engineering proceedings

MDPI

Proceeding Paper

Performance Assessment of Spark-Ignition Engine Combined with an HHO Generator †

Ummi Kultsum *, Andi Ibrahim Soumi, Ananta Baharudin and Putra Dwi Manunggal

Mechanical Engineering, Universitas Muhammadiyah Surakarta, Jl. Ahmad Yani, Surakarta 57169, Indonesia; andiibrahimsoumi1@gmail.com (A.I.S.); ananta.baharudin.ab@gmail.com (A.B.); putradwim15@gmail.com (P.D.M.)

* Correspondence: uk356@ums.ac.id

† Presented at the 7th Mechanical Engineering, Science and Technology International Conference, Surakarta, Indonesia, 21–22 December 2023.

Abstract: This study investigates the performance of a four-stroke, spark-ignition engine equipped with a commercial HHO generator that utilizes tap water for HHO gas production. Employing adjustable voltage levels (15 V, 25 V, and 30 V), the generator's impact on engine performance was assessed through experimental dyno tests, measuring torque, power, and fuel consumption, complemented by numerical analyses of HHO production and thermal efficiency. The results, comparing engine operation with and without the HHO system, aim to evaluate the HHO generator's effectiveness as a fuel supplement for enhancing engine performance.

Keywords: HHO generator; HHO; engine performance; spark ignition; engine; gasoline; oxyhydrogen; alternative fuel

check for updates

Citation: Kultsum, U.; Soumi, A.I.; Baharudin, A.; Manunggal, P.D. Performance Assessment of Spark-Ignition Engine Combined with an HHO Generator. *Eng. Proc.* **2024**, *63*, 3. https://doi.org/10.3390/engproc2024063003

Academic Editors: Waluyo Adi Siswanto, Sarjito, Supriyono, Agus Dwi Anggono, Tri Widodo Besar Riyadi and Taurista Perdana Syawitri

Published: 22 February 2024

1. Introduction

Amidst escalating concerns about global warming, reducing reliance on fossil fuels has become imperative. This shift necessitates a greater reliance on renewable and eco-friendly energy sources [1–3]. Hydrogen, particularly when sourced renewably, serves as a sustainable energy carrier. It finds applications in fuel cells for power generation and, interestingly, in the production of oxyhydrogen (HHO) gas through water electrolysis [4,5]. The use of HHO gas in automotive engines not only promises environmentally benign emissions but also potential enhancements in vehicle performance. Despite these benefits, adopting hydrogen-based technologies, including HHO systems, poses challenges, notably in safe installation and handling due to hydrogen's flammability [3,6]. Given this, numerous studies have explored the efficacy of HHO gas as a supplemental fuel to improve vehicle performance.

Kazim et al. [7] evaluated a 315 cc compression ignition engine with electrolyzed oxyhydrogen. Data of diesel fuel and intake manifold flow rates were taken into consideration. Torque was measured at various test settings for diesel fuel and oxyhydrogen flowrates of 6 and 10 standard cubic feet per hour with the engine mounted to a Thepra test bed. The H10 had the biggest engine performance improvement, boosting torque and power by 22.4% at 3000 r/min. Also, efficiency increased by 19.4% at 2600 r/min. The increased oxyhydrogen flowrate to displacement volume ratio improved engine performance compared to previous findings. According to Matienzo et al. [8], adding an electrolytic commercial cell to a carburetor engine increases fuel consumption since it requires more energy to power. A carburetor for a four-cylinder, spark-ignition engine incorporates the cell after testing. Fuel usage was measured via multiple driving tests. Contrary to cell manufacturers' assertions, fuel consumption did not increase. El-Kassaby et al. [9] designed a basic advanced HHO production system and investigated the effects of adding HHO to gasoline fuel to improve engine performance and emissions. HHO cell design, manufacture, and optimization maximized gas output per power. The number of neutral plates, their spacing, and KOH and NaOH catalyst types and quantities were adjusted. A Skoda Felicia 1.3 GLXi gasoline engine was tested with and without the upgraded HHO cell. A TECNO TEST exhaust gas analyzer TE488 was used to measure CO, HC, and NOx emissions. HHO gas production peaked at 18 L/h with two neutral plates 1 mm apart and 6 g/L KOH. A 10% increase in gasoline engine thermal efficiency, a 34% fuel consumption reduction, a 18% CO reduction, a 14% HC reduction, and a 15% NOx reduction were also shown. In addition, Subramanian and Thangavel investigated electrolysis-based HHO gas generation [10]. The effects of the electrolyte solution concentration on potential and the effects of the solution's temperature on production rate, time, quantity of HHO gas modules, or units for real-time engines, as well as energy required, have been studied. An empirical formula projected HHO gas production. The electrolyser produced 0.75 LPM HHO gas at 80 °C and 40 A-h, and numerical calculations showed 1.3 LPM HHO gas generation under identical conditions. Modeling and testing demonstrated the same HHO gas generation current and rate.

