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Design of a Management System for a Wet-Type HHO Generator Unit with Integrated Programmable Power Control and Safety Features

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Abstract— It is the application of a developed Controlling system to the low-cost, wet-type alkaline HHO (oxyhydrogen) generator/electrolyzer system designed to enhance the traditional stroke gasoline internal combustion engine (ICE) performance and reduce greenhouse gas (GHG) emissions. The system optimizes the gas production of the HHO unit by optimizing the significant parameters with a microcontroller system (Arduino). Gas production was not linearly proportional to power input because of the more energy loss due to heat generation. It resulted from improper significant parameter control, such as temperature, pressure, and current, suggesting that higher power levels must surpass a certain threshold before effective gas production begins, indicating potential inefficiencies in energy usage. The study concludes that integrating a control unit to manage voltage, temperature, and pressure can significantly improve gas production efficiency while preventing overheating by maintaining voltage between 2.4V to 4.2V and 0 to 6.8A current. Further, the Internet of Things (IoT) is a possible solution to enhance the controller unit productivity effectively.

Index Terms— Arduino controller, HHO gas, Internal Combustion Engine, Greenhouse gas emission, Internet of things, Programmable control systems, Stainless Steel, Wet-type oxyhydrogen generator

1. INTRODUCTION

The present condition of energy generation is significantly subjected to fossil fuels, contributing significantly to global greenhouse gas (GHG) emissions. The focus on transitioning to cleaner and more sustainable energy sources has become increasingly urgent as countries strive to achieve net-zero emissions by 2050 [1]. This is insufficient to meet the 2050 targets, necessitating exploring alternative energy solutions [1]. Among these alternatives, hydrogen (H_2) stands out as a trending energy carrier because of the quality of the resource instead of biofuels. Hence, hydrogen has the potential to emit no CO_2, hydrocarbons (HC), or carbon monoxide (CO) during combustion, making it a key player in the global shift towards clean energy compared to traditional fuels such as ethanol, biodiesel, and natural gas [2].

Hydrogen is notable for its high combustion velocity, approximately six times that of gasoline, which enhances its efficiency when used in four-stroke internal combustion engines (ICEs) [3], [4]. Its broad flammability range also makes it adaptable to various energy applications [3]. However, hydrogen production-related major drawbacks are available in the methods used to produce hydrogen. Steam methane reforming, coal gasification, and water electrolysis are vastly applicable production methods [5]. From that, steam methane reforming is widely used, heavily reliant on fossil fuels, resulting in substantial CO_2 emissions [6]. Coal gasification is similarly problematic due to its low efficiency and high environmental impact [6]. Electrolysis is preferred for clean energy applications because it can be powered by renewable electricity; electricity can be introduced as a clean and 2nd level energy source comparing heat and chemical energy[7], [8].

Further, generated hydrogen is named by electricity that is used as a source to generate. Renewable energy sources like solar, wind, or hydropower contribute to generating green hydrogen, and fossil fuels like diesel and gasoline; coal mainly contribute to grey hydrogen [9]. Green hydrogen is a much cleaner alternative that significantly reduces carbon emissions actively and passively [9]. The leading technologies available in electrolysis for hydrogen production are listed below. Table 1 illustrates.

Table 1: Comparison of Electrolysis Technologies and Specifications [9], [10], [11].

Electrolysis Technology	**Definition & Specification**
Alkaline	• Alkaline electrolyte solution mainly uses potassium hydroxide (KOH) or sodium hydroxide (NaOH) to produce Oxyhydrogen (HHO) gas by splitting water molecules. • The operating temperature is typically 60-80°C. • Durable and low cost compared to other methods.
Solid Oxide	• Solid oxide or ceramic electrolyte converts water (H2O) and carbon dioxide (CO2) into hydrogen and carbon monoxide under a high-temperature condition called the high-temperature electrolysis process. • The operating temperature is around 700-1000°C. • Highly efficient in converting thermal energy into chemical energy and suitable with renewable energy sources like solar and wind.
Polymer Exchange Membrane (PEM)	• It uses a solid polymer membrane as an electrolyte to conduct protons while separating hydrogen (H_2) and oxygen (O_2). • The operating temperature is around 50-80°C. • It offers rapid start-up times and high power density. • More compact, suitable for small-scale applications.

