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Design and Manufacture of a Dry HHO (Oxyhydrogen) Electrolysis Module for Emission Reduction in Light Trucks

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Abstract

Oxyhydrogen (HHO), a mixture of hydrogen and oxygen generated by water electrolysis, has been examined as a combustion-supporting additive due to its clean-burning characteristics. This study describes the design and fabrication of an HHO generation and supply system for Thaco Towner 750 vehicles. The system employs a dry-type electrolyser, achieving an electrolysis efficiency of 89.8% and a gas production rate of approximately 613.3 ml/min at an operating current of 11 A, ensuring stable gas delivery during engine operation. Engine tests were performed to evaluate the effects of HHO supplementation on exhaust emissions when used with RON95 gasoline. Compared to baseline operation, average reductions of 8.7% in CO, 19.57% in CO_2, and 21.1% in HC were observed. Additional measurements conducted under two idle operating modes showed that, at low idle speed, CO, CO_2, and HC concentrations decreased by 19%, 14%, and 24%, respectively. At high idle speed, emission levels were also reduced, though to a lesser extent, with CO, CO_2, and HC decreasing by 6%, 4%, and 9%. These results indicate that HHO addition leads to measurable changes in exhaust gas composition under idle and high-idle conditions. Further investigations involving fuel consumption, engine performance, and standardized driving cycles are necessary to evaluate its broader impact on emission reduction.

Keywords: HHO gas, Hydrogen, Renewable fuels, Net-zero, Light truck.

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1. Introduction

The escalating use of fossil fuel-powered vehicles has contributed to increased air pollution and poses a threat to global energy security [1]. In response, many nations have joined international agreements such as the Kyoto Protocol, COP21 (2015), and COP26 (2021), aiming to control the rate of global average temperature increase to no more than 1.5°C. Concurrently, governments are encouraging the research and application of renewable, environmentally friendly energy sources [2].

In Vietnam, the Government has implemented numerous policies to promote the development of renewable energy and reduce greenhouse gas emissions. A specific measure involves encouraging the use of biofuels such as E5 and E10 [3,4]. However, their level of fuel economy and emission reduction efficiency remain limited; thus, solutions based on electrochemical energy, hydrogen, and novel fuels are currently attracting significant research interest [5].

Hydrogen is considered a potential energy source due to its ability to burn cleanly without emitting harmful exhaust gases [6,7]. Nevertheless, its storage and operation at high pressure still entail risks. A viable approach is the utilization of HHO gas generated from water electrolysis. This type of gas exhibits excellent combustion properties, which helps to enhance fuel utilization efficiency and reduce the volume of noxious emissions.

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Light-duty trucks are among the most commonly used vehicles in Vietnam owing to their low operating costs and high flexibility. Integrating an HHO electrolysis system onto this vehicle type not only offers technical benefits but also yields significant practical effectiveness, contributing to fuel savings, emission reduction, and the fulfillment of the carbon neutrality commitment as outlined by the objectives of COP26.

2. HHO electrolysis system applied to vehicles

2.1. Overview of the Thaco Towner 750 vehicle

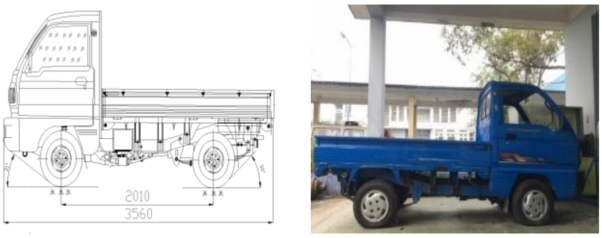


Figure 1. Overview of the Thaco Towner 750 Vehicle

Figure 1 illustrates the Thaco Towner 750 vehicle, which is equipped with the DA465QE/F1 gasoline engine from the DONGAN manufacturer (China). The technical specifications of the engine are presented in Table 1 [8].

Table 1. Engine Specifications

Specifications	Symbol	Unit	Value
Power	N_e	kW	35.3
Compression Ratio	ε	-	9
Engine Speed	n	rpm	5000
Cylinder Bore	D	mm	65.5
Piston Stroke	S	mm	72
Number of Cylinders	i	-	4
Number of Strokes	τ	-	4

2.2. Theoretical Basis of the HHO Electrolyser

2.2.1. Relationship between power and fuel consumption

For engines supplemented with HHO fuel, the total output power of the engine is the sum of the power generated from the combustion processes of gasoline and HHO:

$$P = P_{cg} + mP_{CHHO} \quad (1)$$

Where:

$$P_{cg} = \eta_g . m_g . Q_{LHVg}$$
$$P_{CHHO} = \eta_{HHO} . m_{HHO} . Q_{LHVHO}$$

With:

η_g, η_{HHO}: Energy conversion efficiency of gasoline and HHO;

m_g, m_{HHO}: Mass consumption of each fuel type (kg/s);

$Q_{LHVg} = 44.7$ MJ/kg: Lower heating value (LHV) of gasoline;

$Q_{LHVH2} = 120$ MJ/kg [9].

2.2.2. Fuel consumption calculation

Assuming the engine efficiency using pure gasoline is 25%, we have:

$$m_g = \frac{P_{cg}}{\eta_g * Q_{LHVg}} = \frac{35300}{25\% * 44.7 * 10^6} = 3.15 * 10^{-3} \text{ (kg/s)} \quad (2)$$

+ For an engine with an efficiency of 30%:

$$m_g = \frac{P_{cg}}{\eta_g * Q_{LHVg}} = \frac{35300}{30\% * 44.7 * 10^6} = 2.36 * 10^{-3} \text{ (kg/s)} \quad (3)$$

Assuming HHO replaces X % of the gasoline, and considering the combustion efficiency of both fuel types to be equal ($\eta_g = \eta_{HHO} = \eta$), we have:

$$\eta = \frac{P}{m_g * Q_{LHVg}(100 - X)\% + m_{HHO} * Q_{LVHHO}} \quad (4)$$

Hence, the required mass of HHO is derived:

$$m_{HHO} = \frac{\frac{P}{\eta} - m_g * (100 - X)\%}{Q_{LHVHHO}} \quad (5)$$

With an engine efficiency of η=25 and replacing 10 % of gasoline with HHO gas:

$$m_{HHO} = \frac{\frac{35300}{25\%} - 3.15 * 44.7 * 10^6 (100 - 10)\%}{120 * 10^6} = 0.118 \text{ g/s} \quad (6)$$

We have: $V_{HHO} = \frac{m_{HHO}}{\rho_{HHO}} = \frac{0.118}{0.54} = 0.219$ m³/s = 13.07 litres per minute, with $\rho_{HHO} = 0.54$ kg/m³ [10].