Several research studies that have been mentioned previously demonstrate that the production of HHO gas significantly impacts the performance of a vehicle's engine. The production of HHO gas, both theoretical and actual HHO generation, later stated as H2T and HACT sequentially, can be predicted by numerical simulations utilizing the equation derived from prior research [11–13]:

$$\text{H2T} = \left(\frac{\text{Current (A)} \times \text{ Time (s)}}{\text{Faraday}'\text{s Constant}}\right) \times \text{ Equivalent Weight of Hydrogen} \quad (1)$$

$$\text{H2ACT} = \text{H2T } \times \text{ Electrolysis Efficiency} \quad (2)$$

The variable "Current (A)" represents the magnitude of the electric current supplied to the HHO generator, while the variable "time (s)" represents the duration for which the current passes through the HHO generator. Some important values derived from a well-known theory are Faraday's constant, which is 96,485 C/mol, the equivalent weight of hydrogen at 1.008 g/mol, and an assumed electrolysis efficiency of 60%. The efficiency of electrolysis is dependent upon the specific electrolysis method employed. There are three commonly used forms of electrolysis: alkaline electrolysis, which typically achieves an efficiency of 60–70%; PEM (proton exchange membrane) electrolysis, which achieves an efficiency of 60–80%; and solid oxide electrolysis (SOEC), which can approach 80% efficiency. The HHO generator utilized in this study falls within the category of alkaline electrolysis, which implies an expected efficiency of 60% [14,15]. On the basis of this, the estimated volume production of HHO can be determined as follows [14,16]:

$$\text{HHO Volume} = \left(\frac{\text{H2ACT}}{\text{Equivalent Weight of Hydrogen}}\right) \times \left(\frac{\text{Molar Volume of H2 at STP}}{\text{Time}}\right) \times 60 \quad (3)$$

The molar volume of hydrogen gas at standard temperature and pressure (STP) is 22.414 L per mole. If the efficiency of electrolysis increases, the volume of HHO will theoretically also rise. This can lead to enhanced vehicle performance, particularly in terms of thermal efficiency [17,18]. The anticipated outcome of this improvement can be made using the following equation [6,18,19]:

$$\text{Thermal Efficiency} = \frac{\text{Work Output}}{\text{Fuel Energy Input}} \quad (4)$$

The fuel energy input is obtained by multiplying the mass of fuel consumed by the lower heating value (LHV) of gasoline, which is commonly 43 MJ/kg [19–21].

This study employed an experimental and numerical modeling methodology to examine the application of HHO gas in vehicles, especially motorbikes, utilizing a commercially available HHO generator and investigating the effects of different input voltages. The commercially available HHO generator can be readily found on various e-commerce platforms in Indonesia. Further research is required to evaluate the performance of this product. This research serves as an initial demonstration of the benefits of using an HHO generator in an engine, and the extent of improvement it can achieve using experimental and numerical approaches is shown.

