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Research Paper

Integrated Examines of Hydrolyzers, Compression Ratio, Spark Plugs, and Ethanol Gasoline in Four Stroke Spark Ignition Engine for Potentially Application of Higher Ethanol Application

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Abstract

Optimizing combustion parameters by incorporating alternative fuels and modifying the engine's mechanical properties is essential to improving the thermal efficiency and performance that modern internal combustion engines. This study examines the impact of HHO gas utilization, variations in compression ratios, various types of spark plugs, and ethanol gasoline blends on the torque and other characteristics output of a 4-stroke fuel-injected single cylinder engine. Hydrogen is generated from electrolysis and utilized as supplementary fuel. The Taguchi method was employed to create tests involving four variables: HHO percentage, compression ratio, spark plug type, and ethanol mixture. Testing occurred at 5000 RPM under a load of 1800 Watts. The findings indicated that the amalgamation of 20% HHO, a compression ratio of 16.9:1, platinum spark plugs, and E-80 ethanol yielded optimal engine performance, enhancing thermal efficiency to 60% at a speed of 7500 rpm. Moreover, the results of deposit content analysis after 50 hours of operation indicated that the ideal design produced fewer deposits than RON 92 gasoline.

Keywords: Compression ratio; Gasoline ethanol; HHO; Torque

1. Introduction

Indonesia ranks as the fourth most populated nation globally, with a population of 287.6 million, as reported by the Central Statistics Agency of Indonesia [1]. The substantial population directly influences the rising demand for both public and private transportation. The motorcycle is one of the most prevalent ways of transportation in Indonesia. Nonetheless, fossil fuels present a significant issue, as they generate substantial emissions and necessitate expensive government subsidies for acquisition. Prior research [2], [3], [4] indicates that the utilization of ethanol gasoline and HHO (oxyhydrogen) significantly enhances the performance and sustainability of internal combustion engine. Furthermore, a study on ethanol gasoline methanol blends in single ignition engines [5] demonstrated a 2.4% enhancement in power and a notable decrease in CO, NOx, and HC emissions, despite heightened fuel consumption, highlighting the necessity to optimize the blend ratio to reconcile performance and efficiency.

Research indicates that the incorporation of HHO into gasoline [6], [7], CNG [8], and biofuel systems [9], [10] yields beneficial outcomes, including enhanced combustion rates, a thermal efficiency increase of up to 17%, and a reduction in CO and HC emissions exceeding 20%. However, this is frequently accompanied by a rise in NOx emissions due to elevated peak temperatures [11], [12]. Moreover, the integration

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of bioethanol with HHO supply in spark ignition engine has demonstrated a reduction in specific energy consumption of 9.45% and a decrease in greenhouse gas emissions by up to 10.19%, alongside enhanced engine stability [13]. The incorporation of ethanol gasoline and HHO as alternative fuels may facilitate the shift towards low-emission and more energy-efficient transportation [14], [15]. However, further technical studies are required to solve issues such as elevated fuel consumption, torque characteristics, thermal efficiency, specific fuel consumption (SFC) and the potential decrease in NOx emissions.

The application of ethanol gasoline and HHO in spark ignition engine typically involves modifications to the fuel supply system and the incorporation of electrolysis devices [7], [16]. Ethanol is incorporated into petrol in varying proportions (e.g., E10–E85) through port fuel injection or direct injection systems [17], [18], necessitating minimal modifications to the engine. However, optimal efficiency is typically attained with medium mixtures due to ethanol's elevated latent heat of evaporation [5], [19]. Simultaneously, as reported [20], [21] HHO is generated as needed using water electrolysis employing KOH or NaOH catalysts, thereafter introduced into the intake manifold or via a venturi injection system to enhance the air-fuel combination. This approach has demonstrated efficacy in augmenting cylinder pressure and thermal efficiency, while simultaneously decreasing specific fuel consumption and CO and HC emissions. However, [12], [13], [22] explaining that it frequently results in elevated NOx levels due to increased combustion temperatures. The amalgamation of HHO with bio-ethanol is achieved with the installation of an onboard electrolier in conjunction with an ethanol supply system, leading to enhanced power output, improved energy efficiency, and a notable decrease in greenhouse gas emissions [23], [24]. Consequently, both ethanol and HHO are utilized via a straightforward additive method, yet they effectively enhance engine performance and vehicle energy sustainability.

The engine improvements carried out by Faroog *et al*. [25] rendered HHO operable. Improved torque in spark ignition engines was found by [26] when HHO with increasing variations was applied. In parallel with study [27], [28], [29] explaining that thermal efficiency increased by 20% compared to when HHO was not employed. At exactly the same time, [30] used HHO to shorten the duration it took for ignition to happen and to speed up the length of combustion. utilizing hydrogen is merely one of several important factors affecting combustion performance, others include fuel mixture, spark plug type, compression ratio, and engine oil. Hydrogen and ethanol, which have high octane ratings, work well in engines that have a high compression ratio. The appropriate compression ratio mitigates detonation, enhances combustion uniformity, and increases the engine's thermal efficiency. Conversely, spark plug varieties including nickel, platinum, and iridium possess distinct ignition properties that might influence the ignition velocity of the fuel-air mixture within the combustion chamber. Choosing the correct spark plugs can enhance combustion efficiency, diminish emissions, and augment engine torque and power. Simultaneously, the utilization of ethanol fuel mixes such as E-80, E-85, and E-90 presents benefits for oxygen content and enhanced combustion efficiency relative to pure gasoline.