Although the theoretical calculation above yields an HHO requirement of approximately 13.07 L/min and an electrolysis current exceeding 200A, it is important to emphasize that these values represent idealized conditions based on assumptions of:

- 100% Faraday efficiency;
- the lower heating value of *pure hydrogen* (120 MJ/kg);

- and an unlimited electrical supply capability.

Such assumptions do not reflect the practical constraints of a 12 V automotive electrical system. The alternator of a light truck typically provides a reserve current of only 40-70 A, of which the HHO system can safely utilize no more than 8-12 A without overloading the electrical network. Therefore, the purpose of the HHO system in this context is not to replace a significant fraction of gasoline energy, but to enhance combustion characteristics at low loads.

Furthermore, HHO gas is a stoichiometric mixture of hydrogen and oxygen, possessing an effective lower heating value of only 10-15 MJ/kg, which is substantially lower than that of pure hydrogen. Consequently, applying hydrogen's LHV directly in the energy substitution model leads to an overestimation of the amount of HHO required.

Electrolysis efficiency must also be considered. A dry-cell electrolyser typically achieves 60-70% efficiency due to ohmic losses and polarization effects, reducing the practical HHO production rate to approximately: 6-7 ml/min of H_2 per ampere, corresponding to 500-800 ml/min of mixed HHO gas at 8-12 A.

This practical range aligns closely with the measured output of 613.3 ml/min at 11 A, confirming that the system's operation is consistent with real electrochemical limits. Thus, the theoretical analysis must be interpreted as a boundary condition, while the actual implementation targets stable combustion support, not fuel substitution.

In this study, HHO was employed as a combustion-enhancing additive rather than a replacement for gasoline. It was generated using electrical power from the vehicle's 12 V system, which inherently limited the electrolyzer operating current to approximately 8–12 A. As a result, the amount of HHO produced was sufficient only to promote flame propagation and combustion completeness, particularly under low-load conditions. Accordingly, the observed emission reductions should be attributed to improved combustion rather than to any net energy gain or direct fuel substitution

2.2.3. Calculation of electrolysis current

According to Faraday's law, the gas output of water electrolysis is proportional to the transferred electric charge; under standard conditions and assuming ideal Faradaic efficiency, a current of 1 A sustained for 1 minute theoretically yields about 10.44 ml of HHO gas [8].

$$m_{HHO} = I * n_{cell} * 10.44 \Rightarrow I = \frac{m_{HHO}}{n_{cell} * 10.44} \text{ A} \quad (7)$$

with n_{cell} is the number of water cells (choose n_{cell} = 6

I is the electrical current supplied to the electrolysis unit.

$$I = \frac{13.07*1000}{6*10.44} = 208.72 \text{ A} \quad (8)$$

Table 2. Calculated current intensity supplied to the electrolyser based on blending ratio corresponding to maximum power output

X (%)	m_{HHO} (g/s)		V_{HHO}(ml/min)		I_{lt} (A)	
	25%	30%	25%	30%	25%	30%
1	0.0118	0.010	1307.4	1089.5	20.872	17.393
2	0.023	0.019	2614.815	2179	41.744	34.786
3	0.035	0.029	3922.222	3268.5	62.615	52.179
4	0.047	0.039	5229.63	4358	83.487	69.572
5	0.058	0.049	6537.037	5447.5	104.358	86.966
6	0.0706	0.058	7844.444	6537	125.23	104.359
7	0.08	0.068	9151.852	7626.5	146.102	121.751
8	0.094	0.078	10459.26	8716	166.974	139.145
9	0.1059	0.088	11766.67	9805.6	187.845	156.538
10	**0.117**	**0.098**	**13074.07**	**10895**	**208.72**	**173.93**
11	0.129	0.107	14381.48	11985	229.589	191.324
12	0.141	0.117	15688.89	13074	250.461	208.717
13	0.152	0.127	16996.3	14164	271.332	226.110
14	0.164	0.137	18303.7	15253	292.204	243.503
15	0.176	0.147	19611.11	16343	313.076	260.897
16	0.188	0.156	20918.52	17432	333.948	278.290
17	0.200	0.166	22225.93	18522	354.820	295.683
18	0.211	0.176	23533.33	19611	375.691	313.076
19	0.223	0.186	24840.74	20701	396.563	330.469
20	0.235	0.196	26148.15	21790	417.435	347.862

Thus, theoretically, a current of 208.72A is required across a 6 cell electrolyser to generate 13.07 liters/minute. From this point, calculations were performed to determine the required amount of HHO corresponding to replacement levels ranging from 1-20% of the gasoline fuel, at various engine efficiencies (25% and 30%). The detailed results are presented in Table 2.

The calculations in this section are intended to establish the theoretical upper limit of HHO utilization under idealized assumptions. As such, the results are provided for reference and do not reflect actual engine or vehicle electrical operating conditions. Accordingly, the HHO system in this study is designed to operate within the constraints of a 12 V power supply, delivering a small but stable amount of HHO to support combustion rather than to replace the primary fuel.

2.3. Design and fabrication of a Dry-Cell HHO electrolyser

2.3.1. Technical requirements and electrical circuit configuration

The HHO electrolyser is designed with a rated current ranging from 11 to 12 A. It should be noted that configuring the electrolyser for a rated current of 11-12 A is not only consistent with Faraday Brown electrolysis principles but also essential for ensuring compatibility with the 12-14 V electrical system of the vehicle. Higher current demands, such as those exceeding 100 A suggested in the theoretical substitution model, would be infeasible for automotive applications and could lead to alternator overload and thermal failure.