In Alkaline electrolysis, the water is split into H_2 and O_2 gas using an electrical current where H_2 gas is collected at the cathode and O_2 at the anode. Further, it has two main methods, such as wet and dry type [12]. A wet-type HHO generator operates with a liquid alkaline electrolyte, where the electrode stack sinks in a KOH or NaOH solution [12]. Dry-type alkaline electrolysis uses a gel or highly concentrated electrolyte liquid of typically KOH or NaOH where the electrolyte only touches the surface of the electrodes and thermal resistant rubber gaskets plies to prevent leakages with tightly fit electrodes with casing [12]. This work favors alkaline wet-type electrolysis due to its lower operational costs and simplicity than other methods, such as proton-exchange membrane (PEM) electrolysis.

One emerging approach to effectively utilizing hydrogen is integrating hydrogen with ICEs through hybrid energy systems. These systems, known as Hybrid Renewable Energy Systems (HRES), combine HHO generators with traditional ICEs to improve energy efficiency while improving engine brake power and GHG emissions [13]. HRES can also benefit from hydrogen's flexibility in storage and use, reducing consumption of scarce materials and providing greater tolerance to contamination. HHO-coupled ICEs have the added benefit of producing fewer pollutants, mainly when advanced combustion processes are used to reduce nitroxide (NOx) emissions, bringing them close to zero [12]. However, without a controller or safety measure, the HHO system can't connect directly with ICE because it may reduce the system's efficiency from the main drawbacks of application of the HHO system with ICE like engine knocking, piston damage due to high thermal capacity, etc. [3].

In the electrolysis process, the efficiency of the water-splitting process can be significantly enhanced by ensuring that the electrical input is carefully regulated to avoid overconsumption of energy or damaging the cell components [14]. A programmable system like Arduino can control a Pulse Width Modulation (PWM) controller following program data inputs, which adjusts the current supplied to the generator system, optimizing the electrolysis efficiency and reducing energy losses [14]. Arduino is a cost-effective, flexible, and open-source platform that provides a valve solution for small-scale applications [14]. Furthermore, Programmable Logic Controllers (PLCs) are widely used in the automotive industry for their ability to handle complex control processes in harsh environments [14]. However, it is a thousand times more expensive than the Arduino system, and it is not a practical application because this process only needs limited inputs/outputs (I/O) with processes required to handle [7]. In addition, it can work with functions of automated safety protocols, such as shutting down the system when certain thresholds, like high temperature or pressure, are exceeded [7]. Control system contributes to safer and more efficient hydrogen production, especially in automotive applications where HHO gas improves fuel efficiency [7].

The rise of the Internet of Things (IoT) and automated systems has revolutionized various industries by enabling real-time monitoring, data collection, and control, thus improving efficiency and scalability [15]. IoT can be pivotal in automating and optimizing processes such as water electrolysis in HHO gas generation systems [16]. Sensors and actuators embedded in the HHO system can collect critical data such as temperature, pressure, voltage, current, and gas production rates with IoT [15]. This data can then be transmitted to a central processing system or cloud-based platform for real-time analysis and decision-making, resulting in highly optimized operations [15]. IoT integration can significantly enhance system performance by automating data collection and providing actionable insights to regulate electrolysis [17]. For example, IoT-based systems can detect inefficiencies or irregularities in gas production, voltage fluctuations, or excessive power consumption and adjust the system accordingly [16]. Through cloud-based systems, users can remotely monitor and control the hydrogen production process, making overseeing multiple hydrogen production units across different locations more accessible. This remote accessibility provides flexibility and ensures the system runs efficiently, even when human oversight is limited. Further, it offers predictive maintenance capabilities, where system failures or potential issues are detected before they occur, reducing downtime and increasing the longevity of the equipment [17]. This level of automation can ensure that the hydrogen production process remains efficient while minimizing operational risks.

