *Corresponding author.*
E-mail address: snakmalyusof@unisza.edu.my
♣ *Corresponding author.*
E-mail address: saifulbahri@unisza.edu.my

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temperatures would begin to increase by 1.4–5.8°C by 2100 [1]. The main contributors to greenhouse effects are carbon dioxide (CO_2), water vapor, methane (CH_4), Sulphur dioxide (SO_2), chlorofluorocarbons, and nitrogen dioxide (NOx). Many studies have focused on developing a wide range of renewable energy technologies, such as oxygenated fuels, biofuel (n-butanol), fuel cell, and solar technologies, on lowering fossil fuel consumption and regulating greenhouse gas (GHG) emissions to the environment [2,3]. Reducing CO_2 emissions is one of the most effective strategies for reducing GHG emissions [4-6]. Other than CO_2, the manufacture and combustion of transportation fuels emit CH_4 and nitrous oxide (N_2O), contributing to GHG emissions. Other than using clean fuel alternatives, novel automotive engines with post-combustion emission control devices should be developed to reduce GHG emissions and improve the efficiency of energy systems [7-9]. The use of biodiesel engines in transportation and power generation has progressed in recent decades. The most recent research development trend focuses on developing a novel ICE with low emissions, energy savings, and high-efficiency performance [10]. However, biodiesel fuels have their respective limitations in producing a higher NOx, which leads to poor combustion performance [9]. Thus, to overcome this limitation, using other alternative fuels like hydrogen to fuel IC engines is gaining more attention to enhance the engine speed performance and reduce air pollution [11,12].

HHO, also known as hydroxy or Browns Gas, is a gas created by electrolysis by separating water into hydrogen and oxygen, allowing the gas to remain premixed and used on-demand without the need for storage. It is a promising method of producing hydrogen from renewable sources. The pioneer researcher who studied it was Brown [13], who explored the welding application of the gas. Compared to other alternative fuels, hydrogen has good combustion properties, making it the cleanest fuel for ICEs and has high combustion efficiency [14]. Hydrogen is a flammable gas that is scentless, bland, and colorless in nature. It is known as a diatomic molecule, H_2. Hydrogen is the lightest chemical substance in the world, as well as the most abundant. The diffusion coefficient of hydrogen is ten times gasoline, resulting in greater in-cylinder charge homogeneity [15]. Kazim *et al.*, [16] studied the effect of HHO gas in a small capacity diesel engine. They concluded that adding HHO and diesel in a small capacity diesel engine significantly improved all engine performance factors. The minimum percentage increases in the combustion efficiency were 2.5% and 10.5% for H6 and H10, while the minimum increases in torque were 8% and 15%, respectively. HHO gas was also used as a supplementary fuel in the internal combustion engine without any modification [17]. HHO does not have a predefined burning temperature where it reacts to the substances when burned. HHO would begin imploding rather than exploding since it mainly contains hydrogen (66.67%) and oxygen (33.33%). Furthermore, when HHO is combined with diesel or gasoline, it can significantly improve the burning efficiency. The flame propagation of HHO gas is faster than that of standard liquid fuel because hydrogen possesses a fast-burning velocity [18].

The direct production of H_2 and O gas by electrolysis method is straightforward by using the existing energy on the vehicle that is battery [19]. Several authors have studied this in the literature. Shivaprasad *et al.,* [20], in their study, agreed that H_2 is considered one of the superior alternative fuels for the SI engines. This is due to the particular and most desirable characteristics, such as wide flammability range, higher diffusivity, high flame speed, lower ignition energy, etc. [21,22]. Similar work was also carried out by Falahat *et al.,* [23]. The thermal brake efficiency improves after hydrogen enrichment, reaching a peak of about 23%, thanks to hydrogen's wide flammability and fast flame pace. Recently, Aydin and Kenanoğlu [24] discovered that injecting HHO into the intake manifold of a four-cylinder engine improved the maximum torque and maximum power by 19.1% and 27%, respectively. While in contrast, specific fuel consumption (SFC) decreased by 14%. However, a complete search of the literature revealed no previous research that focuses on the influencing factors of water electrolysis that affect the production of this hydrogen-rich gas. This is the motivation of the present study to conduct an experiment on the three controlled factors of electrode plates which is also one of the significant factors that affect producing hydrogen gas.

This research aims to study engine performance and gas emissions by investigating the effect of the HHO gas generator produced through the electrolysis technique. Several controlled factors used in the electrolysis process to produce HHO gas were studied and analyzed using experimental design methods to see the effect on engine speed and pollution produced.

2. Experimental Setup and Test Procedure

2.1 Experimental Description

A single-cylinder four-stroke SI engine was used as the test engine. The schematic of the experiment setup is shown in Figure 1. Table 1 shows the specifications of the test engine. The properties of hydrogen and gasoline are shown in Table 2. The engine was powered by an electric motor, and some minor physical modifications are needed to allow the HHO portion to be routed through the engine inlet port. A special-purpose electronic device was designed and fabricated to supply a constant 10-Amp 18-Volt direct current to each electrode plate for creating electrolysis phenomena. To observe the engine's power output in terms of engine rotation speed and exhaust gas emissions, the effect of controlled factors, which are area, numbers, and distance between electrode plates on the HHO gas generator, was investigated. A further result of the interaction of control factors and essential factors contributing to hydrogen and oxygen gas development and the speed and release of pollutant gas is also studied.