2. Research Methodology

This study aimed to predict the performance of an SI engine by integrating a commercially available HHO generator into the engine. The HHO generator is readily available on multiple e-commerce platforms in Indonesia. The HHO generator product can be seen in Figure 1. The installation process for this tool is fairly simple. It involves placing the HHO generator outside the SI engine, which is frequently utilized in motorbikes, and then connecting the electric current source to the current input part of the HHO generator tool. Simultaneously, the HHO gases can be channeled towards the intake channel of the combustion chamber. The HHO generator tool utilizes a power supply with a maximum voltage of 30 V as its electrical input. The voltage can be adjusted to 15 V, 25 V, or 30 V. Additionally, tap water is utilized in the HHO gas production process due to its ready availability and cost-effectiveness by eliminating the requirement for additional electrolytes. The installation setup is shown in Figure 2.

Figure 1. Commercialized HHO generator.

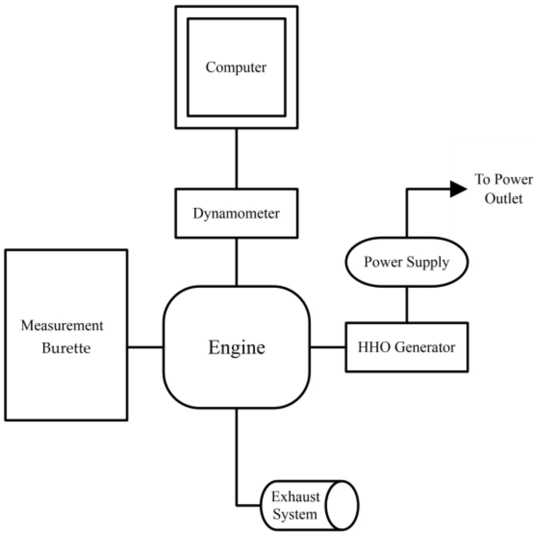

Figure 2. Installation setup.

Data are collected while the vehicle is still under its manufacturer's operating conditions. Data are also collected when the vehicle has an HHO generator. The HHO generator's voltage is gradually raised from 15 V to 25 V to 30 V in each test. Regulating the power supply current allows for capacity adjustment. Experimental data include fuel consumption, torque, and power. An on-wheel dynamometer measures and displays engine speed, torque, and power in real time for Dynotest. The dynamometer system's computer collects this data. The measuring burette is connected to the fuel intake channel and supplied with fuel at specific periods to measure fuel consumption. Fuel consumption time is recorded from the lowest engine speed to the highest. The investigation uses an SI engine with

ASTM D2699-tested gasoline with a RON of 90. The fuel has a density of 715 kg/m^3 at 15 °C, as determined by ASTM D4052 or D1298 testing.

The experimental results accurately depict the engine's peak torque, power, and BSFC (brake specific fuel consumption) for each HHO generator supply voltage change. HHO generation, electrolysis efficiency, and thermal efficiency are also numerically analyzed using standard methods and values. After collecting data using experimental and numerical simulation approaches, the vehicle's performance under conventional settings is compared to the HHO generator's performance with varying supply voltages.

3. Results and Discussion

3.1. Base Engine Performance without HHO Generator

Prior to conducting a detailed analysis of vehicle performance utilizing the HHO generator, initial experimental testing was performed to assess the baseline performance of the unmodified vehicle using Dynotest. Figure 3 displays the performance curve of a vehicle's engine that does not have an HHO generator installed.