The research here investigates the practical application of automated control systems for hydrogen generation, specifically in small-scale setups using wet-type HHO generators and alkaline electrolytes. This system monitors and adjusts hydrogen production in real-time, ensuring optimal performance and safety. By integrating pressure, temperature, voltage, and current sensors, the research highlights the effectiveness of using Arduino-based systems to control hydrogen generation processes, making them more efficient and scalable.

2. EXPERIMENTAL WORK

2.1. HHO System Design and Fabrication

The wet-cell type HHO generator was designed based on results from previous studies, where operating parameters are shown in Table 2. Some parameters are developed for this study with a stainless steel (SS) electrode arrangement in a P-N-P-N-P-N configuration. The electrode plate dimensions were calculated according to the selected IC engine's HHO gas flow requirement. The SolidWorks software was used to construct the HHO generator design, bubbler unit, and ECU casing, as shown in Fig. 1.

Table 2: HHO System Specifications

Specification	Unit	Measurement
HHO generator operating voltage	*V*	1.4 - 4.4
Working current range	*mA*	0-7000
Catalyst electrolyte	-	KOH
Solution molarity	$mole/dm^3$	0.1
Electrode stack arrangement	-	P-N-P-N-P-N
Electrode gap	*mm*	4
Capacity of generator	cm^3	236
Capacity of bubbler	cm^3	196
Controller voltage input	*V*	12

In the HHO generator unit, electrode plates were rigidly connected using SS nuts, bolts, and washers, and rubber washers were used between the anode and cathed to make disconnections to prevent short circuit conditions. SS terminals of nuts and bolts were connected to the terminal plates and the electrode stack, where the anode and cathode were separate. PVC endcaps are connected to the ends of the acrylic tube to make the casing of the HHO generator unit inside available in the electrode stack. The terminals were removed from PVC endcaps using holes and sealed using solvent cement with third seel tapes. Pneumatic fittings were connected to the holes of 4M on both sides. In the bubber unit, PVC endcaps with 4M holes are connected to the ends of the acrylic tube. Pneumatic fittings were fitted to the holes available in the PVC endcaps. Fig. 2 illustrates the completed HHO generator and bubbler unit assembly, and Table 3 illustrates measures of all materials used for the HHO kit.

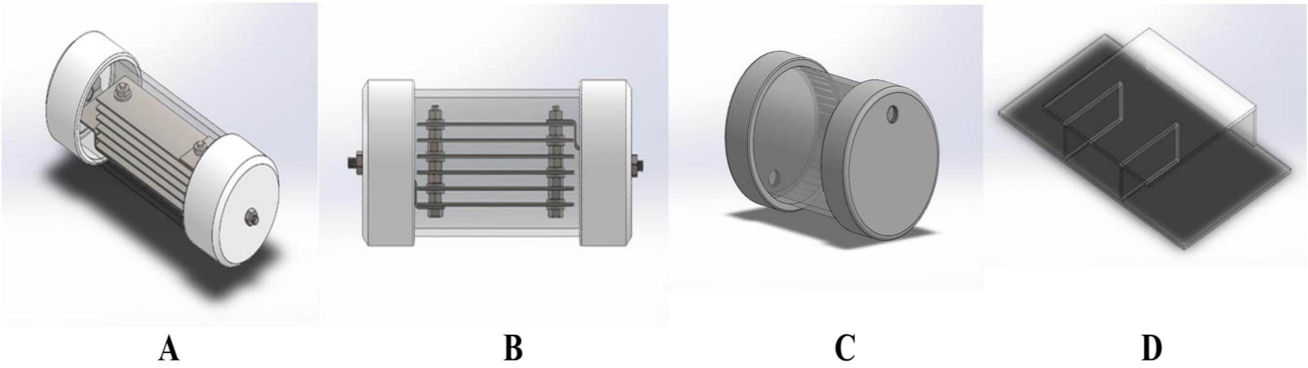

Fig. 1: Isometric View of HHO Generator Unit (A), Front View of HHO Generator Unit (B), Front View of Bubbler Unit (C), Isometric View of Controller Unit Casing (D)