Therefore, the dry-cell stack is intentionally optimized to operate within the 8-12A range, with each of the six cells maintaining an operating voltage of approximately 2.0-2.2V. This configuration ensures safe operation, manageable heat generation, and a practical HHO output suitable for enhancing combustion efficiency rather than serving as an alternative primary fuel source.

The electrode configuration is arranged in the form (- n n n n n +), here the symbol "–" represents the negative plate (cathode), "+" represents the positive plate (anode), and "n" denotes the neutral plates. The power supply utilizes a DC 12 V battery. When the generator is operational, the output voltage stabilizes at approximately 13.4 V. Each cell withstands a voltage of about 2.23 V, which falls within the stable electrolysis region according to the Faraday-Brown-Boycen principle, ensuring optimal electrolysis efficiency and preventing overheating. The electrolyser structure consists of 1 cathode plate, 1 anode plate, and 5 neutral plates, arranged to form a total of 6 dry-type cells. This design helps to reduce the overall dimensions while simultaneously enhancing the gas separation efficiency by limiting the current leakage through the electrolyte solution. Figure 2 illustrates the schematic arrangement of the 6 cell dry-cell HHO electrolyser, clearly showing the electrode structure and the principle of gas separation within the module.

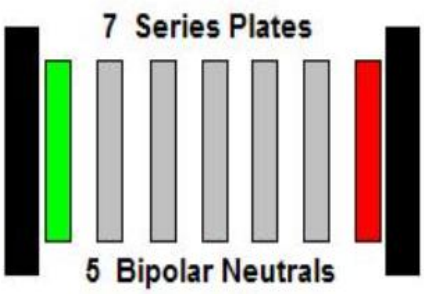


Figure 2. Schematic diagram of the 6 cell dry-type HHO electrolyser

2.3.2. Electrode plate dimensions

According to Faraday's law, with a safe current density of 84 mA/cm² the required area [11]:

$$S = \frac{I}{0.54} * 6.45$$

where:

I*: Current (A);*

6.45*: Conversion factor from square inches to cm².*

Substituting the value $I = 12$ A into the formula, we obtain:

$$S = \frac{12}{0.54} * 6.45 \approx 145.3\ \text{cm}^2$$

To satisfy the above requirement, a square electrode plate with dimensions of 13.6 × 13.6 cm is selected. After subtracting the 3 mm thick and 10 mm wide rubber gasket border, the actual electrolysis area is calculated as follows:

$$S_{\text{thực}} = 13.6^2 - 12.6^2 = 158.76\ \text{cm}^2$$

As $S_{\text{thực}} = 158.76\ \text{cm}^2 > 145.3\ \text{cm}^2$, therefore, the design satisfies the requirements for safe and efficient electrolysis area. Figure 3 illustrates the fabricated electrode plate, rubber gasket and neutral plate.

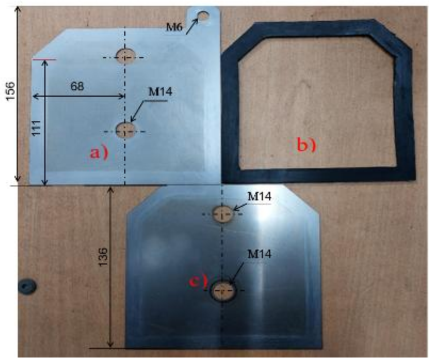
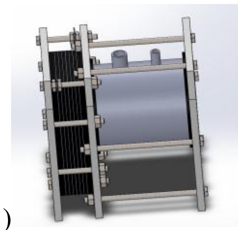


Figure 3. a) Electrode plate; b) Rubber gasket; c) Neutral plate

2.3.3. Electrode Gap and Electrolyte Solution

The gap between the electrode plates significantly affects the resistance of the electrolyte solution as well as the HHO gas generation efficiency. If the gap is too large, resistance increases, leading to energy consumption; conversely, a gap that is too small will impede gas release, reducing electrolysis efficiency and posing a risk of local short circuits. To ensure a balance between electrolysis effectiveness and operational safety, the distance between the two electrode plates is selected to be 3 mm [11].

(1) 

 (2)

Figure 4. 3D Drawing of the HHO electrolyser (1); Actual model of the HHO electrolyser (2)

KOH was selected as the electrolyte due to its high ionic conductivity and widespread use in alkaline electrolysis systems [12]. In this study, a 40% KOH solution was adopted based on preliminary experimental trials, as it provided rapid electrolysis initiation and stable gas production under the tested operating conditions [13]. Nevertheless, long-term operation in an automotive environment requires a careful balance between ionic conductivity, heat generation, corrosion effects, and material durability. Previous studies and empirical observations indicate that moderate KOH concentrations, typically in the range of 20-25 wt%, can improve thermal stability and reduce chemical stress on sealing materials while still maintaining sufficient gas production, particularly under a 12 V electrical system [14]. Therefore, the selection of electrolyte concentration should account not only for electrochemical performance but also for the thermal and mechanical constraints of the HHO module during prolonged engine operation.

The electrolyte solution uses KOH (potassium hydroxide) at a concentration of 40% by mass, which was determined through experimentation. At this concentration, the system achieves a starting current of approximately 8 A , ensuring stable electrolysis and high gas generation efficiency. The complete system is modeled using 3D drawings, including the main components: the electrolyser, the gas collection chamber, the HHO outlet, and anti-leak connections. Figure 4 presents the 3D Drawing of the HHO electrolyser and the actual model of the HHO electrolyser.

In summary, the practical design of the HHO system for a light-duty truck must prioritize electrical compatibility, thermal safety, and realistic gas production rates. While theoretical calculations suggest high flow requirements for fuel replacement, the actual objective of the implemented system is to support combustion quality, particularly at low engine speeds, by providing a small but effective amount of hydrogen-oxygen mixture. This design philosophy ensures that the system operates safely within the constraints of a standard 12 V vehicle electrical network while still achieving measurable emission reductions.

2.4. Vehicle HHO supply control circuit

The Towner 750 vehicle features a high ground clearance design, which is advantageous for the placement of supplementary equipment used for research. The HHO gas supply control system is designed to stabilize the electrical current and adjust the amount of HHO gas generated corresponding to the engine load.