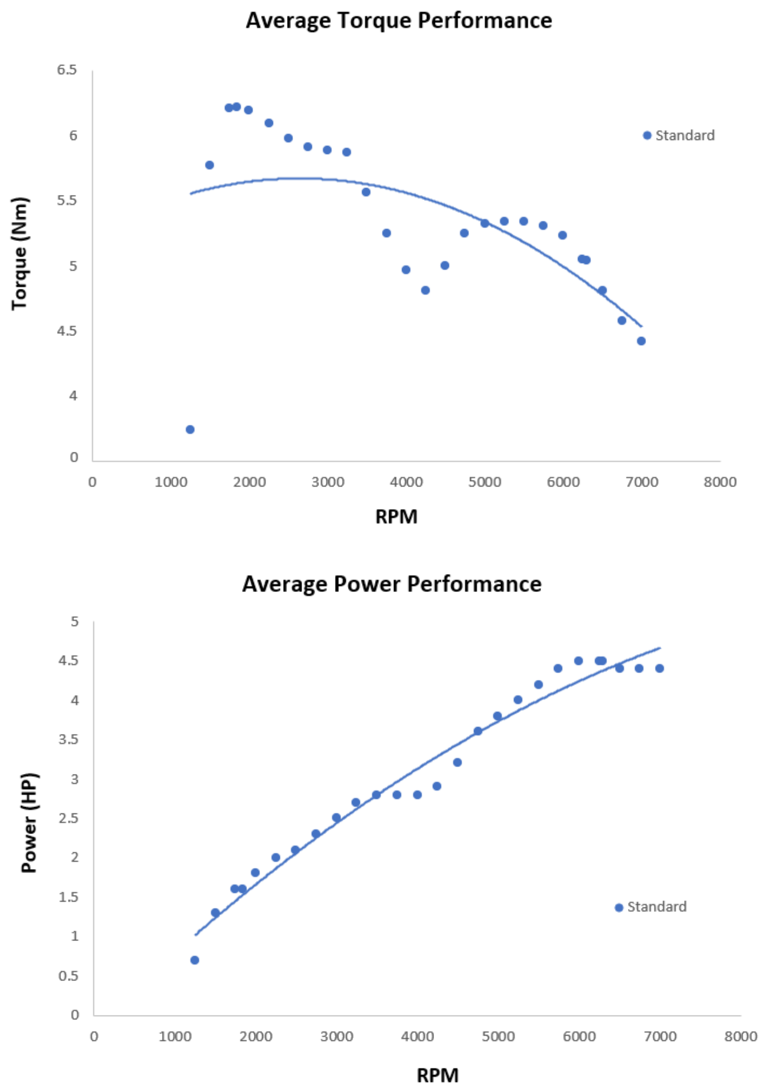

Figure 3. Engine torque and power performance graph without HHO generator.

Given that no alterations were implemented under this setting, the operation of the engines adhered to the specifications set by the manufacturer. The data collected indicate that the engine exhibits a maximum torque of 6.22 Nm at an engine speed of 1840 RPM and a maximum power output of 4.5 HP at 6293 RPM. The engine's fuel consumption rate is 0.987648456 kg per hour, while the brake specific fuel consumption (BSFC) value is 0.219477435 kg per hour per horsepower.

3.2. Performance Metric with HHO Systems

Once data on vehicle performance under normal conditions were gathered via the dynamometer test, a subsequent dynamometer test was conducted on the engine equipped with an HHO generator. The power supply's supply voltage commences at 15 V and continues to 25 V and 30 V. The data obtained from the Dynotest are displayed in Figure 4.