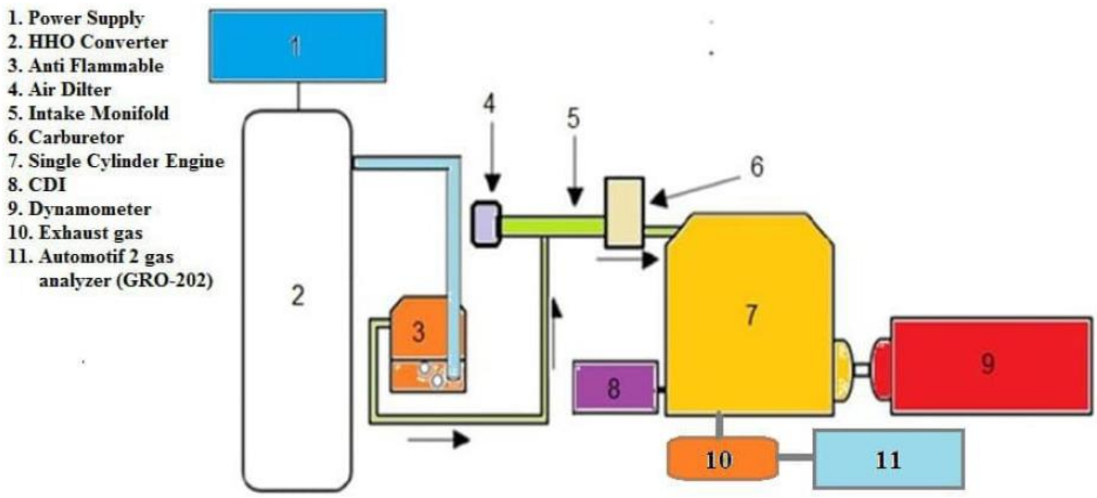

Fig. 1. Experimental test preparation scheme involving a test band engine and a hydroxy gas generator

Table 1
Engine Specifications

Engine type	Four strokes, single-cylinder
Fuel type	Petrol
Cooling system	Water-cooled
Size (D x L)	87 mm x 66 mm
Power	5 KW at 3000 min^{-1}
Dimension	500 x 345 x 310 mm
Weight	34 kg

Table 2
The properties of hydrogen and gasoline [25]

Property	Hydrogen	Gasoline
Molecular mass(kg/kmol)	114	2.016
Theoretical air–fuel ratio (kg/kg comb)	14.5	34.32
Density, at 0°C and 760 mm Hg, (kg/m3	0.735-0.760	0.0899
Flammability limits in air, at 20°C and 760 mm Hg % vol.	1.48-2.3	4.1-75.6
λ	1.1-0.709	10.12-0.136
Flame velocity in air (λ = 1), at 20°C and 760 mm Hg (m/s)	0.12	2.37
Octane number	90-98	>130
Min. ignition energy in air (mJ)	0.2-0.3	0.018
Auto-ignition temperature(K)	753-823	848-853
Lower Heating Value (gas at 0°C and 760 mm Hg)	3661	3178
Stoichiometric fuel–air mixture (kJ/m3) (kJ/kg)	42690	119600

All the data such as engine speed and HC, and CO emissions were measured using a Dynamometer and Automotive Gas Analyzer, as shown in Figure 2. All the measured data are recorded in tabular form. This data was entered into the Expert Design application (DOE) software to conduct statistical analysis based on the two-level factorial full design approach (RBFAD) [26,27]. Analysis of variance, using ANOVA, was used to identify the relationship between the controlled parameters and the significant influence. In this study, one mm-thick of stainless steel was chosen as the electrode plate material due to its affordable cost, suitability, and in-market availability. Stainless steel offers superior mechanical qualities at room temperature compared to other materials. It combines ductility, elasticity, and hardness, allowing it to be employed in difficult metal forming modes (deep stamping, flat bending, extrusion, and so on) while also providing heavy wear resistance (friction, abrasion, impact, elasticity, etc.). It also has good mechanical properties at both high and low temperatures. Two sets of stainless steel were cut into two different sizes and labelled with a group A1 for an area of 10 cm x 30 cm x 2 (600 cm^2) and group A2 for 20 cm x 30 cm x 2 (1200 cm^2). The total number of stainless-steel plates for each group, A1, and A2, together with the area, is 24 pieces. The characteristic of electrode plates based on matrix experiments proposed by the RBFAD approach is given in Table 3. The 16 experiments were done by using the number of electrodes 12 and 24; the distance between electrode plates were 1 and 2 cm, and the area of electrode plates were 600 and 1200 cm^2.

Fig. 2. HC and CO measurement instrument (Model: QRO-202)

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Table 3
The characteristic of electrode plates

No.	Number of electrodes	Distance between electrode plates (cm)	Area of electrode plates (cm^2)
1	24	1	1200
2	24	2	1200
3	24	1	600
4	12	1	600
5	12	2	600
6	12	1	1200
7	24	2	600
8	12	2	1200
9	24	1	1200
10	24	2	1200
11	24	1	600
12	12	1	600
13	12	2	600
14	12	1	1200
15	24	2	600
16	12	2	1200

2.2 HHO Gas Generator and Fuel Cell Fabrication

To trigger the process of water electrolysis, an electric current has to be flowed through the electrolyte using an electrode plate connected to the positive terminal called the anode and an electrode plate attached to the negative terminal called the cathode. A fixed rated direct current electricity of 10-Amp 18-Volt is supplied to the electrode plate [28]. Two sets of power suppliers were developed to supply 10-amp, 18-volt direct current electricity to the HHO gas generator to trigger the electrolysis operation. The step-down transformer (SDT) is used since the source of electrical power supplied by TNB is 240 volts. A total of 6 SDT were connected to 12 electrode plates, and 12 SDT were connected to 24 plate electrodes. Figure 3 shows a schematic diagram of 24 plates representing 12 sets of electrode plates (1 plate each for the anode and cathode), including a distance between 1 cm and an area of 1200 cm^2 for the electrolysis process.