The system is composed of the following main components: The HHO electrolyser; The PWM chopper unit; The Arduino Uno module; The ECU (Engine Control Unit).

3. Design and Control of the HHO Module in an Automobile

3.1. Overall structure of the system

The HHO system installed on the THACO Towner 750 truck includes:

6 cell dry-type HHO electrolyser: used to generate HHO gas from the KOH electrolyte solution.

PWM current controller: adjusts the frequency and duty cycle of the current, which helps stabilize the electrolysis process and prevent overheating.

Arduino Uno controller: receives signals from engine sensors, controls the HHO supply volume, and coordinates with the fuel injection system.

Sensor and control relay system: ensures safety, automatically shutting off the system in case of overcurrent or when the engine is turned off.

3.2. Control circuit design

The HHO electrolyser draws power from the vehicle's battery (12V). This current passes through the PWM control circuit, which functions to adjust the current intensity suitable for the electrolysis process, ensuring stable gas generation efficiency. Figure 5 presents the wiring diagram of the gasoline/HHO fuel system.

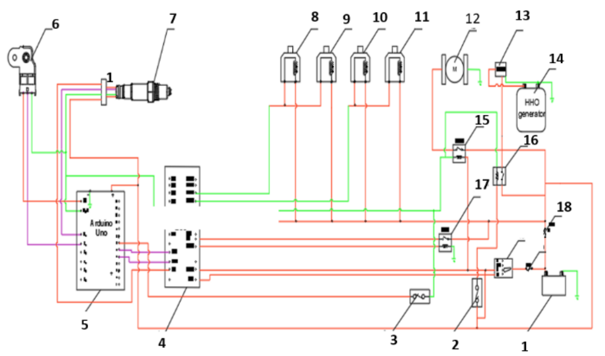


Figure 5. Wiring diagram of the gasoline/HHO fuel system
1-Battery; 2-Switch; 3-Changeover switch; 4-ECU; 5-Arduino; 6-MAP sensor; 7-Oxygen sensor; 8-Fuel injector-cylinder 2; 9-Fuel injector-cylinder 4; 10-Fuel injector-cylinder 3; 11-Fuel injector-cylinder 1; 12-Fuel pump; 13-PWM; 14-HHO electrolyser; 15-Relay C/OPN; 16-Relay borsch; 17-Relay main; 18-Bat/P/I fuse; 19-Ignition switch; 20-AM2 fuse

The structure and operating principles include:

Battery (1): supplies electrical power to the vehicle.

Protection relay (2) and fuse (18): ensure electrical safety, cutting off the circuit in case of overload failure.

Mode selector switch (3): allows selection between the 'Pure Gasoline' and 'Gasoline + HHO' operating modes.
Arduino controller (5): receives and processes signals from the MAP sensor (6) and the O_2 sensor (7).
PWM circuit (13): regulates the current supplied to the HHO electrolyser (14) to control the gas generation rate, matching the engine load.
ECU (4): receives signals from the Arduino to automatically adjust the air-fuel ratio when HHO is supplemented.
Principle of operation:

When the ignition switch (19) is turned to the IG position, current flows into the C/OPN relay (15), activating the power supply circuit to the FC pin of the ECU (4). Here, the relay's coil becomes an electromagnet, pulling the contact closed, allowing the fuel pump (12) to operate and supply fuel to the injectors (8-11). When switch (2) is turned on, current flows through the Bosch relay (16); this relay's coil is energized, creating a magnetic field that attracts the contact to close the circuit, supplying power from the battery (1) to the positive terminal of the PWM (13), then to the HHO electrolyser (14), and back to ground. At this point, the HHO electrolyser begins operation, generating HHO gas.

When the mode selector switch (3) is activated, the system switches to the "Gasoline + HHO" mode. Signals from the MAP sensor (6) and the O_2 sensor (7) are sent to the Arduino (5), processed and modified before being transmitted back to the ECU (4). The ECU then adjusts the fuel injection timing and ratio, ensuring an optimal air-fuel mixture when HHO gas is supplemented into the combustion chamber.

3.3. Electronic control circuit

To synchronize with the system, the research team designed a central processing circuit based on the Arduino Uno R3. The system receives signals from the sensors, processes the input voltage, and generates corresponding control signals. The main components include: the O_2 sensor, the MAP sensor, a mode switch, and the control output to the ECU).

The signal control system schematic includes elements such as the MAP sensor, the O_2 sensor, along with their heating power wires, signal wires, and ground wires. All signals from the sensors are sent to the ECU via the Arduino control circuit, where they are calibrated by adding or subtracting a compensating voltage, depending on the operating mode of the system. Figure 6 illustrates the wiring diagram of the HHO supply signal control system.

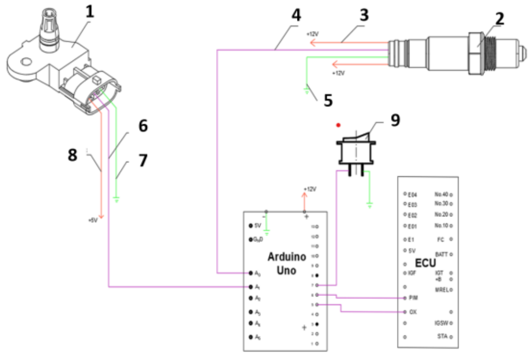


Figure 6. Wiring diagram of the hho supply signal control system
1-MAP sensor; 2-O_2 sensor; 3-12 V heater power wire; 4-O_2 sensor signal wire; 5-O_2 sensor ground wire; 6-MAP sensor signal wire; 7-MAP sensor signal wire, 8-MAP sensor power wire; 9-Changeover switch

The signals from the MAP and O_2 sensors are fed into the Arduino circuit for processing, rather than being transmitted directly to the ECU. The controller receives the signal from the mode switch (9) to determine the system's operating mode.In the "Gasoline + HHO" mode, the voltage values obtained from the MAP and O_2 sensors are routed to the A0 and A1 analog pins of the Arduino microcontroller. Here, the data is processed and calibrated using a pre-programmed algorithm. Subsequently, the output signal is transmitted to the ECU at pins 5 and 6 to adjust the air-fuel ratio, optimizing the combustion process when HHO gas is supplemented into the combustion chamber.