An examination of earlier studies identified numerous critical deficiencies, especially with the restricted diversity of experimental circumstances and optimization methodologies employed. The majority of study on ethanol-gasoline blends and HHO supplementation primarily examines the influence of fuel composition on engine performance and emissions, neglecting the interaction of engine design variables such as spark plug type and compression ratio, which substantially impact peak cylinder pressure, heat release rate, and combustion stability [3], [31]. The combustion characteristics in 4-stroke injection engines arise from the concurrent interactions of fuel and mechanical parameters; thus, a partial approach may yield less thorough conclusions. Moreover, despite the application of optimization techniques like Response Surface Methodology (RSM) [32], [33], there remains a paucity of research that systematically assesses multi-factor combinations via experimental designs that are both efficient and sufficiently adept at capturing the principal effects and interactions of variables. This constraint establishes a notable research void, especially in the formulation of a cohesive optimization framework that concurrently addresses engine performance, specific fuel consumption (SFC), thermal efficiency, and the propensity for deposit accumulation. This study introduces innovation by employing the Taguchi method utilizing orthogonal arrays to systematically integrate four critical variables HHO percentage, ethanol-gasoline mixture, spark plug type, and compression ratio into a comprehensive multi-response optimization framework. This methodology not only addresses the shortcomings of prior research regarding experimental efficiency but also offers a thorough assessment of the interactions among combustion parameters that have not been examined cohesively. This work offers substantial methodological and technical advancements for the creation of more efficient and ecologically sustainable engine optimization solutions.

2. Analysis of HHO, Ethanol Gasoline Engine Performances

The deliberate inclusion of HHO gas to gasoline and ethanol mixtures has been demonstrated in numerous recent experiments to enhance the performance of gasoline engines. Supplying HHO to engines powered by gasoline-ethanol mixtures could improve combustion stability and thermal efficiency, according to a study by [34]. There was an improvement in brake thermal efficiency (BTE) compared to engines that ran on pure gasoline-ethanol blends. At medium to high workloads, the torque was either maintained or slightly enhanced, and the emissions of CO and HC were reduced as a result of greater oxidation brought about by the addition of oxygen from HHO gas. Having said that [35], the study confirmed that peak combustion temperature increases may lead to an increase in NO_x emissions under some scenarios. In specifically investigating the impact of HHO addition on the performance of gasoline engines, the study of [12], [36], [37] supports these conclusions. At medium to high workloads, the findings demonstrate an enhancement in combustion acceleration and a decrease in specific fuel consumption (BSFC). In addition to a steady decline in CO and HC emissions, engine torque also gained at elevated rpm. Consistent with earlier research, NO_x emissions rose as the mixture approached stoichiometric values, suggesting that ignition management and fuel-air ratio control are critical for maximizing HHO's advantages.

Based on Inbanaathan *et al*. [10] that conducted an extensive study that looked at variable speed gasoline engines using hydrogen, gasoline, and ethanol mixtures. This combination may boost thermal efficiency at medium speeds, decrease combustion length, and allow for early ignition due to better knocking resistance, according to the outcomes of the tests. So, compared to simply employing gasoline or gasoline with ethanol, the torque at high revs was increased. As a result of better combustion, CO and HC emissions declined further, while CO_2 per unit of electricity stayed reasonably constant. A proper supply and engine control mechanism are essential for using hydrogen or HHO, according to the researchers. The reason is due to unchecked increases in combustion temperature might contribute to a rise in NO_x emissions. Compared to burning pure gasoline, the chemical reaction dynamics of burning an ethanol- gasoline blend with additional HHO gas (a stoichiometric mixture of hydrogen and oxygen, $2H_2 + O_2$) are greater in complexity. In order to completely burn when burned, ethanol (C_2H_5OH) and gasoline (approximated as iso-octane C_6H_{18}) need an adequate quantity of oxygen from outside sources as Eq. (1).

The addition of peroxide from hydrogen (HHO) to the circulatory system speeds up the process because hydrogen burns at a high rate ($2H_2 + O_2 \rightarrow 2H_2O$), leading to a quicker flame and an increase in active radicals (OH) in the combustion zone. Incomplete carbon processes (CO and HC) are inhibited by the presence of internal oxygen from ethanol and HHO, which decreases the need for oxygen from the air. According to [2], [3], [38], when HHO is mixed with ethanol and gasoline, there is a decrease in CO or HC emissions and an increase in thermal efficiency. Nevertheless, managing the air-fuel ratio and ignition timing are crucial components of this technology's implementation due to the fact that the rapid reaction rate of hydrogen can raise peak flame temperatures, leading to a larger tendency for NO_x generation through the thermal mechanism.

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O \text{ and } C_8H_{18} + 12.5O_2 \rightarrow 8CO_2 + 9H_2O \quad (1)$$

3. Method

This study used the Taguchi method as a systematic experimental methodology to investigate the effects of various factors on torque and power in a modified 4-stroke injection single spark ignition engine. This method was chosen given its potential to reduce the number of examinations required while delivering precise and efficient results. This study employed the Taguchi technique utilizing a four-factor, three-level configuration with a L9 experimental design to achieve an efficient and systematic experimental framework. The primary objective function was established as torque, enabling the Signal-to-Noise (S/N) ratio analysis to employ the larger-the-better criterion for determining the parameter combination that yielded optimal performance resilient to fluctuations in operating conditions. The variables studied included the compression ratio, spark plug type, percentage of HHO gas combination, and percentage of fuel gasoline ethanol content. The investigation was carried out at a constant engine speed of 5000 RPM using the measurement scheme depicted in **Figure 1**, based on observations [6], [16] indicating that a highly substantial enhancement in torque and power occurred at low to medium speeds when mixed gasoline ethanol fuel was used. In this regard, compression ratio change represented one of the key variables investigated to establish its impact on engine performance, particularly under these operating conditions. Torque data were collected using a dynamometer with an 1800 Watt, and the experimental outcomes were examined using the Taguchi optimization approach to determine the best treatments combination for engine performance.

In this study, the variables are defined in order to support Taguchi-method experiments. Torque is the objective function that serves as the observed response variable. This torque shows the engines performance after adjusting the ethanol and HHO. Meanwhile, the variables and factors are divided into four primary categories, each with three treatment levels (**Table 1**). The first variable, HHO gas which is produced by water electrolysis and utilized as an extra fuel, varies according to the PWM duty cycle, with options of 20% (2.4 Volts), 50% (6 Volts), and 80% (9.6 Volts). The HHO Production as shown in **Figure 2** The electrodes will be immersed in the electrolyte solution (0.5 Liter of distilled water with a pH of 6 to 8.5 + 5 grams of $NaHCO_3$), followed by a 5.8-volt electric current from the battery flowing to the positive (anode) and negative (cathode) poles. The presence of the electrolyte solution immersing the electrode and cathode creates a connection that allows electric current to flow from the anode to the cathode. The flow of electric current via the electrodes initiates the electrolysis process and produces air bubbles, indicating that a reaction is taking place.