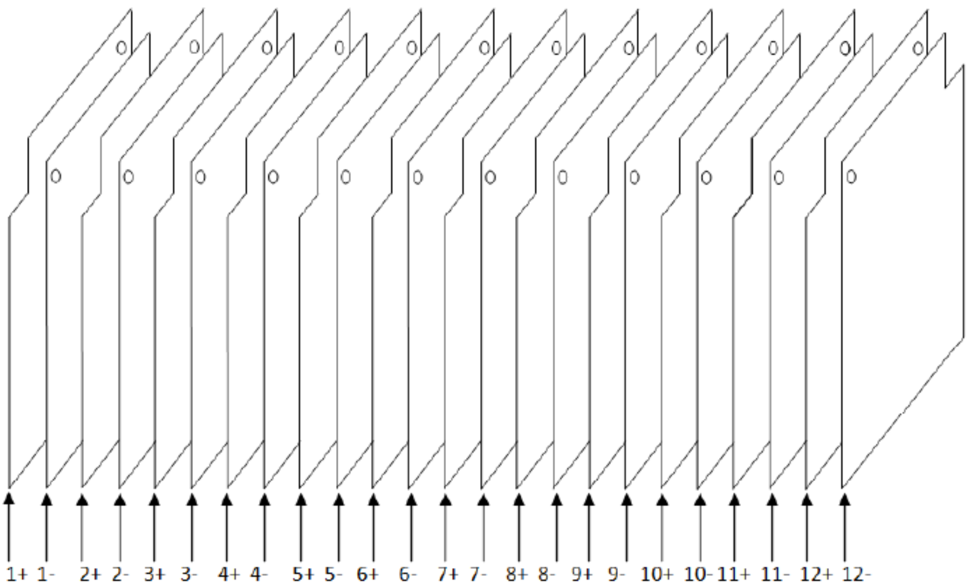


Fig. 3. 24 electrode plates

2.3 Statistical Analysis

Statistical analysis of engine speed and exhaust gas emissions was analyzed using variance or ANOVA analysis, taking into account the alpha (α) level was 0.05 with a corresponding confidence level of 95%. The F test in the ANOVA table is to determine whether there is a significant influence and interaction between the controlled factors in this study. Therefore, the use of ANOVA in this study evaluates the main influence and interaction between controlled factors in the electrode design that significantly affect engine performance, CO and HC gas emissions.

3. Results and Discussion

3.1 Results

Experiments were performed based on Table 3. Each investigation was conducted for 7 minutes, equivalent to 1 litre of gasoline. This step lasted until 16 experimental tests were done. All data collected will be used in RBFAD and ANOVA analysis through the Design Expert application. The average benchmark data values related to the engine rotation speed (1754 rpm), HC concentration (150) and CO percentage (3.13) measured and recorded are in Table 4.

Table 4
Benchmark data

Test	RPM	HC ppm	CO Percentage	1 litre of Petrol	Heat
1	1754	150	3.13	7 min	30.0 ^{0}C
2	1754	148	3.14	7 min	30.1 ^{0}C
3	1754	151	3.12	7 min	30.1 ^{0}C
4	1754	149	3.13	7 min	30.0 ^{0}C
5	1754	150	3.13	7 min	30.2 ^{0}C
Average	1754	150	3.13	7 min	30.2 ^{0}C

RBFAD -based Design Expert application version 9, which refers to a 2k factorial design where k is the number of parameters studied. This formulation was used to determine the number of experiments to be conducted based on three controlled factors which are number, distance and area as shown in Table 5. A total of 8 experiments with 1 repetition were proposed for this study by RBFAD. The results of the experimental tests are shown in Table 6. The average values of these data which are 2203 rpm, 1.78% and 64 PPM for engine rotation, CO and HC, respectively will be used as a benchmark and optimization of experimental test comparisons for engine speed and gas emissions.

Table 5
Parameters of electrode plates for HHO gas generator

Controlled parameters (Electrode plates)	Unit	Min	Max
A-Number	Plates	12	24
B-Distance	cm	1	2
C-Area	cm^2	600	1200

Table 6
Experimental results

No.	Controlled factors (Electrode plates) Number	Distance (cm)	Area (cm^2)	Experimental results Engine rotation (rpm)	CO (%)	HC (ppm)
1	24	1	1200	2346	1.82	52
2	24	2	1200	2270	1.78	47
3	24	1	600	2215	1.74	46
4	12	1	600	2182	1.71	45
5	12	2	600	2174	1.76	53
6	12	1	1200	2163	1.86	69
7	24	2	600	2141	1.81	95
8	12	2	1200	2135	1.79	107
9	24	1	1200	2342	1.82	51
10	24	2	1200	2267	1.76	47
11	24	1	600	2217	1.73	43
12	12	1	600	2183	1.69	46
13	12	2	600	2173	1.77	51
14	12	1	1200	2160	1.84	68
15	24	2	600	2138	1.8	92
16	12	2	1200	2134	1.79	109
Average				2203	1.78	64

3.2 Effect of Electrode Plates on the Engine Performance

The ANOVA table for engine performance is shown in Table 7. From the observations made on the statistical values, R^2 is 0.9997, Adj R^2 is 0.9994, which indicates a reasonable agreement. The Adeq precision (AP) = 167.600 greater than 4 is desirable, as it measures the signal-to-noise ratio. A similar result is generated for P when the value is smaller than 0.05. This means that the primary influence and interaction between controlled factors significantly impact engine speed efficiency.

The mathematical model as a function of describing the rotational speed of the engine consists of the distance, number, and area are as follows: -

Engine speed (rev/min) = 470.68877 - (2.51350 * **Number of electrode plates**) + (95.83071 * **Distance between electrode plates** - (0.23636 * **Area of electrode plates**) - (7.22249 * **Number of electrode plates** * **Distance between electrode plates**) + (0.019252 * **Number of electrode plates** * **Area of electrode plates**) - (0.065753 * **Distance between electrode plates** * **Area of electrode plates**) + (2.81376E-003 * **Number of electrode plates** * **Distance between electrode plates** * **Area of electrode plates**)

Table 7
Analysis of variance (ANOVA) for engine performance

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Model	72151	7	10307	3298.33	< 0.0001	significant
A (number of electrode plates	24947	1	24947	7982.99	< 0.0001	
B (distance between electrode plates	8835	1	8835	2827.34	< 0.0001	
C (area of electrode plates	9702	1	9702	3104.72	< 0.0001	
AB	3364	1	3364	1076.60	< 0.0001	
AC	25122	1	25122	8039.12	< 0.0001	
BC	72	1	72	23.12	0.0013	
ABC	90	1	90	28.88	0.0007	
Pure Error	25	8	3			
Cor Total	72176	15				

The effect of these controlled elements is determined by comparing the values of the benchmark data in Table 4 with the experimental results in Table 6, as shown in this table. There is an increase in the engine rotational speed and a reduction in HC and CO gas emissions. These findings are also supported by El-Kassaby *et al.,* [29], Madyira and Harding [30], Yilmaz *et al.,* [31]. Therefore, it is concluded that the number of electrode plates (A), the distance between the electrode plates (B), and the area of the electrode plates (C) have a significant influence and interaction. The effect of electrode plates parameters on the engine speed performance can be compared with the help of perturbation plots, as illustrated in Figure 4. The perturbation plot facilitates observing all influencing factors at the center point in the design space for coded values. The line gradients in the graph show the influence and sensitivity of the respective electrode plate parameters for engine speed performance. As shown in Figure 4, the trends for the number of electrode plates (A) and the area of the electrode plates (C) have the same gradient. By increasing the number and area of the electrode plates can cause the engine speed to increase.