Table 3: HHO System Fabrication Materials

Application	Materials and Equipment	Unit	Measurement
HHO Generator Unit	Acrylic tube	mm	120 x Φ 50
	PVC endcap	mm	Φ 50
	306-grade SS electrodes	mm	85 x 25 x 2
	SS bolts, nuts, washers	mm	Φ 3
	Rubber washers	mm	Φ 3
Bubbler Unit	Acrylic Tube	mm	100 x Φ 50
	PVC Endcap	mm	Φ 50
Controlling Unit	Arduino Uno	-	-
	Pressure Transducer (SKU237545)	mm	Φ 6
	Voltage and current sensor	-	-
	Buzzer module	-	-
	OLED display module	pixel	128 x 64
	Jumper wires (M to F)	-	-
	Power module	V	12
	SS nuts and bolts	mm	Φ 2
Pneumatic Fixings	Plastic fittings	mm	Φ 4
	Rubber Hose	mm	Φ 4

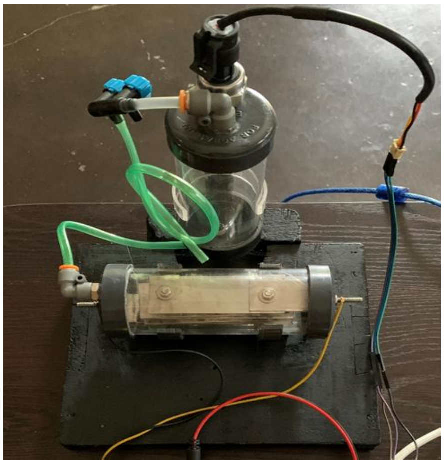

Fig. 2: Constructed HHO Generator & Bubbler Unit Assembly

2.2. Control Unit Design and Construction

The control unit's schematic diagram was developed using Adobe Illustrator, and the circuit diagram (Fig. 3) was KiCAD software. Before constructing the controlling unit, it was virtually simulated using KiCAD software. Then, after that, the construction was done with an Arduino Uno microcontroller, where the sensors and display units were connected using jumper wires following the virtual diagram that was conducted. Fig. 4 illustrates the completed unit. The power supply unit was connected to the completed controlling unit to power up and work the test of the constructed unit. An automated electronic control unit was developed to manage the voltage supplied to the HHO generator. OLED display module presented real-time data updates, including HHO gas pressure, current, voltage, and temperature with humidity. Finally, the components were securely mounted to the constructed casing with adequate wiring and signal routing.