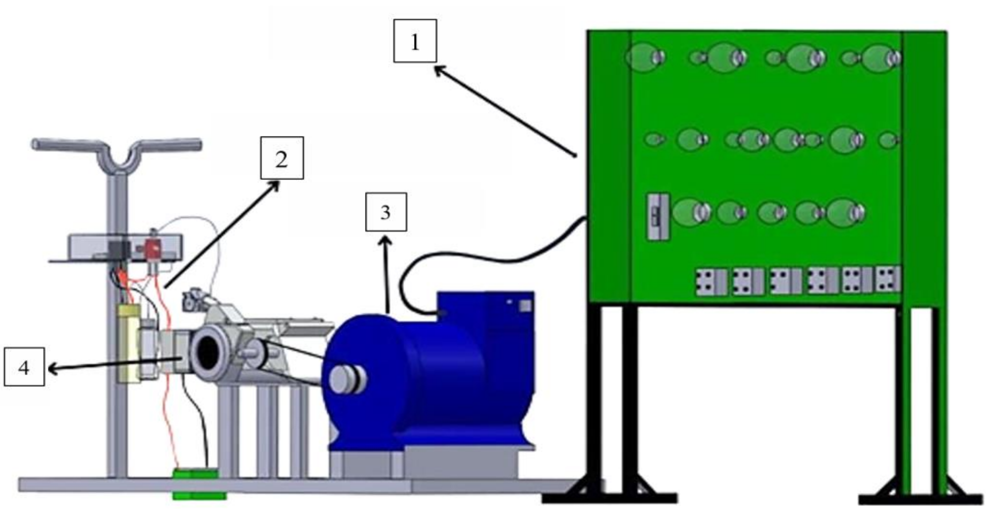

Figure 1. Torque examinations: 1) load with lamp, 2) HHO installation, 3) generator, 4) internal combustion engine

Table 1. Matrix orthogonal

Factor code	Factor	Level code		
		1	2	3
A	HHO	20%	50%	80%
B	Compression ratio	15.8:1	16.4:1	16.9:1
C	Spark Plug	Nikel	Platinum	Iridium
D	Ethanol content	E-80	E-85	E-90

The air bubbles are then pumped into a tube that separates both water and gas (water trap). The water trap separates water vapors and HHO gas. This happens due HHO gas mixed with water vapors from the electrolyzed tube is delivered into the water trap, which has been engineered to come into direct contact with water, allowing the HHO gas to be purified before any rises. In addition, beyond earlier research, the present device has a gas flow controller and monitor. As a limitation to flowing HHO gas into the combustion chamber, it is important to determine the amount of HHO gas produced each minute and limit it using this control mechanism. As a limitation to flowing HHO gas into the combustion chamber, it is important to determine the amount of HHO gas produced each minute and limit it using this control mechanism. The hydrogen gas is subsequently introduced into the intake manifold using a vacuum created within the cylinder chamber. The gas delivered into the intake manifold is going to combine with fuel and air to create a homogenous mixture.

The second variable is the rate of compression of the engine employed in the study, which is 15.8:1, 16.4:1, and 16.9:1, to determine the influence on the combustion effectiveness. The third variable is the type of spark plug applied, which may include nickel, platinum, and iridium, with all of them varying conductivity and heat resistance. Furthermore, the fourth variable is the ethanol and petrol mixture, which is available in three levels: E-80, E-85, and E-90, indicating the amount of ethanol in the fuel. This investigation utilized ethanol at a concentration of 99.7%, adhering to the Indonesian national standard SNI DT 27-0001-2006, as the biofuel. The adjustment of these four elements is intended to reveal the best combination for enhancing vehicle performance, particularly in engine torque at 5.000 RPM. Meanwhile, Table 2 shows the engine specifications.

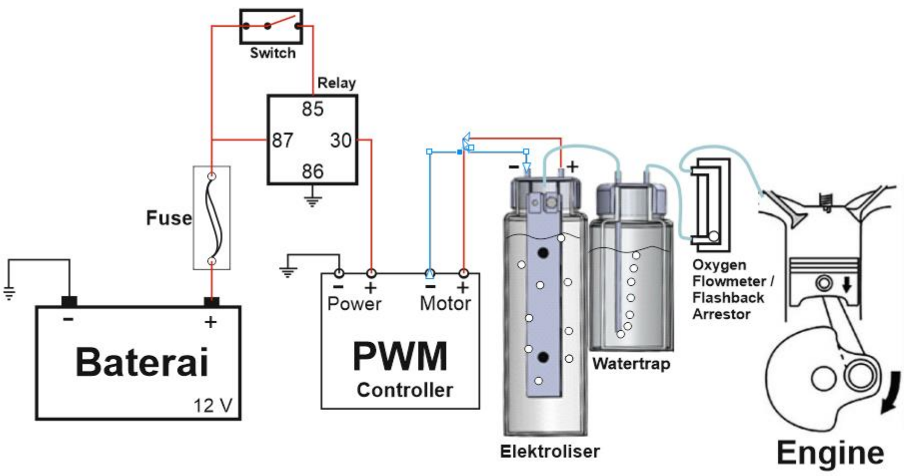

Figure 2. Schematic for HHO production

Table 2. Ignition engine specifications

Engine Specifications	Dimentions
Engine type	4 stroke SOHC, air cooling mechanism
Cylinder Diameter x stroke	50 mm x 57.9 mm
Cylinder Standard	113.7 cc
Transmission	4 Speed gear box
Fuel system	Injection