The area surface of the electrode plate plays an important role in the hydrogen production system through electrolysis. The larger area of the electrode plates will cause more water molecules to decompose and form hydrogen gas and oxygen gas [32]. However, the engine speed performance decreased as the distance between the electrode plates (B) increased. This finding is consistent with De Silva *et al.,* [33], who found that the current used by the HHO generator is inversely proportional to the distance between the electrode plates. The result can be explained by the fact that when the distance between the electrodes is too far, the influence of the electric current becomes weak the process of electrolysis of water cannot be done well. This condition simultaneously reduces the formation of H_2 and O_2, because according to Faraday's law of electrolysis, the rate of hydrogen production is directly proportional to the current [34,35].

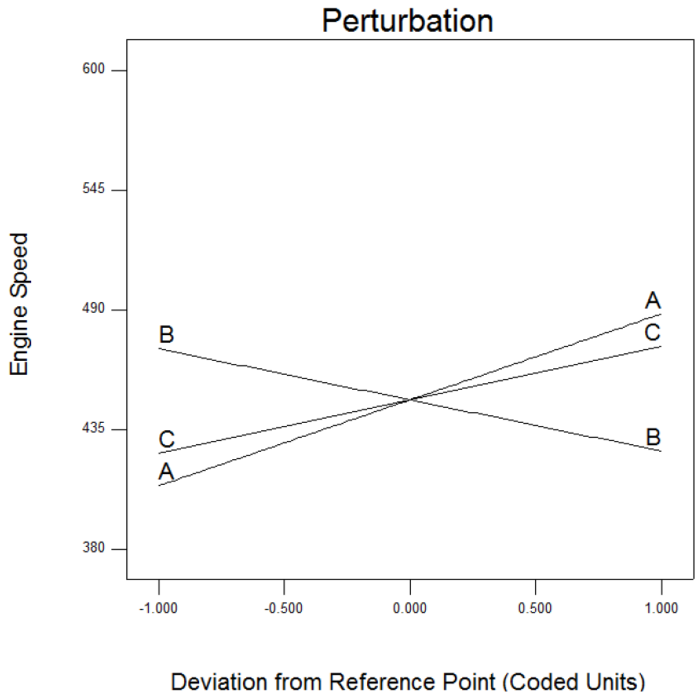
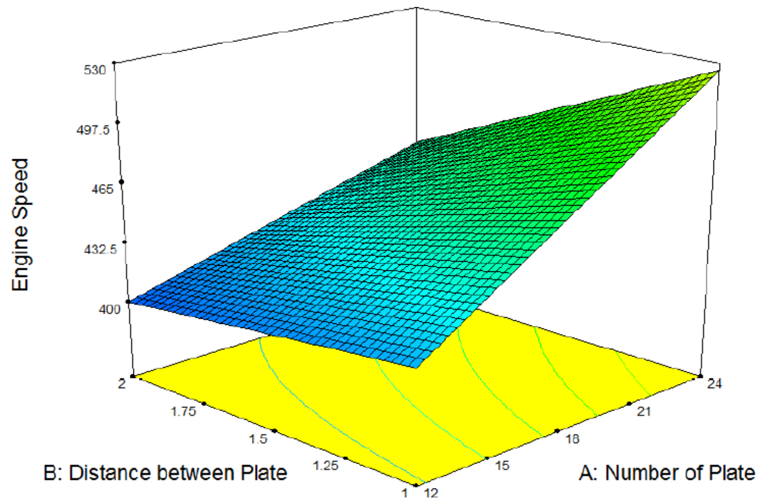


Fig. 4. Perturbation plot for engine speed

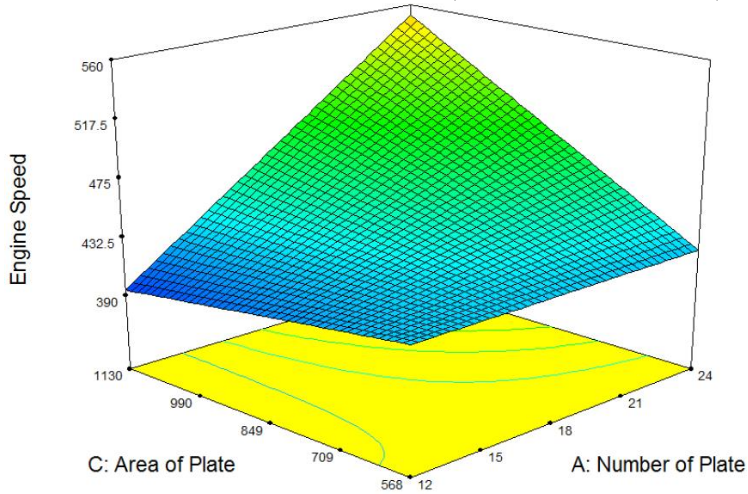
The interaction of the controlled factors with the engine speed is plotted in Figure 5. As in Figure 5(a), using a distance of 1 cm on 24 electrode plates decreases the water resistance, causing more electric current to flow [36,37]. In general, electric current plays an essential role in the production of hydrogen and oxygen. Thus, many electrode plates produce many gas bubbles, which interact with a high electric current that can break down the molecular mass of water into oxygen gas and hydrogen gas. However, by using a distance of 1 cm on 12 electrode plates, the speed of the machine decreased. These results may reflect insufficient HHO gas production because the number of electrode plates is the dominant factor of the electrode plate distance, as found by the ANOVA results in Table 7. It was found that the interaction of the number of electrode plates, and distance of electrode plates (AB), number of electrode plates and area of electrode plates (AC), a distance of electrode plates and area of electrode plates (BC) had a significant effect on engine speed, as presented in Table 7 referred to the values -p.