When the ignition switch is turned to the IG position, current flows through the C/OPN relay, activating the power supply circuit for the fuel pump, ensuring fuel is delivered to the injectors. When switch (2) is turned on, current flows through the Bosch relay, activating the power supply circuit for the PWM and the HHO electrolyser. At this point, the HHO electrolyser begins operation, generating HHO gas to mix with the intake air. After the mode selector switch (3) is engaged, the Arduino formally takes control, receiving and processing signals from the MAP and O_2 sensors, and then transmitting the modified control signal back to the ECU. The ECU uses this value to alter the injection timing and air-fuel ratio, making it suitable for the supplemented HHO volume.

3.4. Algorithm and control code

The control software is written using the Arduino IDE, featuring two operating modes:
Manual Mode: The engine operates entirely on gasoline; sensor signals are transmitted directly to the ECU without intervention from the microcontroller.

HHO Mode: The HHO system is activated, and the Arduino automatically calibrates the sensor signals so that the ECU recognizes the correct air-fuel ratio.

The flowchart for the control program algorithm is presented in Figure 7.

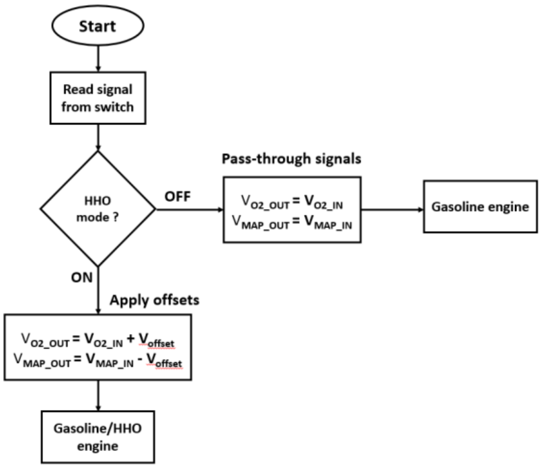


Figure 7. Flowchart of the control program algorithm

In HHO mode, the additional oxygen present in the mixture may cause the ECU to enrich fuel. To prevent excessive enrichment and maintain stable combustion, a fixed offset of +0.35 V is added to the O_2 sensor signal, while -0.2 V is applied to the MAP signal. These values were selected empirically to ensure consistent engine behaviour during HHO operation. The detailed control code is provided in Appendix A.

3.5. Experimental verification of the electrolyser's efficiency

In HHO mode, the Arduino applies the predefined offsets to the O_2 and MAP sensor voltages (+0.35 V and −0.2 V, respectively) before sending them to the ECU. This adjustment helps maintain suitable mixture control when HHO is supplied. The offsets act as practical compensation parameters rather than optimized calibration values.

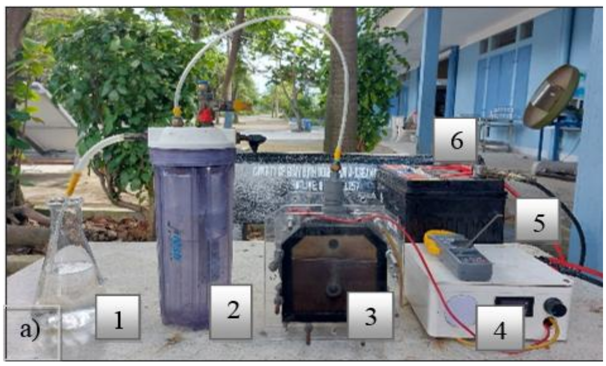


Figure 8. Experimental setup for measuring HHO gas flow rate

1. Water vessel for gas testing; 2. Separator; 3. Dry-Cell HHO clectrolyzer; 4. PWM chopper unit;5. Ammeter;6. Battery

The HHO gas flow rate was determined using the water displacement method, measuring the volume of water displaced in a graduated cylinder, combined with a stopwatch to determine the amount of gas generated over time. Figure 8 illustrates the experimental setup for measuring the HHO gas flow rate.

Table 3. HHO gas flow rate generated during experimental measurement

HHO Gas flow rate (ml/min) corresponding to current (A		
	11 (A)	12 (A)
Test 1	610ml/min	740ml/min
Test 2	620ml/min	750ml/min
Test 3	610ml/min	750ml/min
Average	**613.3ml/min**	**746.7ml/min**

Table 3 shows that the average HHO gas flow rate at 11 A reached 613.3 ml/min, which closely approximates the theoretical calculated value of 626.1 ml/min, demonstrating that the electrolysis system operates stably and with high accuracy.

The calibration of O_2 and MAP sensor signals via Arduino to help the ECU maintain appropriate air excess coefficients when HHO is added can be considered a potential factor related to emission variability, in addition to the direct chemical effects of HHO.

3.5. Installation and placement in the vehicle

3.5.1. Installation of the control circuit

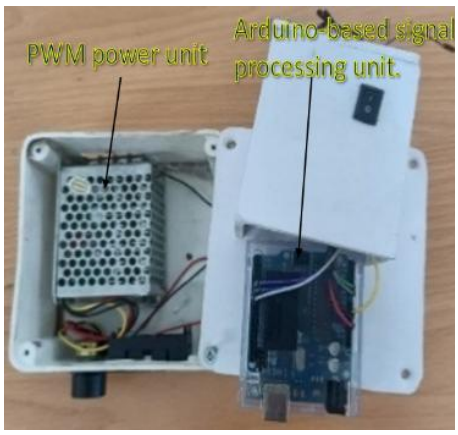


Figure 11. Gasoline - HHO dual-fuel injection control circuit

After the simulation and bench testing processes yielded stable results, the Gasoline–HHO dual-fuel injection control circuit was fabricated manually and installed directly onto the test vehicle. The main devices were neatly arranged in the engine compartment, including: The mode selector switch, the PWM control unit, and an LCD display unit for monitoring the electrolysis voltage and current. Figure 11 illustrates the Gasoline –HHO fuel injection control circuit.