The data collecting strategy used in this study was designed to capture the necessary information in a systematic and structured process as shown in **Figure 3**, which is consistent with the Taguchi method architecture. Data was collected using the L9(3^4) Orthogonal Matrix. Experiments were designed with four elements, each with three levels, resulting in nine efficient and balanced test combinations (**Table 3**). The experiments were carried out with modifications in the HHO gas combination, compression ratio, spark plug type, and ethanol mixture, all in accordance with the orthogonal matrix design. Each combination was tested directly utilizing torque testing procedures. Before experimentation started, the engine was driven until it achieved normal operating temperature and stabilized at 5000 RPM, which meant that all L9 experiments took place at that speed. The load was gradually provided utilizing a load light bulb attached to the dynamometer's electrical output, as illustrated in **Figure 1** After these steps, the output voltage and current were taken into consideration. This procedure was conducted three times for each treatment combination to ensure accurate data. The torque value was determined using the applicable formula from the study [38], [39] and the data was entered into a table and analyzed as a percentage graph to determine the effect of each variable on engine performance. These results were subsequently employed to determine the most effective treatment combination for boosting vehicle torque.

The Taguchi approach was utilized in this study's data analysis, which is considered to be effective in determining the best combination of many experimental conditions. The first level of data analysis involves using an experimental design with an orthogonal table. An L9(3^4) orthogonal table is used to represent three factors with three levels overall. This table enables the creation of nine efficient experiments to assess the impact of each factor combination on the response, in this case torque. The following step is to determine the Signal to Noise Ratio (SNR) to evaluate the accuracy of the data. Considering the primary goal of this research is to maximize

Figure 3. Experimental process flowchart

Table 3. Matrix orthogonal L9(3^4)

Order	Factor			
	A	B	C	D
1.	20%	15.8:1	Nikel	E-80
2.	20%	16.4:1	Platinum	E-85
3.	20%	16.9:1	Iridium	E-90
4.	50%	15.8:1	Platinum	E-90
5.	50%	16.4:1	Iridium	E-80
6.	50%	16.9:1	Nikel	E-85
7.	80%	15.8:1	Iridium	E-85
8.	80%	16.4:1	Nikel	E-90
9.	80%	16.9:1	Platinum	E-80

torque or larger the better as formulation. This SNR value serves as the foundation for identifying the ideal parameter configuration. Then, an Analysis of Variance (ANOVA) was performed to evaluate how much each element influenced the response. The final phase was to refine and validate the design that was deemed ideal based on its greatest SNR value.

Validation was performed by comparing predicted values to actual test results to guarantee the ideal design's accuracy. The research flow in this work is depicted in **Figure 3**. Furthermore, Dynamic evaluation was used to assess the properties of the combustion chamber and the deposits that accumulated. The test engine functioned for 50 hours, with daily operations calibrated to the typical vehicle activity of 6 hours. The deposit formation test took place on a flat, uphill road in Padang city that is commonly used by motorcycles. The places passed by the vehicle during testing with RON 92 gasoline, optimal prediction, and U_Prediction are the identical, thus the route followed each day will be documented to ensure that the assessment is completed under identical circumstances. Additionally, before switching from one treatment to another, the engine oil is replaced with an identical specification, and periodic inspection is performed to ensure that each treatment is carried out in the same manner. Thus, the acquired findings will provide an accurate representation of the impact of the fuel alteration.

4. Result and Discussion

4.1. Condition of the Engine at the Beginning of Application

The intention of this investigation is to assess the influence of HHO gas mixtures, compression ratio modifications, spark plug types, and ethanol-gasoline fuel combinations on motorcycle engine torque and power. The findings indicate that under cold engine temperatures, the engine feels more responsive and stable. This is why engines that run on a combination of ethanol gasoline and HHO exhibit more robust and faster combustion characteristics owing to the complimentary chemical features of the two components. Ethanol has a high-octane rating and natural oxygen content, which aids in the homogeneity of the fuel atomization process, but HHO, with its rapid flame propagation speed, can expedite the ignition process and broaden the limits of the fuel-air mixture. This combination makes the engine easier to start in cold temperatures, optimizes early throttle response, and decreases cycle fluctuation, which is common during the warm-up phase. Furthermore, during the early phases of operation, volumetric efficiency appears to be higher due to evaporative cooling from the ethanol, which decreases the intake air temperature and increases air density. Thus, engines that use ethanol gasoline and HHO have the potential to produce smoother, more responsive, and environmentally friendly initial characteristics than engines that use pure petrol, according to previous research [3], [31].

The addition of high-octane ethanol and natural oxygen content improves combustion quality, whereas HHO increases flame rate and decreases CO and HC emissions [4]. Overheating causes some components, such as spark plugs and the ignition system, to work less effectively than they operate in cold temperatures, resulting in unstable engine performance. In tests with different engine speeds, at low RPM (gear 1), the power provided was insufficient to switch on the lights since the generator shaft speed remained low. This circumstance remained in gear 2, where the RPM began to grow but had not yet reached the appropriate point to turn on the load. The combustion engine eventually generated the greatest torque in gear 3, with a 1:1 rotation ratio between the output and input shafts on the dynamometer, allowing the load lamp to turn on. In addition, the production of HHO gas per second was estimated to assess the role of gas in increasing the engine's overall efficiency and performance. The data from these tests will be used to analyze the relationship between treatment modifications and engine torque output. The findings of the HHO gas generation measurement are shown in **Table 4**. Subsequently, the compression ratio was computed. When altering the compression ratio, numerous computations were performed to find the suitable compression ratio comparison. **Table 2** lists the characteristics that must be considered while changing compression ratio changes. The burette method, which involves installing the cylinder head and positioning the piston at Top Dead Centre (TDC), can be used for assessing the compression ratio of an engine. The spark plug hole is used to fill the combustion chamber with liquid using the burette, and the quantities of liquid required to fill it reflects the combustion chamber volume (Vc). The burette measurement results indicate a volume of 8-9 mL (mm^3 is presumed to be the incorrect unit; it should be mL). The engine modification calculations as stated in **Table 5** yield the following results.