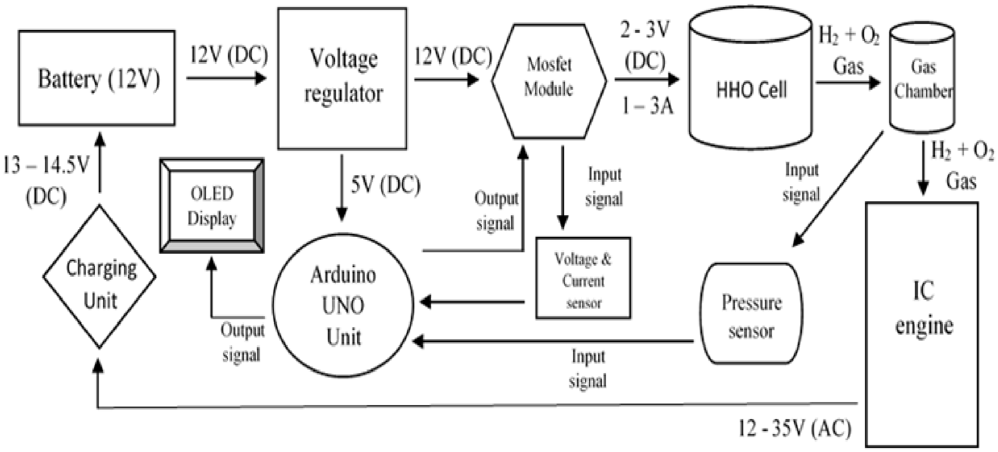

Fig. 3: Flow Diagram of whole System

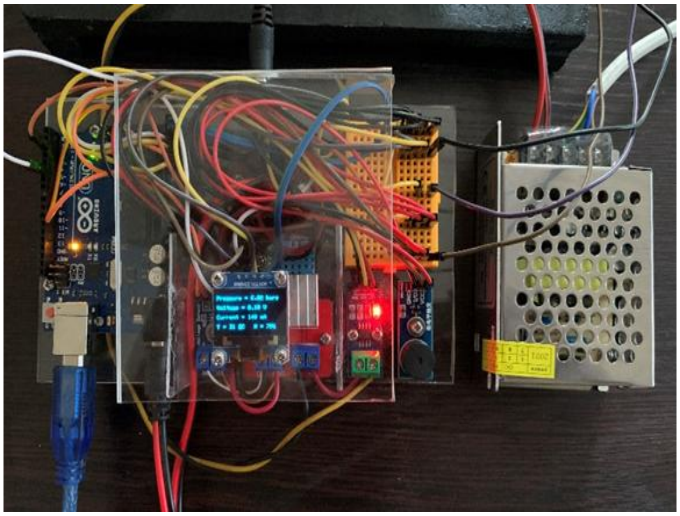

Fig. 4: Completed Controlling Unit

2.3. Testing of the System

The testing stage involved setting up the HHO generator in a controlled environment of 25 ^{0}C and 1 atm to measure gas production under various voltage and current conditions during the same periods. When data were collected to observe the development of HHO generator unit behavior to calibrate and program the system, a bench power supply was provided DC power as a variable power source manually, with a multimeter (potentiometer) used to conduct the testing work by changing the voltage to find out the optimum point range that was dealing with perfect with parameters of KOH 0.1M concentration. And the generated gas was collected in graduated cylinders to measure the output. Fig. 5 shows the testing of the HHO generator unit without controlling the unit.

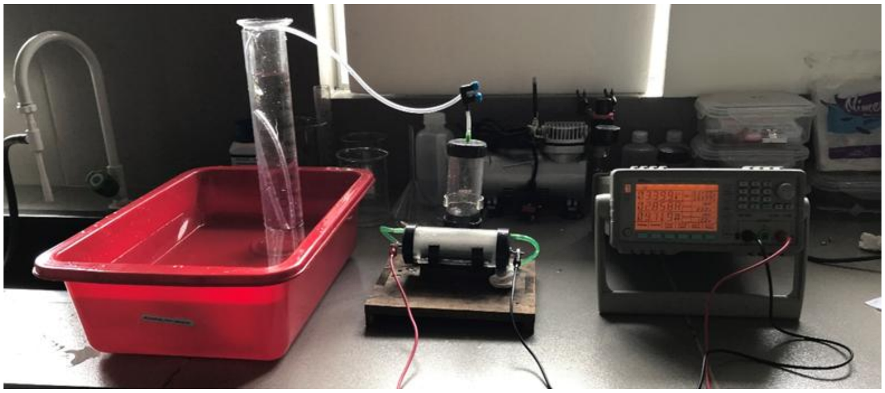

Fig. 5: Testing of the HHO Generator Unit with Bubbler Unit

The test results were analyzed to identify the optimal operating conditions for maximum gas production with minimal energy consumption. The data were used to complete calibration through calculations for the Arduino microcontroller program to determine whether it can identify which point is good. The Arduino code used in this research is available on Github [18]. Based on gas pressure readings from a pressure transducer, it was assisted in powering up and adjusting the current supplied to the generator.