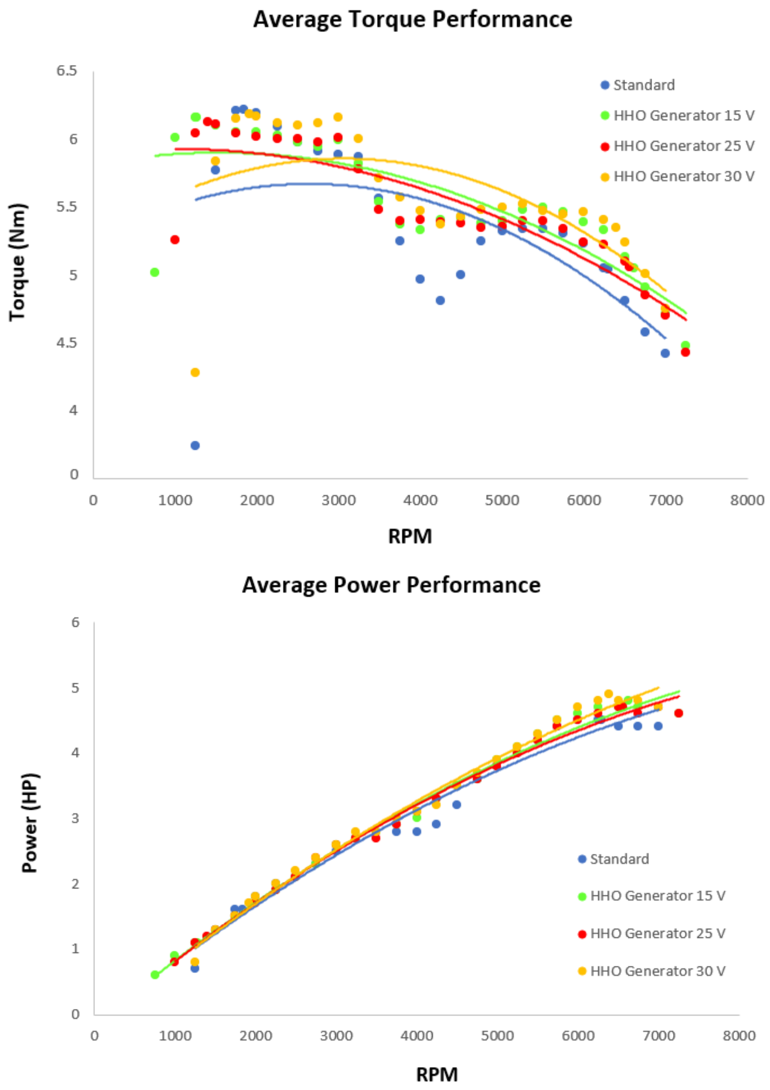

Figure 4. Engine torque and power performance graph with and without HHO generator.

The Dyno test findings revealed that employing an HHO generator with a voltage of 30 V enables the engine to sustain elevated levels of torque and engine power at high engine speeds, in contrast to engines that do not utilize an HHO generator. The enhancement in performance, while modest, indicates a potential benefit of HHO integration in terms of engine output. However, the observed enhancement is not particularly significant. The mean improvement in torque is 0.7%, while power shows a 1.38% enhancement.

Due to energy loss at each stage because of transferring electrical energy to chemical energy and finally to mechanical energy, this value is hardly significant. The generation of HHO gas involves numerous stages that can dissipate energy [22]. Heat dissipation, electrolysis cell resistance, and electrolyte solution inefficiencies prevent some electrical energy from being converted into chemical energy when producing HHO gas [10,14]. For this study, tap water was used as a conductive medium for HHO gas generation, although it is not a specialized electrolyte. After producing HHO gas, the engine must burn it to provide mechanical energy. Partial combustion, heat dissipation to the engine and exhaust, and frictional losses due to engine mechanics make combustion inefficient. These inefficiencies partially convert input energy (electricity needed to generate HHO gas) into output energy (engine torque and power) [23–25]. This may explain the slight engine performance increases from the HHO generator.

3.3. Theoretical and Actual Hydrogen Production Comparison

The quantity of HHO generated by the HHO generator is directly linked to the performance of the engine. The data pertaining to HHO production were calculated theoretically utilizing the numerical equation and are presented in Table 1.

Table 1. Numerical simulation of theoretical and actual hydrogen production.

Voltage (V)	Theoretical H2 Production (g)	Actual H2 Production (g)	HHO Volume (LPM)
15	0.0000394	0.0000237	0.0033452
25	0.0000736	0.0000442	0.0060214
30	0.0000841	0.0000505	0.0081121

The greatest quantity of HHO is produced when the HHO generator is powered by 30 volts of electricity. A higher voltage can accelerate the separation of water molecules into hydrogen and oxygen gases during electrolysis, presuming that the resistance and temperature of the electrolyte remain constant. In the context of this study, tap water is utilized as the electrolyte. This serves to illustrate that a higher voltage can give a greater quantity of energy to overcome the electrical resistance of the water and the solution of tap water, which ultimately results in an increased rate of the electrochemical process. [26]. Therefore, when the voltage provided to an electrolysis setup is increased, it is generally anticipated that there will be a proportional rise in the generation rate of HHO gas, as indicated by the data simulation. This relationship demonstrates the direct implementation of Faraday's laws of electrolysis, which assert that the extent of chemical transformation during electrolysis is directly proportional to the amount of electricity employed [27,28].