The relation between the area and the number of electrode plates, as determined by the ANOVA in Table 7, significantly impacts the engine rpm. As several electrode plates interact with a large area of the electrode plates, as seen in Figure 5(b), an improvement in the engine speed can be achieved. Although the number of electrode plates was a significant factor in producing HHO gas, the results found that the number of plates had little effect on engine speed when interacting with a smaller electrode plate area. This phenomenon occurs due to Ohmic resistance as described when bubbles form and rise to the plate surface. The newly formed bubbles will accumulate into the newly formed bubbles and can cover some of the areas of the electrode plate. And at the same time, it prevents water from touching the plate surface to reduce the flow of electric current, causing the system formation rate to decrease oxygen and hydrogen production [38].

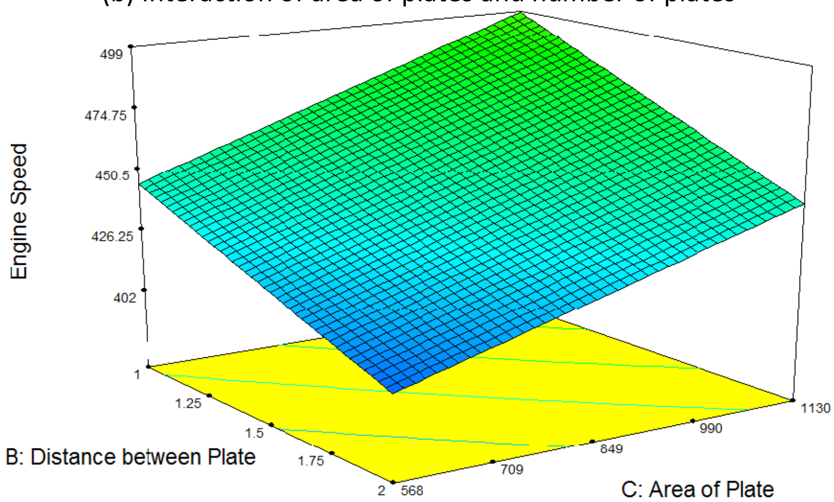
An adequate distance between the electrode and a wide water contact area on the electrode plate's surface leads to an improvement in oxygen and hydrogen gases, instantly improving the engine's speed efficiency. This setup allows for a smooth flow of electricity through each electrode plate. This phenomenon is also stated by Jumiati *et al.,* [39]. They emphasize that the design and dimensions of the fuel cell, such as the area of the electrode plates, can regulate internal combustion efficiency. The greater the area of the electrode plates traversed by water, the more water molecules are affected, forming hydrogen and oxygen atoms. When H_2 is combined with O_2, its explosive nature causes an increase in engine speed.



(a) Interaction of distance between plates and number of plates



(b) Interaction of area of plates and number of plates



(c) Interaction of distance between plates and area of plates

Fig. 5. The interactions of controlled factors (electrode plates) to the engine speed

3.3 Effect of Electrode Plates on the Reduction of CO Gas Emissions

The ANOVA table for CO gas emissions is shown in Table 8. The result of R^2 is 0.9970, Adj R^2 is 0.9986, which indicates a reasonable agreement with each other. The AP is 97.599. As mentioned earlier, AP greater than 4 is acceptable. The mathematical model as a function of describing the reducing CO gas emissions consists of the distance, number, and area are as follows: -

CO = (0.28689 * **Number of electrode plates**) + (4.95593 * **Distance between electrode plates**) + (7.02847E-003 * **Area of electrode plates**) - (0.30359 * **Number of electrode plates** * **Distance between electrode plates**) - (3.75415E-004 * **Number of electrode plates** * **Area of electrode plates**) - (7.14398E-003 * **Distance between electrode plates** * **Area of electrode plates**) + (3.82079E-004 * **Number of electrode plates** * **Distance between electrode plates** * **Area of electrode plates**) – 2.78535

The effect of electrode plate parameters on reducing CO gas emissions in the exhaust gas can be compared with the help of perturbation plots, as illustrated in Figure 6. According to Figure 6, the number of electrode plates (A) and the area of the electrode plates (C) have the same gradient. Increasing the number of electrode plates and the area of the electrode plates can lead to a reduction in CO gas production [40]. The interaction of the controlled factors with the CO gas emission in the exhaust gas is plotted in Figure 7. It was found that the interaction of AB, AC and BC had a significant effect on the CO gas emissions, as shown in Table 8.

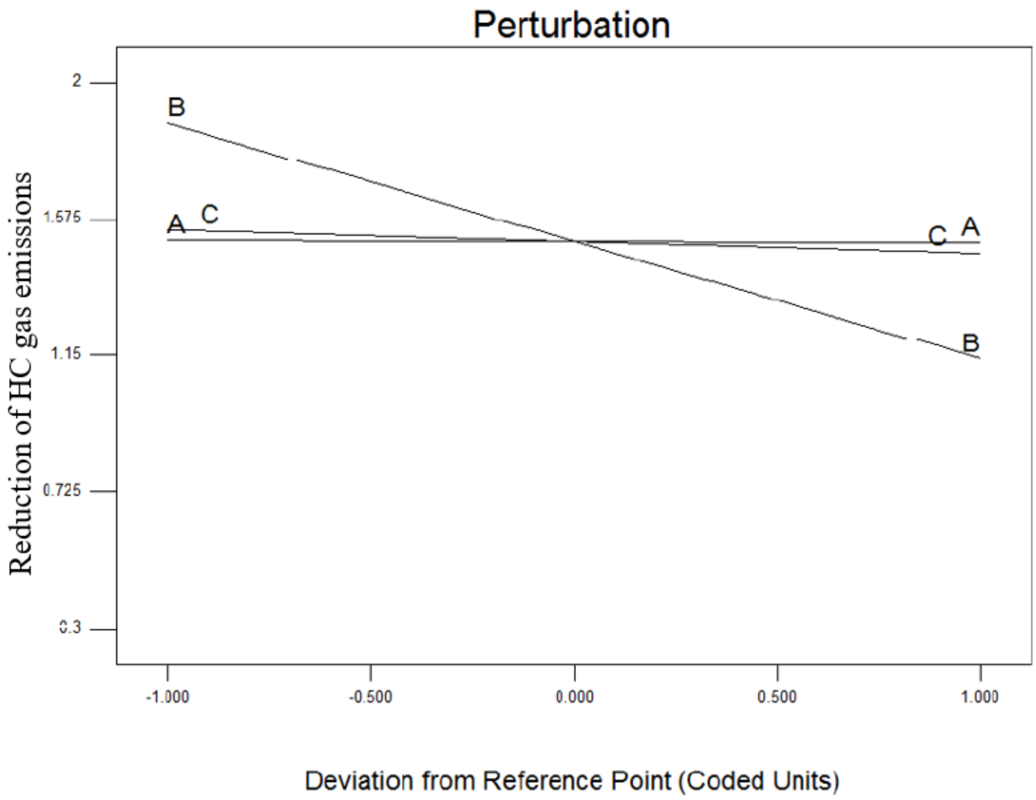
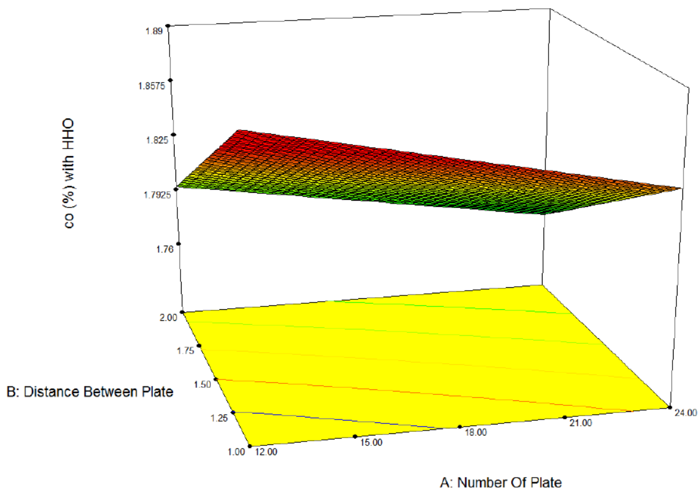