Principle of operation

System power supply: When the ignition or vehicle lock is switched on, the control circuit becomes operational.

Engine start-up: After the engine is started, the operator turns on the Gasoline/HHO mode selector switch, which simultaneously activates the PWM controller.

Electrolysis adjustment: Parameters on the PWM chopper unit are adjusted to achieve an appropriate voltage, allowing the HHO electrolyser to generate a gas volume suitable for the engine load.

To facilitate observation and adjustment, several components in the control circuit (such as the mode switch and the LCD screen) are installed in the area in front of the driver, making it easy for the operator to manipulate and monitor the parameters during operation.

3.5.2. Installation process of the HHO system

Figure 12. Installation of the venturi mixer and layout of the HHO electrolyser on the Thaco Towner 750 vehicle

Step 1: Prepare tools (wrenches, screwdrivers, cable ties, rubber hoses, silicone, sealant, etc.).
Step 2: Mount the Venturi mixer into the intake manifold, securing it with screws and airtight sealant.
Step 3: Connect the gas-carrying rubber hose from the electrolyser to the Venturi, using clamping rings for fixation.
Step 4: Secure all conduits using cable ties, ensuring no vibration and no air leaks.

System operation procedure

1. Turn the ignition key to power the entire system.
2. Start the engine and turn on the PWM switch to activate the HHO electrolyser.
3. Switch to the "Gasoline + HHO" mode, and monitor the voltage and current parameters on the LCD screen.

The system is designed for ease of installation, disassembly, and convenient maintenance, while simultaneously ensuring absolute safety for the vehicle's electrical and fuel systems. Figure 12 illustrates the installation process of the venturi mixer and the layout of the HHO electrolyser on the Thaco Towner 750 vehicle.

4. Experimental testing and evaluation of results

4.1. Objectives

The objectives of the experimental section are to:

- Evaluate the practical operational capability of the HHO system when installed on the THACO Towner 750 light truck.
- Analyze the exhaust gas components (CO, CO_2, HC) of the engine when using the gasoline-HHO fuel mixture, and compare the results with the case where the engine only uses RON95 gasoline.
- Examine the safety and stability of the HHO electrolysis module under various operating conditions.

Within the scope of this research, engine power and torque measurements were not conducted due to limitations in measuring equipment. The experiments focused on exhaust gas analysis to assess the impact of HHO supplementation on combustion efficiency and emission levels.

4.2. Experimental setup

4.2.1. Experimental equipment

- Thaco Towner 750 truck (with integrated HHO system.
- MGT-5 gasoline engine exhaust gas analyzer, manufactured in Germany and certified for compliance in Vietnam under Decision No. 245/2005/ĐK by the Vietnam Register [15]. Figure 13 illustrates the MGT-5 gasoline engine exhaust gas testing equipment, and Table 4 presents the main technical specifications of the device.

Figure 13. MGT 5 gasoline engine exhaust gas analyzer

Table 4. MGT 5 technical characteristics parameters

Measuring range		Measurement accuracy	Method for gas measurement
CO	0-15.00 vol %	0.06 vol %	Infrared
CO_2	0- 20.0 vol %	0.5 vol %	Infrared
HC	0-4.000 ppm vol	12 ppm vol	Infrared
O_2	0- 25.00 vol %	0.1 vol %	Electrochemical

4.2.2. Measurement system layout diagram

Figure 14. Experimental system layout diagram

Figure 14 presents the layout diagram of the experimental system for measuring pollutant emission concentration for the Thaco Towner truck.

The experimental system was set up as follows:

- The exhaust pipe was connected from the engine muffler to the MGT-5 probe.

A speed sensor monitored the engine rotational speed to ensure stable measurement during idling conditions.

- The HHO power supply and control unit were active.

The exhaust gas measurement procedure was conducted under two modes: (1) low idle speed at 850 rpm and (2) high idle speed at 2400 rpm.

Case 1: Low idle speed (850 rpm)

The vehicle was operated at idle, the engine was warmed up to its working temperature. Additionally, the exhaust system was checked for leaks, and all auxiliary loads (A/C, radiator fans, electrical devices) were turned off. Measurements were taken 5 times for each fuel type (RON95 and RON95–HHO). When the engine speed stabilized at approximately 850 rpm, the MGT-5 device recorded the average values of the exhaust gas components.

Case 2: High idle speed (2400 rpm)

The operating conditions were performed similarly to Case 1. Measurements were taken 5 times for each fuel type. When the engine speed stabilized at 2400 rpm, the MGT-5 device recorded the average values of the exhaust gas components.

4.3. Measurement results and analysis

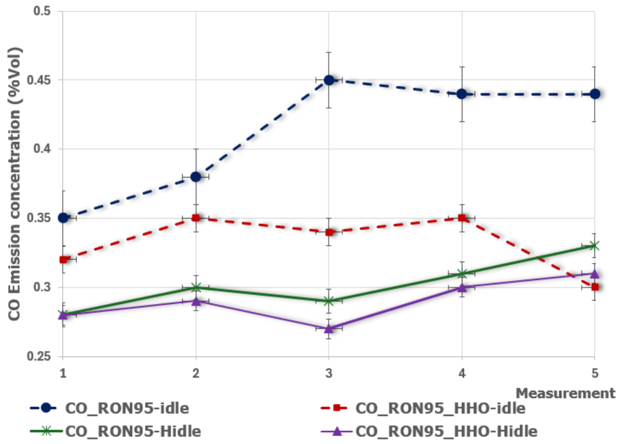


Figure 15. Trend of CO emission concentration versus measurement run for RON95 and RON95_HHO fuels under low idle and high idle conditions. Each data point corresponds to a repeated measurement; error bars indicate data dispersion.