3.4. Fuel Consumption Analysis

Fuel consumption is measured during engine operation, regardless of whether or not the HHO generator is being operated. The analysis of fuel consumption is presented in Table 2.

Table 2. Analysis of engine fuel consumption with and without the HHO generator.

Variations	Overall Fuel Consumption (kg/h)	Brake Specific Fuel Consumption (Kg/hHP)
Standard	0.987648456	0.219477435
HHO generator 15V	1.174576271	0.24470339
HHO generator 25V	1.047640449	0.222902223
HHO generator 30V	1.001927711	0.204475043

The fuel consumption data show that the HHO generator increases fuel usage. Fuel usage is highest when the engine uses the HHO generator with a 15 V input voltage, and it decreases with voltage. The engine used the least amount of fuel without the HHO generator. Fuel usage was not statistically significant with the 30 V HHO generator compared to without it. We found that installing the HHO generator in the engine does not always improve fuel efficiency and may even increase fuel usage, especially at 15 V. This may be caused by the engine performance not compensating for the energy needed to produce HHO gas [9,23]. However, at 30V, fuel utilization is equivalent to the typical arrangement, suggesting that higher voltages may improve HHO generation or engine integration. The system's design may be more efficient or optimized at higher voltages.

3.5. Thermal Efficiency Evaluation

The thermal efficiency of the engine is determined through the application of numerical simulation. The thermal efficiency data are displayed in Table 3.

Table 3. Thermal efficiency data of engine with and without the HHO generator.

Variations	Work Output (J)	Fuel Energy Input (J)	Thermal Efficiency
Standard	18557.325	92235	0.2012
HHO generator 15 V	20766.254	122980	0.1689
HHO generator 25 V	21951.557	113756.5	0.1930
HHO generator 30 V	18545.825	92235	0.2011

The data presented in the table demonstrate that the installation of the HHO generator operating at 30V does not have significant effects on the thermal efficiency of the engine. Both configurations, the standard setup and the one with the HHO generator, exhibit approximately 20% efficiency. Nevertheless, the efficiency decreases while using the lower voltages of 15 V and 25 V. The data indicate that the operational voltage of the HHO generator has an effect on engine efficiency. Increasing the voltage settings can potentially improve the HHO generation process or enhance the engine's capacity to consume the HHO gas, resulting in efficiency levels that are comparable to standard conditions. In contrast, lower voltages seem to have a reduced impact, resulting in a decrease in thermal efficiency [9,10].

4. Conclusions

Using an HHO generator to improve vehicle performance is promising, especially regarding practicality, economic value, and accessibility to the general public. However, from the results of experimental testing and numerical simulations that have been discussed, several points need to be considered regarding the use of commercialized HHO generators:

- In general, the difference in engine performance between having an HHO generator and not having one was not enough to be considered noteworthy. Some data indicated that vehicles operated without an HHO generator performed better. The utilization of local tap water, which is contaminated with a variety of pollutants that have the potential to influence the effectiveness of the electrolysis process in the HHO generator, could be the cause of this phenomenon. Future study could consider utilizing a medium that enhances electrolysis efficiency, like distilled water with an additional electrolyte, or investigating catalysts to improve the electrolysis process.
- The electricity source in this research was a power supply, which has space limitations, considering that the power supply requires electrical input from another source. It would be better if future studies were carried out with an automotive battery so that the mobility would be higher and more accurately describe the original situation in which the HHO generator is used in a vehicle.
- It is necessary to carry out experimental research with more detailed data collection methods, such as details of actual HHO gas production and emissions analysis. This is useful for providing comprehensive research based on validated data.
- Given that our engine performance results were not significant, that the data were not validated experimentally, and that some parameters lacked detail, the results of this study are more suitable as a simple illustration of the use of commercialized HHO generators for motorized vehicles.