Fig. 6. Perturbation plot for CO gas emissions in the exhaust gas

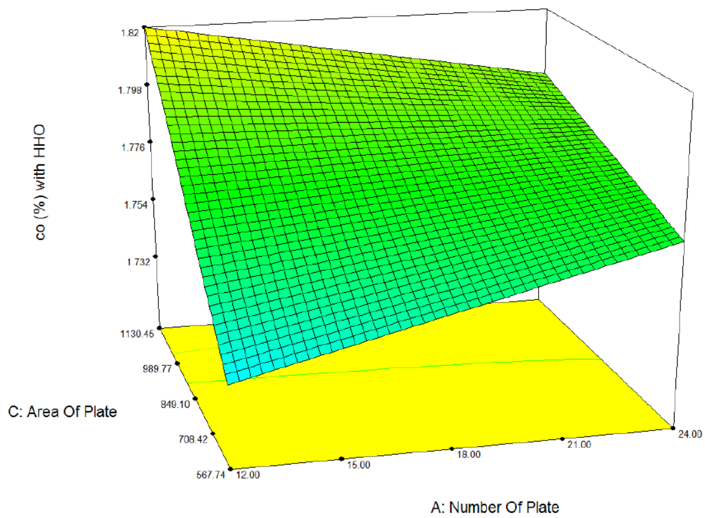
Table 8
Analysis of variance (ANOVA) for CO gas emissions

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Model	5.71	7	0.82	1518.53	< 0.0001	significant
A (number of electrode plates	2.250E-004	1	2.250E-004	0.42	< 0.5358	
B (distance of electrode plates	2.16	1	2.16	4020.28	< 0.0001	
C (area of electrode plates	0.021	1	0.021	39.12	< 0.0002	
AB	0.063	1	0.063	116.28	< 0.0001	
AC	1.78	1	1.78	3315.77	< 0.0001	
BC	0.022	1	0.022	41.86	0.002	
ABC	1.66	1	1.66	3096	< 0.0001	
Pure Error	4.300E-003	8	5.375E-004			
Cor Total	5.72	15				

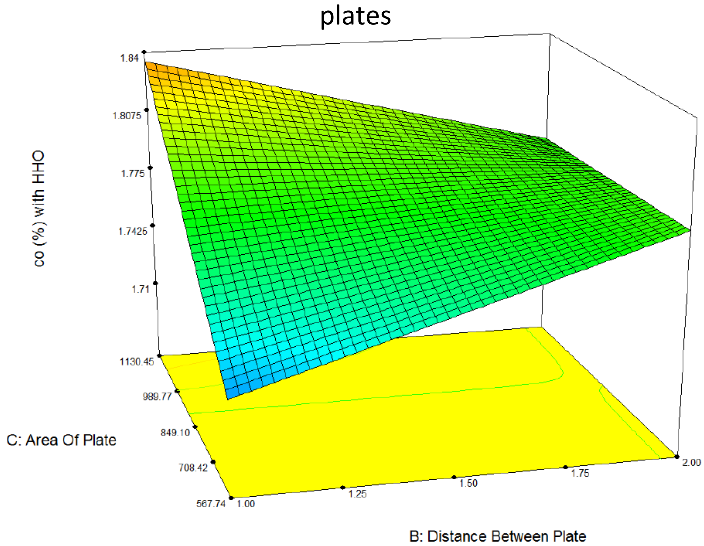
Using a minimum distance configuration on 24 electrode plates, the results indicate that CO reduction has occurred [40]. However, using the minimum distance on 12 electrode plates, the CO reduction was not significant compared to higher electrode plate spacing. These results may reflect insufficient HHO gas production because the number of plates is the dominant factor of the plate distance. The relation between the area and the number of electrode plates, as determined by the ANOVA in Table 8, has a significant impact on the CO gas emissions. According to Figure 7(b), CO reduction can be achieved when a high number of plates interact with the area of electrode plates. Although the surface area of the electrode plate is a significant factor in producing HHO gas, the results found that the number of plates had little effect on CO gas emissions when interacting with the smaller area of the electrode plates. As mentioned previously, this phenomenon occurs due to Ohmic resistance [39]. According to Figure 7(c), a sufficient distance between the electrode plates and the area of electrode plates leads to an increase in H_2 and O_2 gas production, thus lowering CO emissions. This electrode plate has a large surface area that allows electric current to flow freely. This result has an agreement with the studies by Uludamar *et al.,* [40], and Calo [41]. CO gas is produced when fuel is burned without enough oxygen to contain carbon dioxide (CO2).