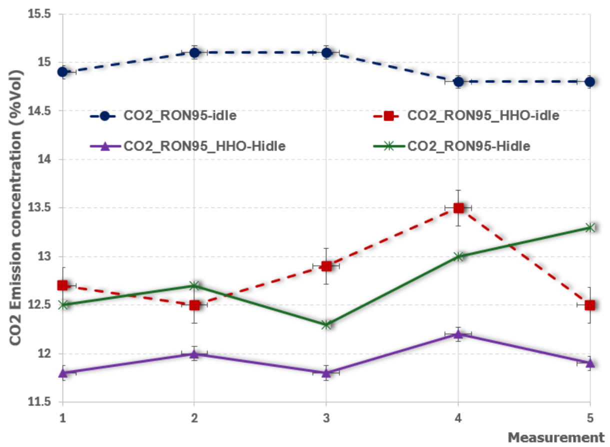


Figure 16. Trend of CO_2 emission concentration versus measurement run for RON95 and RON95_HHO fuels under low idle and high idle conditions. Error bars represent measurement variability.

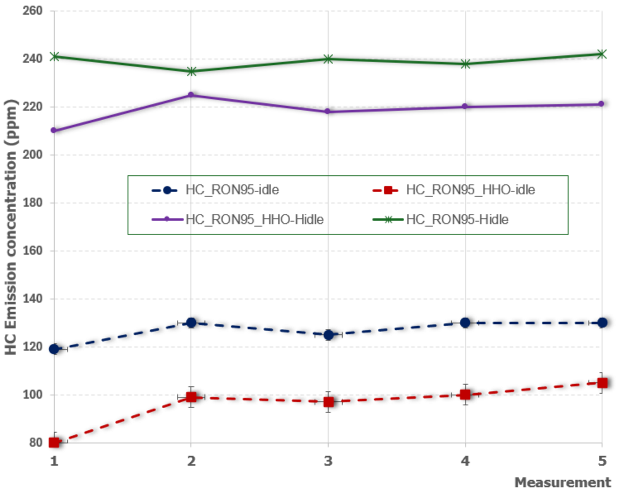


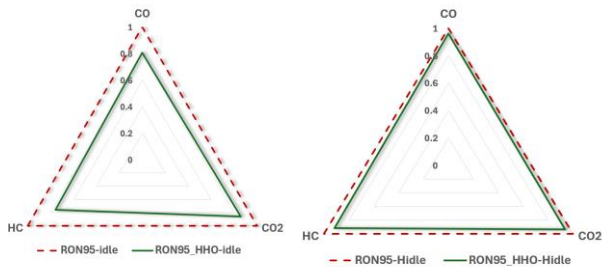
Figure 17. Trend of HC emission concentration versus measurement run for RON95 and RON95_HHO fuels under low idle and high idle conditions

Figures 15, 16, and 17 indicate that the supplementation of HHO into RON95 fuel significantly reduces the emission concentration of CO, CO_2, and HC in both idle modes. At low idle mode Idle-850 rpm): CO decreased from 0.35-0.45 %vol to 0.30-0.35 %vol, corresponding to an average reduction of 20-22%. Similarly, HC decreased from 20-130 ppm to 80-105 ppm, a reduction of 15-25%. This decline reflects a more complete combustion process when HHO is present, as hydrogen increases the flame propagation speed and promotes the oxidation of unburnt fuel. CO_2 concentration decreased slightly in both modes with HHO supplementation, falling from approximately 15.0 % vol to 12.5-13.5 % vol in idle mode. This is consistent, as hydrogen does not produce CO_2 when combusted and shifts the mixture towards a leaner state.

High idle mode (2400 rpm): HHO continued to reduce CO and HC, but the reduction rate was lower, approximately 4-6% for CO and 8-12 % for HC, respectively. This is because the combustion process at 2400 rpm is inherently more stable and complete.

The emission results presented in Figures 15–17 were obtained from repeated measurements conducted under identical operating conditions. The dispersion among measurements reflects the inherent variability of the experimental process. For CO and CO_2, consistent emission reductions were observed with HHO addition under both idle modes. For HC, although individual measurement values are reported, the overall trend similarly indicates lower emissions with HHO supplementation. Within the scope of this study, the results demonstrate acceptable measurement repeatability and stability of the observed trends.

In summary, the three graphs demonstrate that HHO delivers a clear effect in reducing CO and HC emissions, while also causing a slight reduction in CO_2 across both idle modes, with the highest efficiency achieved in the low idle mode.



Low idle speed (850 rpm)

	CO (%V)	CO_2 (%V)	HC (ppm)
Coefficient	0.412	14.94	126.8

High idle speed (2400 rpm)

	CO (%V)	CO_2 (%V)	HC (ppm)
Coefficient	0.302	12.76	239.2

Figure 18. Summary of CO, CO_2 and HC emission concentrations for low idle and high idle conditions

The exhaust gas measurement results in the two idle modes show that supplementing RON95 fuel with HHO simultaneously reduces the emission components of CO, CO_2, and HC. At low idle condition, the reduction is more pronounced, with CO decreasing by 19 %, CO_2 by 14 %, and HC by 24 %. This indicates that HHO significantly helps improve the combustion process, which is inherently less optimal at low speeds. At high idle condition, emission concentrations also decreased, but with smaller reductions CO decreased by 4 %, CO_2 by 6%, and HC by 9 %). This reflects that the engine already burns more efficiently at high speeds, making the impact of HHO less prominent.

In conclusion, the overall results demonstrate that HHO plays a positive role in increasing combustion efficiency, reducing unburnt fuel, lowering toxic gases, and decreasing greenhouse gases, thereby contributing to the improvement of the exhaust gas quality of the gasoline engine in both operating modes.

5. Conclusion

From this research, it can be concluded that the HHO electrolysis module for the Thaco TOWNER 750 vehicle was successfully designed and fabricated. The dry-cell HHO electrolyser achieved a high efficiency of 89.8 %, producing a gas flow rate of 613.3 ml/min at a current of 11 A, which satisfies the requirement for a stable HHO supply to the engine. The installation of the HHO system did not affect the original structure of the vehicle and ensured flexibility for assembly, maintenance, and repair. In addition, a supplementary electronic control system was integrated to modify sensor voltage signals, enabling the engine to operate more accurately and stably when HHO gas was introduced. Experimental results showed that at low idle speed (850 rpm), the average CO concentration decreased by 20–22 % and HC by 15–25 %, indicating a significant improvement in the combustion process due to HHO addition, while CO_2 concentration slightly decreased in both operating modes. At high idle speed (2400 rpm), HHO continued to reduce CO and HC emissions, although to a lesser extent, with reductions of approximately 4–6 % and 8–12 %, respectively. However, within the scope of this study, engine power, torque, and fuel consumption were not evaluated on a dynamometer; these parameters will be investigated in future research to further assess the impact of HHO application.