Author Contributions: Conceptualization, U.K. and A.I.S.; methodology U.K. and A.I.S.; software, A.I.S. and A.B.; validation, U.K. and A.I.S.; formal analysis, U.K. and A.I.S.; investigation, U.K., A.I.S. and A.B.; resources, U.K., A.I.S., A.B. and P.D.M.; data curation, U.K. and A.I.S.; writing—original draft preparation, U.K.; writing—review and editing, U.K. and A.I.S.; visualization, U.K. and A.I.S.; supervision, U.K.; project administration, U.K.; funding acquisition, U.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research is part of the "TRIDARMA INTEGRATION GRANT FOR HIGHER EDUCATION, FACULTY OF ENGINEERING, UNIVERSITAS MUHAMMADIYAH SURAKARTA" 2023, with reference number 057/A.3-III/FT/I/2023.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets presented in this article are not readily available because the data are part of an ongoing study. Requests to access the datasets should be directed to the corresponding author.

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

References

1. Riyadi, T.W.; Spraggon, M.; Herawan, S.G.; Idris, M.; Paristiawan, P.A.; Putra, N.R.; Silambarasan, R.; Veza, I. Biodiesel for HCCI engine: Prospects and challenges of sustainability biodiesel for energy transition. *Results Eng.* **2023**, *17*, 100916. [CrossRef]
2. Sunaryo, M.; Efendy, S.; Kamarrudin, N.S. Pyrolysis of plastic waste as an alternative fuel in spark ignition engine. *Int. J. Emerg. Trends Eng. Res.* **2019**, *7*, 454–459. [CrossRef]
3. Syawitri, T.P. A Review: The Effect of Operating Conditions and Thermal Management on The Performances of Metal Hydride Hydrogen Storage Tanks. *J. Ilm. Tek. Mesin* **2016**, *17*, 38–43. [CrossRef]
4. Naqvi, S.A.H.; Taner, T.; Ozkaymak, M.; Ali, H.M. Hydrogen Production through Alkaline Electrolyzers: A Techno-Economic and Enviro-Economic Analysis. *Chem. Eng. Technol.* **2023**, *46*, 474–481. [CrossRef]
5. Paparao, J.; Murugan, S. Oxy-hydrogen gas as an alternative fuel for heat and power generation applications—A review. *Int. J. Hydrogen Energy* **2021**, *46*, 37705–37735. [CrossRef]
6. Nabil, T.; Dawood, M.M.K. Enabling efficient use of oxy-hydrogen gas (HHO) in selected engineering applications; transportation and sustainable power generation. *J. Clean. Prod.* **2019**, *237*, 117798. [CrossRef]
7. Kazim, A.H.; Khan, M.B.; Nazir, R.; Shabbir, A.; Abbasi, M.S.; Rab, H.A.; Qureishi, N.S. Effects of oxyhydrogen gas induction on the performance of a small-capacity diesel engine. *Sci. Prog.* **2020**, *103*, 0036850420921685. [CrossRef] [PubMed]
8. Matienzo, J.R. An Evaluation of the Effect of HHO in Carburetor Automotive Engines in Road Conditions. Available online: http://rie.cujae.edu.cu/index.php/RIE (accessed on 14 December 2023).
9. El-Kassaby, M.M.; Eldrainy, Y.A.; Khidr, M.E.; Khidr, K.I. Effect of hydroxy (HHO) gas addition on gasoline engine performance and emiss ions. *Alex. Eng. J.* **2016**, *55*, 243–251. [CrossRef]
10. Subramanian, B.; Thangavel, V. Analysis of onsite HHO gas generation system. *Int. J. Hydrogen Energy* **2020**, *45*, 14218–14231. [CrossRef]
11. Li, W.; Tian, H.; Ma, L.; Wang, Y.; Liu, X.; Gao, X. Low-temperature water electrolysis: Fundamentals, progress, and new strategies. *Mater. Adv.* **2022**, *3*, 5598–5644. [CrossRef]
12. Zhang, H.; Su, S.; Lin, G.; Chen, J. Configuration Designs and Parametric Optimum Criteria of an Alkaline Water Electrolyzer System for Hydrogen Production. 2011. Available online: www.electrochemsci.org (accessed on 26 December 2023).
13. Zhang, H.; Lin, G.; Chen, J. The performance analysis and multi-objective optimization of a typical alkaline fuel cell. *Energy* **2011**, *36*, 4327–4332. [CrossRef]
14. Jannah, Z.; Susilo, S.H. Design of HHO generators as producers of water fuel (HHO generator product analysis based on electric current and catalyst). *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1073*, 012034. [CrossRef]
15. Susilo, S.H.; Jannah, Z.; Author, C. Effect of Electrodes, Electric Currents, And Nahco 3 Concentration against Hho Pressure Generator. 2020. Available online: www.researchinventy.com (accessed on 14 December 2023).
16. Krv, S. The Electrolysis of Water to Generate Hydrogen (Hho) and a Study of the Effect of Addition of Hho To Gasoline as an Engine Performance Improver. 2018. Available online: www.tjprc.org (accessed on 14 December 2023).
17. De Silva, S.; Senevirathne, L. HHO Generator-An Approach to Increase Fuel Efficiency in Spark Ignition Engines. 2015. Available online: https://www.researchgate.net/publication/283710268 (accessed on 14 December 2023).
18. Al-Rousan, A.A.; Alkheder, S.; Musmar, S.A.; Al-Dabbas, M.A. Green transportation: Increasing fuel consumption efficiency through HHO gas injection in diesel vehicles. *Int. J. Glob. Warm.* **2018**, *14*, 372–384. [CrossRef]
19. Salek, F.; Zamen, M.; Hosseini, S.V. Experimental study, energy assessment and improvement of hydroxy generator coupled with a gasoline engine. *Energy Rep.* **2020**, *6*, 146–156. [CrossRef]
20. Shapouri, H.; Duffield, J.A.; Wang, M. *The Energy Balance of Corn Ethanol: An Update*; Scholar's Choice: New York, NY, USA, 2002.