(a) Interaction of distance between plates and area of plates



(b) Interaction of area of plates and number of electrode plates



(c) Interaction of area of plates and distance between electrode plates

Fig. 7. The interactions of controlled factors (electrode plates) to the CO gas emissions

3.4 Effect of Electrode Plates on the Reduction of HC Gas Emissions

The ANOVA table for HC gas emissions is shown in Table 9. The result of R^2 is 0.9915, Adj R^2 is 0.9840, which indicates a reasonable agreement with each other. The AP is 42.286. As mentioned earlier, AP greater than 4 is acceptable. The mathematical model as a function of describing the reducing HC gas emissions consists of the distance, number, and area are as follows: -

HC = (8.36503 * **Number of electrode plates**) + (130.15749 * **Distance between electrode plates**) + (0.35809 * **Area of electrode plates**) - (5.38100 * **Number of electrode plates** * **Distance between electrode plates**)) - (0.014587 * **Number of electrode plates** * **Area of electrode plates**) - (0.23014 * **Distance between electrode plates**) * **Area of electrode plates**) + (9.47792E-003 * **Number of electrode plates** * **Distance between electrode plates**) * **Area of electrode plates**) - 161.30104

Table 9
Analysis of variance (ANOVA) for HC gas emissions

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Model	4416	7	630.86	132.81	< 0.0001	significant
A (number of electrode plates	0.25	1	0.25	0.053	0.8243	
B (distance of electrode plates	1190.25	1	1190.25	250.58	< 0.0001	
C (area of electrode plates	49	1	49	10.32	0.0124	
AB	1024	1	1024	215.58	< 0.0001	
AC	6.25	1	6.25	1.32	0.2845	
BC	1122.25	1	1122.25	236.26	< 0.0001	
ABC	1024	1	1024	215.58	< 0.0001	
Pure Error	38	8	4.75			
Cor Total	4454	15				

The effect of electrode plate parameters on reducing HC gas emissions can be compared with the presence of perturbation plots, as illustrated in Figure 8. As shown in Figure 8, the trend is similar to the results of CO gas emissions. Increasing the number of electrode plates and the area of the electrode plates can lead to a reduction in HC gas production. O_2 gas has benefited in completing the combustion, resulting in a decrease in the emissions of HC gas.

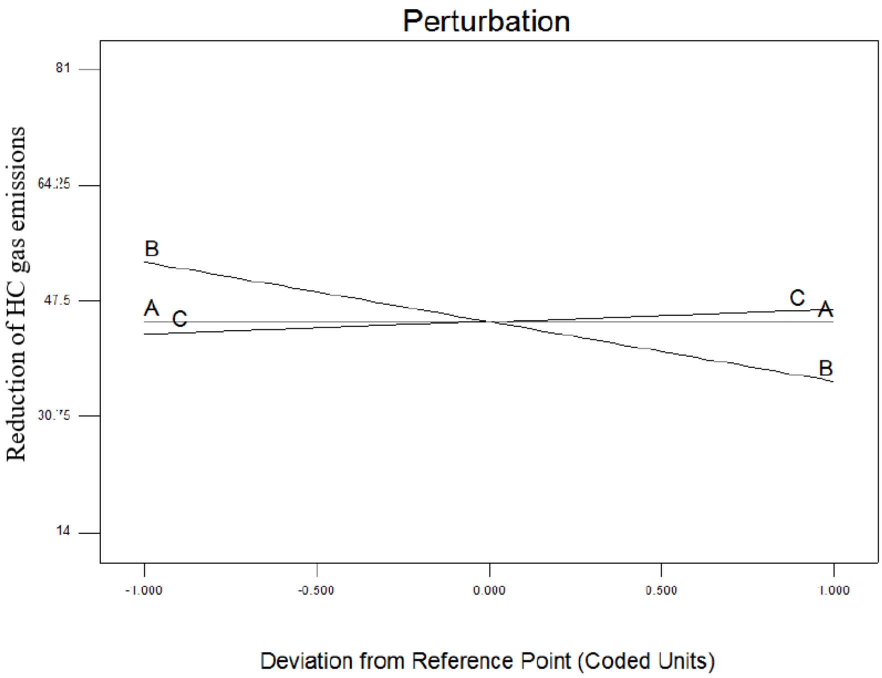


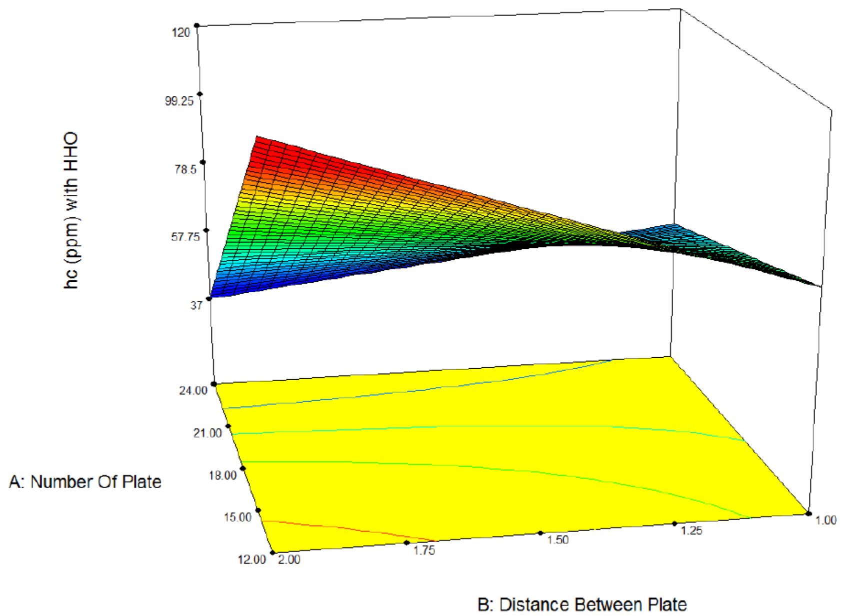
Fig. 8. Perturbation plot for HC gas emissions in the exhaust gas

The interaction of the controlled factors with the CO gas emission in the exhaust gas is plotted in Figure 9. It was found that the interaction of AB, AC and BC had a significant effect on the CO gas emissions, as shown in Table 9. In general, electric current plays an important role in the production of H2 and O2 gases. In Figure 9(a), using the minimum distance and the maximum number of electrode plates, the water resistance decreases, causing the electric current flow to be higher [36,41]. HC, on the other hand, is closer to higher plate distances. These results can illustrate the unnecessary H2 and O2 gases production because the number of electrode plates is the dominant factor. However, the distance between electrode plates reduces HC almost to higher distance plates.