Appendix A. Control code

```
#define O2_pin A0
#define Ap_pin A1
#define o2Out 5
#define apOut 6
#define switchPin 7
float VO2_In, VO2_Out, VAp_In, VAp_Out;
float VO2_PLUS = 0.35;  // cộng thêm cho tín hiệu O2
float VAP_DECRE = 0.2;  // giảm cho tín hiệu MAP
void setup() {
  Serial.begin(115200);
  pinMode(o2Out, OUTPUT);
  pinMode(apOut, OUTPUT);
  pinMode(switchPin, INPUT_PULLUP);
}
void loop() {
  int switchState = digitalRead(switchPin);
  if (switchState == LOW) {
    HHO_Mode();
  } else {
    Manual_Mode();
  }
  analogWrite(o2Out, PWM(VO2_Out));
  analogWrite(apOut, PWM(VAp_Out));

  Serial.println(String(VO2_Out, 2) + " -- " + String(VAp_Out, 2));
}
int PWM(float voltage) {
  if (voltage < 0) voltage = 0;
  if (voltage > 5.0) voltage = 5.0;
  return (255 * voltage) / 5.0;
}
void Manual_Mode() {
  VO2_In = analogRead(O2_pin);
  VAp_In = analogRead(Ap_pin);
  VO2_Out = (VO2_In / 1023.0) * 5.0;
  VAp_Out = (VAp_In / 1023.0) * 5.0;
}
void HHO_Mode() {
  VO2_In = analogRead(O2_pin);
  VAp_In = analogRead(Ap_pin);
  VO2_Out = (VO2_In / 1023.0) * 5.0 + VO2_PLUS;
  if (VO2_Out > 4.85) VO2_Out = 4.85;
  VAp_Out = (VAp_In / 1023.0) * 5.0 - VAP_DECRE;
  if (VAp_Out < 0) VAp_Out = 0;
}
```

References

[1] United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol-Targets for the First Commitment Period, 2005.

[2] Ministry of Industry and Trade of Vietnam. Strategy for Renewable Energy Development of Vietnam to 2030, Vision to 2050. Hanoi, Vietnam, 2023.

[3] Ministry of Industry and Trade of Vietnam, "Proposal for nationwide implementation of E10 bio-gasoline from January 1, 2026," Government Electronic Newspaper, Aug. 26, 2025. [Online]. Available: https://baochinhphu.vn/de-xuat-su-dung-xang-sinh-hoc-e10-tren-toan-quoc-tu-1-1-2026-102250826104452711.htm

[4] Ministry of Natural Resources and Environment of Vietnam. Action Plan for Implementing Greenhouse Gas Emission Reduction Commitments under COP26 in Vietnam. Hanoi, Vietnam, 2022.

[5] B. Rajendra Prasath, E. Leelakrishnan, N. Lokesh, H. Suriyan, E. Guru Prakash, and K. Omur Mustaq Ahmed. Hydrogen operated internal combustion engines - A new generation fuel. International Journal of Emerging Technology and Advanced Engineering. 2012; vol. 2, no. 4.

[6] D. N. L. Huynh, T. H. Nguyen, D. C. Nguyen, A. V. Vo, D. T. Nguyen, V. Q. Nguyen, and H. C. Le. Using hydrogen as potential fuel for internal combustion engines: A comprehensive assessment. International Journal of Renewable Energy Development. 2025; vol. 14, no. 1: pp. 83-103. https://doi.org/10.14710/ijred.2025.60707

[7] A. M. Sadeq, R. Z. Homod, A. K. Hussein, H. Togun, A. Mahmoodi, H. F. Isleem, A. R. Patil, and A. H. Moghaddam. Hydrogen energy systems: Technologies, trends, and future prospects. Science of the Total Environment. 2024; vol. 939, Art. no. 173622. https://doi.org/10.1016/j.scitotenv.2024.173622

[8] Z. Dulger and K. R. Ozcelik. Fuel economy improvement by on-board electrolytic hydrogen production. International Journal of Hydrogen Energy. 2000, vol. 25: pp. 895-897.

[9] M. M. H. Bhuiyan and Z. Siddique. Hydrogen as an alternative fuel: A comprehensive review of challenges and opportunities in production, storage, and transportation. International Journal of Hydrogen Energy. Feb. 2025; vol. 102, pp. 1026-1044.

[10] M. S. Gad, A. S. ElShafay, Ü. Ağbulut, and H. Panchal. Impact of produced oxyhydrogen gas (HHO) from dry cell electrolyzer on spark ignition engine characteristics. International Journal of Hydrogen Energy. 2024; vol. 49, part C: pp. 553-563.

[11] A. R. A. Elmaihy, Theoretical and experimental performance of oxyhydrogen generators. Arabian Journal for Science and Engineering. 2018; vol. 43: pp. 1279-1289.

[12] K. Zeng and D. Zhang, "Recent progress in alkaline water electrolysis for hydrogen production and applications," Progress in Energy and Combustion Science. June 2010; Vol. 36, no. 3: pp. 307-326.

[13] K. Ramzy and W. A. El-Askary. Assessment of hydrogen production using NaOH and KOH alkaline with different plates and concentrations: An experimental approach. Energy Reports. Dec. 2025; vol. 14: pp. 3420-3436.

[14] F. Araújo, R. C. Neto, and A. S. Moita. Alkaline water electrolysis: Ultrasonic field and hydrogen bubble

formation. International Journal of Hydrogen Energy Aug 2024; vol. 78: pp. 594-603.
[15] MAHA GmbH, Co. KG. Emission testers for diesel, gasoline and gas engines. [Online]. Available: https://produkt.si/wp-content/uploads/2021/01/MAHA_MGT5_PRODUKT.pdf.