3. RESULTS AND DISCUSSION

3.1. HHO Gas Production vs Voltage

The graph (Fig.6) shows the relationship between voltage and HHO gas production in milliliters per minute. Gas production is expected to rise as the voltage increases due to higher energy input into the HHO generator. However, based on the graph, gas production started a linear relationship at 2.4V to 4.4V. This could suggest the gas production proportional behavior that occurs with supply voltage. After the 4.5V, the final point effectively generated gas because of the heat generated. As a result, electrodes heated, and steam generated additional HHO gas. That’s why the final point appears that some gas production is lower than the previous. Finally, it can be concluded that the reaction's practically starting point is 2.2V, and the endpoint is 4.2V with an SS electrode stack.

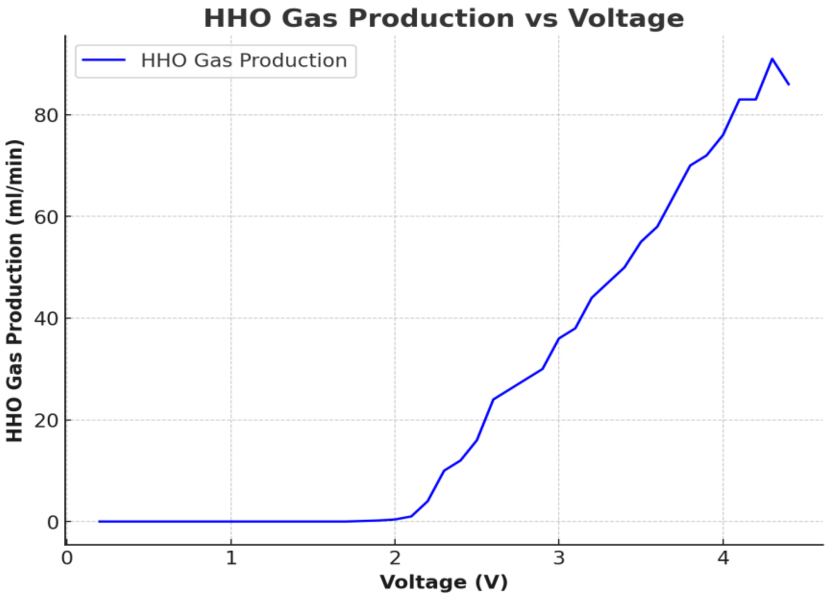

Fig. 6: HHO Gas Production Vs Voltage (25 ^{0}C, 1atm)

3.2. Current vs Voltage

This graph (Fig 7) highlights the relationship between Voltage and Current, and there is a linear increase in current with the voltage increases. This behavior was the same as the graph of Fig 6, typical in electrical systems where Ohm’s Law [9] suggests that the resistance of the HHO generator remains constant or that the increase in voltage directly results in an increase in current flow. The low current values indicate that the system operates with minimal power draw, which may be appropriate for the experimental setup but could also indicate insufficient supply for substantial HHO generation. Hence, the voltage needs to vary between 2.4V and 4.2V to maintain the current consumption between 0 and 7A current range.

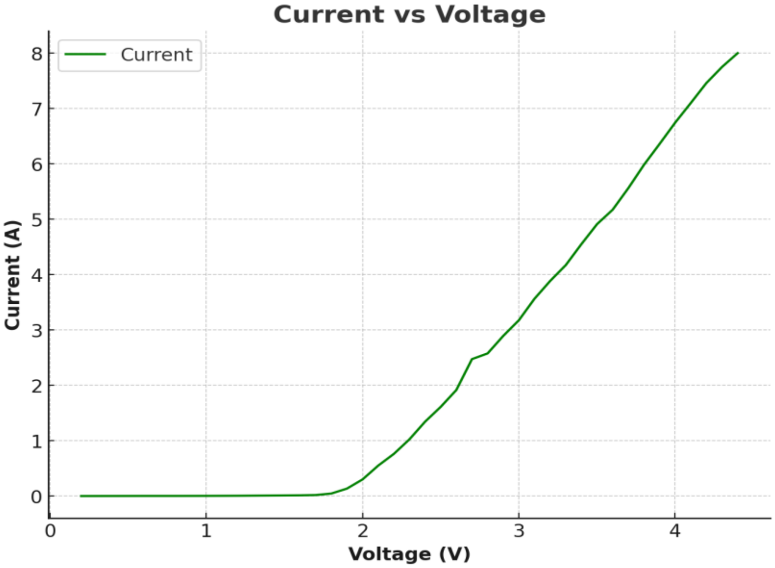

Fig. 7: Current Vs Voltage (25 ^{0}C, 1atm)