Engine performance evaluation was carried out to investigate the impact of HHO gas, compression ratio modifications, spark plug types, and ethanol fuel combinations on the increase in torque and power of a rebuilt 4-stroke injection motorbike. The examination concentrated on engine speeds of 5000 RPM, with a dynamometer generator designed for providing a maximum load of 1800 watts. The results revealed a significant increase in torque (Nm) after altering the combustion system and using alternative fuels. This improvement implies that the treatments applied, particularly the appropriate compression ratio and HHO gas injection, might enhance combustion efficiency and raise the engine's mechanical energy output. **Table 6** shows the complete data on the torque test results.

Table 6 indicates that the subsequent level is torque measurement evaluation. The processes are in this order: determine the average value, execute an effect plot analysis on the average value, and conduct an analysis of variance (ANOVA). First, the average value and SNR are determined using the larger is better method, which states that the higher the average value and SNR, the better the torque performance will demonstrate. Using the Larger is better principle, the system will be directed to provide the largest achievable torque value while preserving consistency. This means that the test results must not only be high, but also consistent over trial repeats. A high SNR number shows that the procedure is not only effective but also robust to changes. **Table 7** summarizes the average value and SNR torque estimates.

The engine's performance was tested using average values and SNR analysis with a larger-is-better approach, and the second treatment combination produced the best results. This combination produces an average torque of 6.53 Nm and an SNR of 16.31 dB, as well as 4.58 HP and an SNR of 13.23 dB. These findings suggest that this combination is the most beneficial for

Table 4. HHO production

Percentage (%)	Time (s)	Volt (V)	Measurement (ml)			Average (ml)	Debit (ml/s)
			1	2	3		
20	30	2.4	6.0	8.9	6.5	7.1	0.23
50	30	6	17.5	16	17	16.8	0.56
80	30	9.6	33.8	35	34.7	34.5	1.15

Table 5. Engine modification calculation results

Compression ratio	Volume of Clearance (cm^3)	Volume of Gasket (cm^3)	Gasket thickness (cm)	Volume of Dome Piston (cm^3)
15.8:1	8.776	2.47	0.11	
16.4:1	8.46	2.02	0.09	5.351
16.9:1	8.167	1.572	0.07	

Table 6. Torque measurement results

Order	Desgn of experimental				Torque results measurement		
	A	B	C	D	1	2	3
1	1	1	1	1	5.496	5.703	5.628
2	1	2	2	2	6.236	6.568	6.784
3	1	3	3	3	4.89	5.322	5.369
4	2	1	2	3	4.587	4.964	5.06
5	2	2	3	1	3.857	3.799	4.099
6	2	3	1	2	5.03	5.331	5.476
7	3	1	3	2	3.104	3.381	3.531
8	3	2	1	3	4.387	4.956	4.669
9	3	3	2	1	4.66	4.93	5.2

Table 7. SNR torque estimates

Order	Torque measurement (Nm)			Average (Nm)	SNR
1	5.496	5.703	5.628	5.61	14.98
2	6.236	6.568	6.784	6.53	16.31
3	4.89	5.322	5.369	5.19	14.32
4	4.587	4.964	5.06	4.87	13.76
5	3.857	3.799	4.099	3.92	11.87
6	5.03	5.331	5.476	5.28	14.46
7	3.104	3.381	3.531	3.34	10.49
8	4.387	4.956	4.669	4.67	13.40
9	4.66	4.93	5.2	4.93	13.87

enhancing engine performance. After establishing the SNR values for each combination, additional analysis is performed to guarantee that combination 2 genuinely contributes optimally to the increase in torque characteristics. Table 8 provides complete information on the response table.

After computing the response for each factor level, the study proceeded to generate an effect plot to show the corresponding impact of each factor level on torque values. This plot is presented as a line, with a flat line indicating an inconsequential influence and a steep slope indicating a significant effect on the response variable. This visualisation allows you to rapidly identify the elements that contribute the most to improving system performance. The effect plot results, as shown in Figure 4, provide a crucial foundation for determining the ideal combination of component levels.

The plot effect analysis revealed that torque may be optimized by combining A1, B3, C2, and D3. This combination involves treatment with 20% HHO gas, a compression ratio of 16.9:1, platinum spark plugs, and E-90 ethanol, all of which can provide maximum torque. After collecting the response table findings, use an analysis of variance (ANOVA) to assess the extent to which each element contributes to variations in torque values. The findings of this analysis provide an overview of which factors had the most influence during the trial. In addition to identifying the most influential elements, ANOVA can also determine if these influences are

Table 8. Torque response

Combination	Factor			
	A	B	C	D
Level 1	15.20	13.08	14.28	13.57
Level 2	13.36	13.86	14.65	13.75
Level 3	12.59	14.22	12.23	13.83
Max	15.20	14.22	14.65	13.83
Min	12.59	13.08	12.23	13.57
Diff	2.61	1.14	2.42	0.26
Rank	1	3	2	4
Optimal	A1	B3	C2	D3

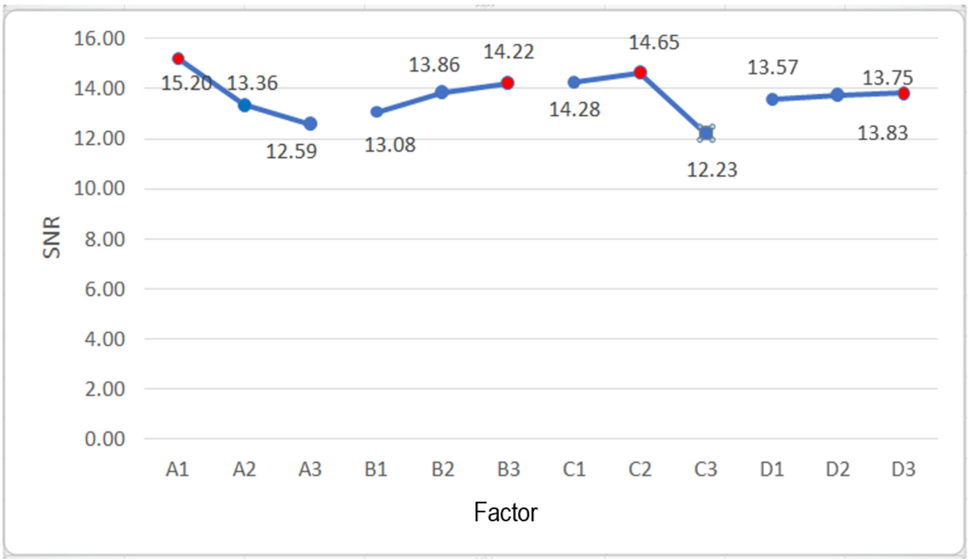

Figure 4. Torque effect plot

genuine or coincidental. **Table 9** contains details of the ANOVA calculation results.