21. *Methodology for Thermal Efficiency and Energy Input Calculations and Analysis of Biomass Cogeneration Unit Characteristics*; U.S. Environmental Protection Agency Office of Air and Radiation: Washington, DC, USA, 2007.
22. Alfimov, M.V.; Razumov, V.F. Modern energetics: Current problems in energy conversion and utilization of produced energy. *Pure Appl. Chem.* **2017**, *89*, 1521–1534. [CrossRef]
23. Patil, N.N.; Chavan, C.B.; More, A.S.; Baskar, P. Generation of oxy-hydrogen gas and its effect on performance of spark ignition engine. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *263*, 062036. [CrossRef]
24. Sayed, M.M.; Shalaby, M.S.; Rady, W.; Hussien, W.; Magdy, M.; El-Sabagh, K.; Mohamed, A.; Eldin, A.N.; Maher, F.; Osama, M. Design of HHO cell as energy source for electric vehicles. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *610*, 012089. [CrossRef]
25. Zhao, Z.; Huang, Y.; Yu, X.; Sun, P.; Li, M.; Shi, W.; Guo, Z.; Wang, T. Effect of HHO addition on combustion and emission in SI engine with butanol direct injection and gasoline port injection. *Case Stud. Therm. Eng.* **2023**, *42*, 102746. [CrossRef]
26. Albornoz, M.; Rivera, M.; Wheeler, P.; Ramírez, R. High Pulsed Voltage Alkaline Electrolysis for Water Splitting. *Sensors* **2023**, *23*, 3820. [CrossRef] [PubMed]
27. JBabu, J.; Kumar, K.S.; Kumar, R.R.; Ağbulut, Ü.; Razak, A.; Thakur, D.; Sundara, V.; Asif, M. Production of HHO gas in the water-electrolysis unit and the influences of its introduction to CI engine along with diesel-biodiesel blends at varying injection pressures. *Int. J. Hydrogen Energy* **2024**, *52*, 865–885. [CrossRef]
28. Singla, A.; Singh, Y. Analysis of HHO gas generation rate under KOH & NaOH electrolytic solution. *AIP Conf. Proc.* **2023**, *2521*, 030006. [CrossRef]