3.3. HHO Gas Production vs Power

The HHO Gas Production vs Power graph (Fig. 8) shows no measurable gas production despite increasing power input, indicating potential inefficiencies in the system. HHO gas production with power is not linear regression; hence, higher power levels must reach a threshold before production starts due to internal resistance to absorbing more electrons at the start-up of the reaction. Further, increasing the power input range to test for a production threshold, optimizing the electrode surface with modification for better efficiency, and inspecting the system's components for mechanical or electrical issues because of uncontrollable power supply receives to the unit excepting controller system. Hence, the controller unit must monitor temperature and pressure effects to enhance system performance. Finally, it can be concluded that the controller unit must couple with the developed HHO system to achieve more performance and improve gas production effectively in a safe manner to prevent heat generation.

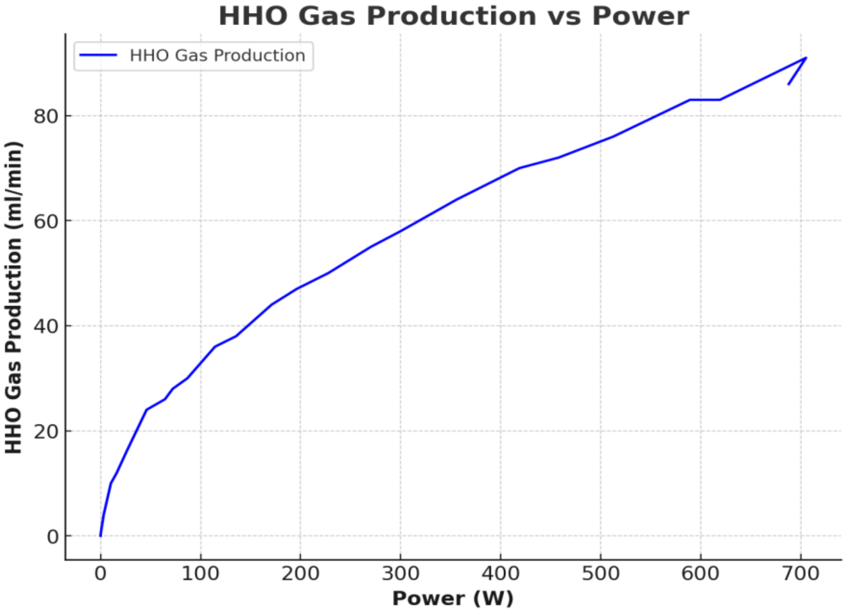

Fig. 8: HHO Gas Production vs Power (25 ^{0}C, 1atm)

4. FUTURE WORK

The developed system will also be applied to ICEs for further testing and validation utilizing this work data. Additional enhancements will focus on expanding the system to a cloud-based platform, including mobile and PC versions. This platform will enable real-time performance monitoring and predictive maintenance after the unit is commercially available to customers. Furthermore, the system will track and update global carbon emission savings from the customer base to provide live updates on environmental impact through the website. These advancements aim to improve the system's efficiency and user experience in real-world applications.

5. CONCLUSION

The developed HHO system has demonstrated a linear power supply unit by rehoming a controlling unit to collect data from the behavior of the HHO generator unit. The voltage potential of 2.4V is the reaction starting point, and the final optimum point of 4.2V is recorded and added to the control system's program to maintain automated voltage management effectively. By employing a wet-type HHO generator integrated with a programmable control unit, the system ensures optimal gas production while mitigating risks associated with excessive gas production or overpressure. Experimental results have validated the system's efficiency, highlighting its effectiveness in real-world automotive applications. Future research should optimize the control unit, integrate IoT technologies for real-time monitoring, and extend the system's applicability in automotive applications.

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