In analysis of variance (ANOVA), the factors with the smallest sum of squares are aggregated into a pooled error group, which typically accounts for about half of the overall contribution of the factors studied. The results of the ANOVA calculation for torque measurements show that factor A has the most dominant influence, accounting for 42.1%. Meanwhile, the ANOVA findings for torque show that factor A is the most relevant factor, accounting for 20.2% of the increase in engine torque. The final step is performing a verification test. The verification assessment seeks to estimate the design's potential outcomes. The level of accuracy is determined by comparing these estimations to the actual experiment findings. The following is a table of verification test results with varied loads and RPMs from **Table 10**. **Table 10** displays the torque and power verification test results with a load of 1800 watts and an engine speed of 5000 RPM based on three measurements. The average power generated was 4.43 with a standard deviation (STDEV) of 0.06, and the average torque was 6.32 with an STDEV of 0.09, demonstrating minimal data variance. The Signal to Noise Ratio (SNR) for power and torque is 12.944 Hp and 16.02 Nm, respectively, showing acceptable data consistency. The anticipated ideal values (U_Prediction) for power and torque are 13.66 Hp and 16.74 Nm, respectively, while the actual results are lower, with errors of 5.60% and 4.52%.

4.2. *Performance Measurement*

The engine's performance characteristics were subsequently established using statistical tests, as illustrated in **Figure 1**. The measurements were conducted with various load variations and RPMs, ranging from 1400 to 3000 watts and 2000 to 7500 RPMs. **Figure 5** shows the results of torque charactristics between engine with E80 optimal design and forecast versus gasoline RON 92 in the identical engine, demonstrating that E80 allows

Table 9. ANOVA of torque

Parameters	SS	Df	Ms	Fratio	SS′	Presentation effect (%)
A	10.81	2	5.41	10.09	9.74	42.1%
B	2.04	2	1.02	1.90	0.97	4.18%
C	10.20	2	5.10	9.52	9.13	39.44%
D	0.10	2	0.05	0.10	-0.97	-4.18%
Pooled *e*	2.14	4	0.54		4.29	18.50%
SSt	23.16	8	2.90		23.16	100%
Mean	1693.55	1				
SSTotal	1716.71	9				

Table 10. Verification measurement

Measurement	Torque and power	
	Power (Hp)	Torque (Nm)
1	4.363	6.219
2	4.473	6.377
3	4.465	6.365
Average	4.43	6.32
STDEV	0.06	0.09
SNR	12.94	16.02
U_Prediction	13.66	16.74
Error (%)	5.60	4.52
Total Error (%)	10.12	

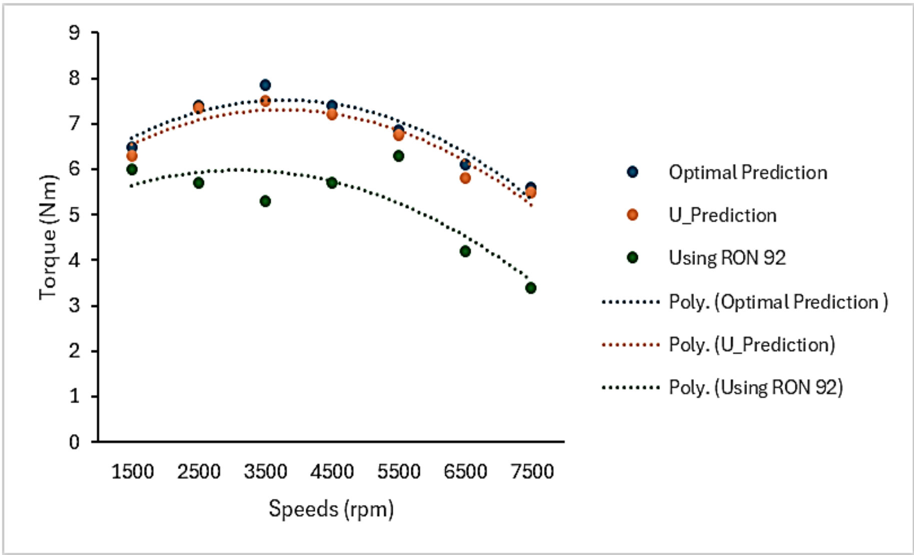

Figure 5. Torque characteristics curve

for advance ignition and a greater knock buffer at high RPM. The physicochemical and thermodynamic qualities of the gasoline are primarily responsible for the difference in torque characteristics between engines running E80 and RON 92 gasoline. The ethanol in the E80 blend has a higher-octane value, which renders it more resistant to knocking. The result enables the engine to run or develop greater advanced ignition and, in some situations, an increase in effective compression ratio. As a result, at medium to high speeds, combustion might take place effectively, resulting in higher peak cylinder pressure and torque. However, at low engine speeds, ethanol has a lower energy density (lower heating value) than gasoline, resulting in less energy released per unit volume of fuel. If a fuel enrichment technique neglects to compensate, this leads to in a modest reduction in initial torque response and acceleration at low speeds. Thus, the torque curve of an E80-fueled engine tends to indicate potential for enhanced power at high speeds, but at the expense of a modest drop in low-rpm performance when compared to RON 92 gasoline.