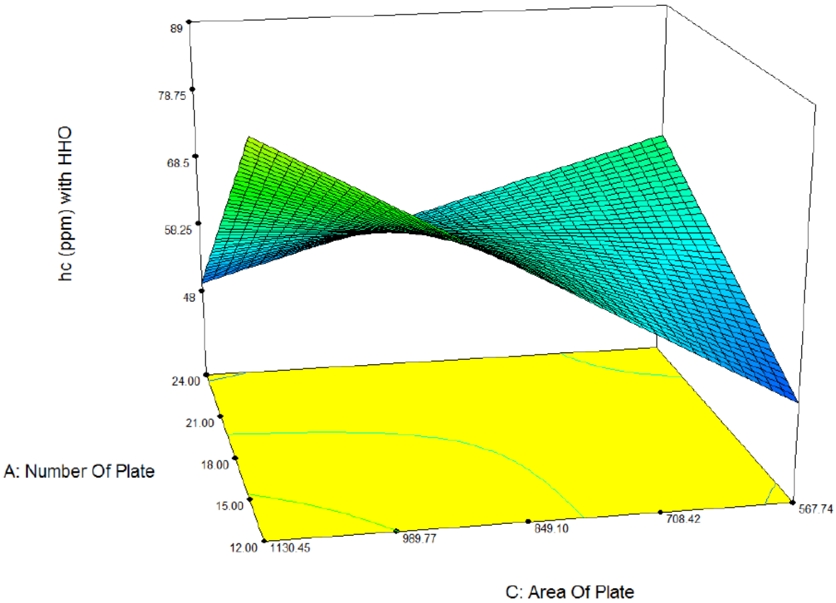
These results may reflect insufficient H_2 and O_2 gas production because the number of plates is the dominant factor of plate distance.

The water resistance decreases in Figure 9(b) when the minimum distance and the maximum number of electrode plates are used, resulting in a higher electric current flow [34,36,41]. Electric current is crucial in the processing of H_2 and O_2 gases in general. Reduced HC almost results in a higher plate spacing using a minimum spacing and a minimum number of electrode plates. Since the number of plates is the most critical factor in plate distance, these findings could indicate a lack of H_2 and O_2 gas output. Among the interaction factors and terms, the interaction of area and the number of electrode plates greatly influence the HC production. Based on Figure 9(b), HC reduction can be achieved when the highest number of electrode plates interacts with a larger area of the electrode plates. Although the number of plates played a significant factor in producing H_2 and O_2 gases, the results found that the number of plates had little effect on the HC gas produced when interacting with a smaller area of electrode plates.

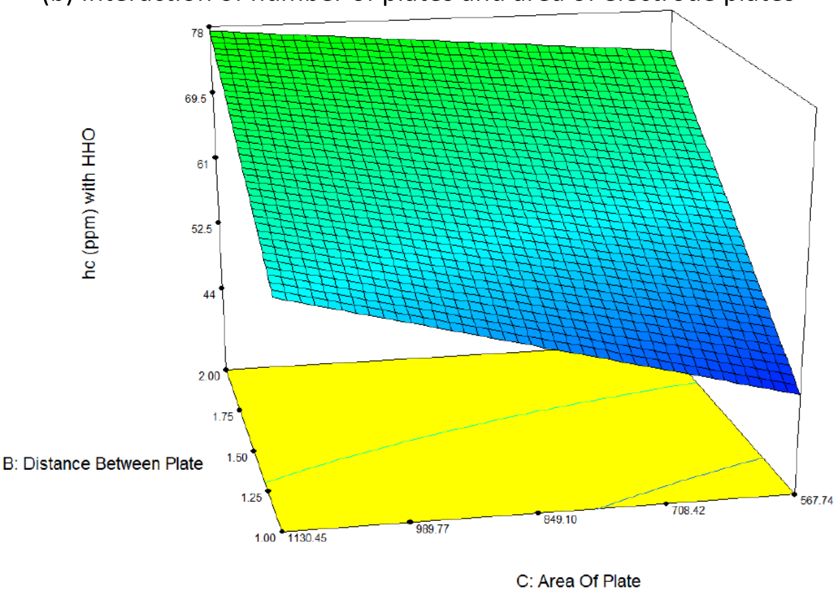
According to Figure 9(c), the minimum distance and maximum area of the electrode plates increase $H_{2,}$ and O_2 gases immediately reduce the HC. High HC gas emissions are due to imperfect gasoline combustion. O_2 gas has benefited in completing the combustion, resulting in a decrease in the emissions of HC gas.



(a) Interaction of number of plates and distance between plates



(b) Interaction of number of plates and area of electrode plates



(c) Interaction of distance between plates and area of electrode plates

Fig. 9. The interactions of controlled factors (electrode plates) to the HC gas emissions

4. Conclusion

Hydrogen and oxygen gas (HHO) seemed to be the best possible alternative energy solution and were produced via water electrolysis. The effectiveness generation of HHO gas depends on the characteristic of the electrode plates. The following conclusions were obtained:

(i) It was found that the number of plates that interacted with a large area of electrode plate is a significant factor that caused an increase in engine speed on an average of 26%, an average reduction in CO by 43%, and a decrease in HC gas by 42%.

(ii) The HHO gas supplied to the engine gives an average CO reduction of 53%. The area of the electrode plates influences the optimal presence of O_2 gas, distance and number of electrode plates. The increase of O_2 supplied by the HHO gas generator has reduced the CO release content to 1.78 %. Which is optimal, then the O_2 gas supplied has the role of converting CO gas to CO_2, an additional 14.8%.

(iii) The incomplete combustion of the mixing fuel in the engine combustion chamber has produced HC gas emissions. The presence of increased O_2 in the fuel complex mixture has resulted in incomplete combustion. This situation has reduced HC release by 57%.

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