Simultaneously, Figure 6 and Figure 7 display the fuel mass flow rate and specific fuel consumption (SFC). It is known that after optimizing the engine parameters (HHO composition, compression ratio, spark plug type, and ethanol gasoline ratio), the mass flow rate and SFC of vehicles fuelled with a mixture of ethanol gasoline and HHO-enriched gasoline can be lower than pure gasoline. Ethanol contains intrinsic oxygen, has a high octane number, and produces a substantial amount of evaporation heat, which cools the charge. This mixture lowers knocking, allowing for effective compression and more advanced ignition, enhances combustion efficiency, and at medium load-speed ranges, provide thermal efficiency when compared to pure gsoline (as shown in Figure 8). At low engine speeds, pure gasoline provides greater torque than ethanol (Figure 5), but as rpm increase, ethanol

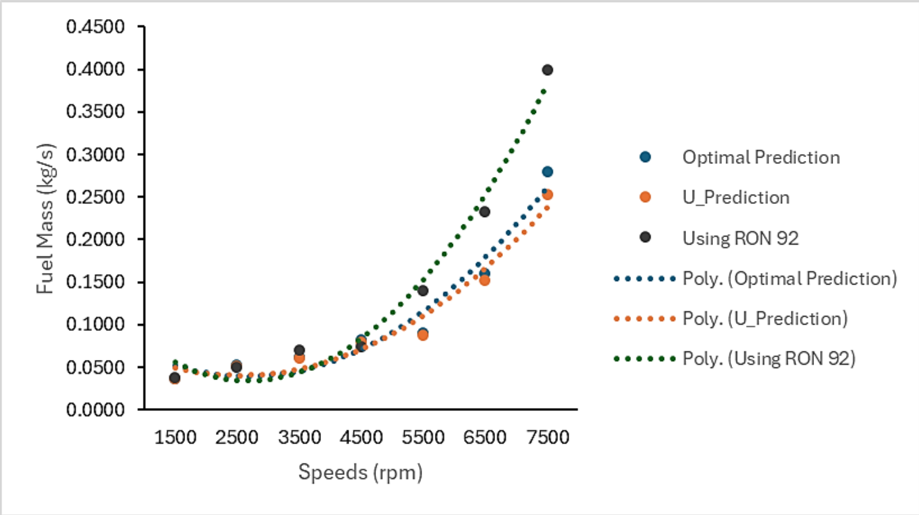

Figure 6. fuel mass vs speeds

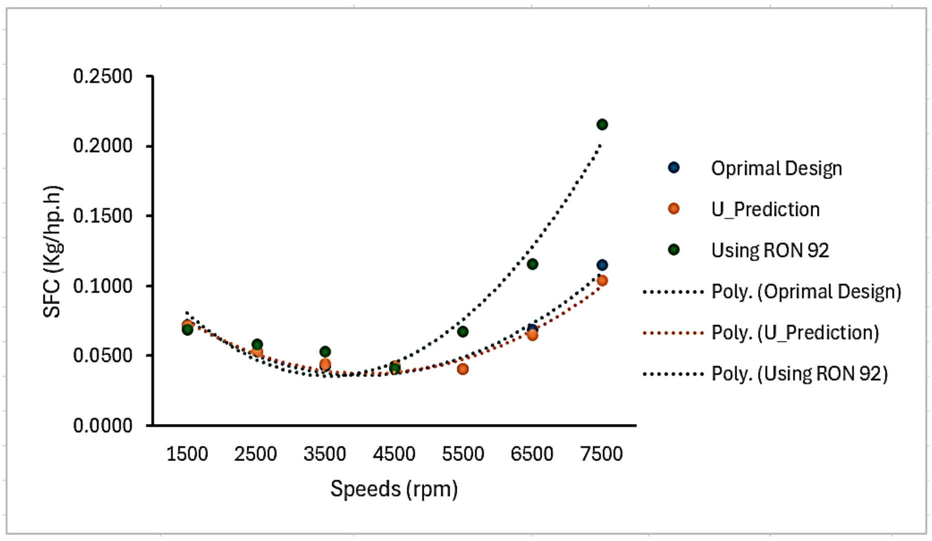

Figure 7. SFC vs speeds characteristics

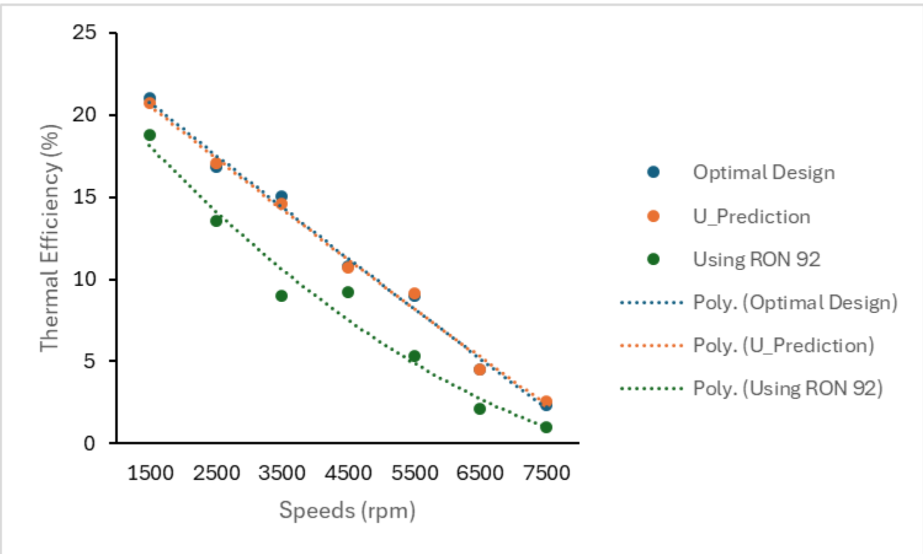

Figure 8. Effisiensi thermal vs speeds

ethanol gasoline produces higher thermal efficiency due to having superior combustion properties. Similar findings were reported by [21], [25]. This study discovered that using E80 ethanol gasoline with HHO resulted in an exceptionally high degree of thermal efficiency, reaching 60% at a speed of 7500 rpm, as illustrated in **Figure 9**.

4.3. Deposit Generated Measurement

Table 11 shows the piston's configuration after deposit creation. After 50 hours of operation on RON 92 gasoline, the piston was totally covered in thick black deposits, with only a little area free of deposits. The condition of the piston treated with RON 92 revealed uneven thick crust formation, indicating poor combustion. The condition of the piston treated with the optimal design and U_prediction yielded favorable and clean results, with only minor traces of combustion on the left side of the piston. Thus, following a 50-hour deposit test, implementing the optimal design and U_prediction yielded improved results than using RON 92. After 50 hours of endurance examination without the utilization of RON 92 fuel, the combustion process exhibited uniformity, evidenced by the development of a thin layer of deposits distributed equally throughout the combustion chamber's surface. The thick crust and light brown color of the EX valve showed an adequate combustion performance, with significant quantities of combustion residue adhering to the valve. When RON 92 was used in the combustion chamber, the EX valve developed a brown color and displayed even crust formation. Meanwhile, the combustion chamber condition in the ideal design and U_prediction revealed moderate crust formation with a relatively clean outside, indicating reduced combustion.

Under high RON 92 SFC and poor thermal efficiency conditions, the mixture tends to be richer and combustion less complete. This increases soot precursors, reduces oxidation time, and decreases wall temperature, allowing heavy portions of fuel and oil to condense in the quench zone. The two main causes of deposits are unburned hydrocarbon fractions and pyrolyzed oil films. Both rise as efficiency falls [33], [40]. Deposits are thicker on the piston, notably on the outer crown, squish land, and piston ring gap, compared on the combustion chamber roof (as shown in **Table 11**). When combustion is inadequate, the combination of wall wetting and oil pyrolysis creates a porous carbon layer that soon builds. The piston edge zone and squish are cooler than the crown core, resulting in a slower burn-off rate and more buildup. In contrast, the combustion chamber ceiling and the area around the spark plug or valve receive a higher heat flux, which bakes or oxidizes deposits, allowing them to accumulate more slowly, albeit their surface may become harder [41], [42].

Deposits on pistons in high SFC circumstances are often thicker, softer, and oilier, and they easily flake off into small particles, increasing wear on rings and liners. Deposits in the combustion chamber or cylinder head tend to be thinner but harder and denser due to thermal sintering; they have the potential to generate hot spots that cause pre-ignition or knocking when local thickness grows around the spark plug or valve edge [13].

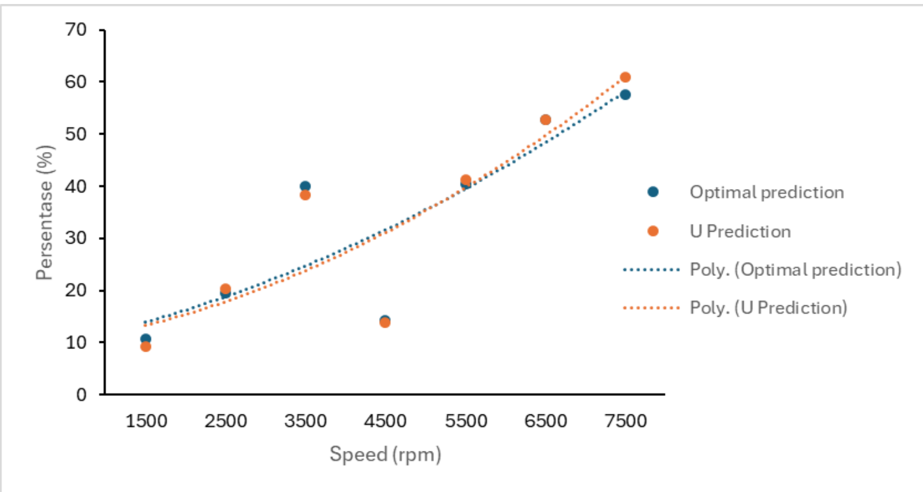

Figure 9. The thermal efficiency percentage produced by optimal prediction and U_prediction compared to RON 92 gasoline

Table 11. Comparison of piston and combustion chamber conditions after 50 hours of durability assesing

Deposite Measurement at 50 Hours	Using RON 92	Optimal design	U_Prediction
Piston surface			
Cylinder head			

The utilization of fuel that is inconsistent with the specifications of the ignition system or the engines compression ratio, as mentioned in [5], [43] concerning combustion delay and the necessity for a more accurate ignition system, might culminate in suboptimal combustion performance. This circumstance may elevate the frequency of incomplete combustion, hence expediting deposit development, especially in cooler regions like the piston cooling zone and crevice volume.

5. Conclusion

This study effectively established that the combination of HHO gas use, compression ratio adjustment, spark plug type, and ethanol proportion in fuel had a substantial impact on the performance of a modified 4-stroke injection system motorcycle engine. According to the findings of investigations utilizing the Taguchi method and analysis of variance (ANOVA), the best treatment combination is 20% HHO gas, a compression ratio of 16.9:1, platinum spark plugs, and an E-90 fuel mixture. This combination resulted in a considerable improvement in average torque of 6.32 Nm and average power of 4.43 HP at 5000 RPM with a load of 1800 W. SNR analysis and verification suggest that this setup could boost combustion efficiency, improve engine response, and indirectly reduce emissions by promoting enhanced combustion. The essential elements in boosting torque are lower specific fuel consumption, higher thermal efficiency, and lower deposits. However, according to the ANOVA results, the most influential element is the use of HHO gas, followed by the kind of spark plug and the compression ratio. Despite a variation between expected and actual test results, tool values remained within the using prediction and optimal design, suggesting strong dependability in the experimental design. Thus, this investigation demonstrates that integrating HHO electrolyser technology with the appropriate engine parameter settings may represent a viable approach for boosting the performance of vehicle engines in an efficient and environmentally responsible approach.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Competing interests

The authors declare no competing interest.

Additional information

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