EXPERIMENTAL STUDY ON HEV SERIES TRUCK MODEL

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Abstract – This study presents the design of a serial HEV model and experimental evaluation of performance, fuel consumption measurement, and pollution emission index. Experimental results of fuel consumption measurement on the same cycle show that fuel consumption in HEV mode is reduced by 36.72% compared to ICE mode. The HEV model has a significantly lower emission index than the ICE internal combustion engine during most of the cycle. During the operating stages, the emission time of the ICE experimental cycle always has a period of emission maintenance at 800 rpm. Both cycles reach a sudden emission level of up to about 1.7%, however, the HEV cycle remains essentially HSU emission-free throughout the first 150 minutes and more than 120 minutes of operation at 1500 rpm of the ICE. The smoke coefficient of the test cycle is within the allowable limits of the national standard QCVN 09:2024/BGTVT.

Key words – Hybrid Electric Vehicle; Experimental Model; Fuel consumption; HSU Smoke level; ICE

1. Introduction

Amid growing concerns about energy scarcity and environmental pollution, hybrid electric vehicles (HEVs) have emerged as a promising solution for sustainable transportation. By combining an internal combustion engine with an electric powertrain, HEVs can reduce fuel consumption and greenhouse gas emissions while adapting to a variety of driving conditions. As the demand for energy-efficient, low-emission vehicles increases, HEVs offer a practical and efficient path to sustainable transportation [1-5]. Typically, series HEVs are popular when the goals are fuel economy, emission reduction, mechanical simplicity, and efficient energy management, especially for vehicles with variable driving conditions and short to medium urban routes.

In Vietnam, research on HEV has begun to receive attention in recent years. Many studies has been focused on the calculation and design of hybrid vehicle powertrains, the author has proposed a solution to coordinate power sources in a mixed manner and the theoretical basis for calculating the design of hybrid vehicle powertrains, calculating the design of powertrain transmissions on Inventor software, studying simulation and experiment to evaluate the ability to coordinate power sources on hybrid vehicles [6-8]; Khong et al. [9] developed a hybrid vehicle powertrain system model combining a continuously variable transmission (CVT) with a one-way clutch using AVL-Cruise software. The research results showed that fuel consumption was reduced by 74.9% when running on the UDC (Urban Driving Cycle) test cycle, when compared to a conventional vehicle. Other studies mainly focus on theoretical simulation, optimizing control strategies, and analyzing system energy, studying parallel HEV structures, mixed HEVs [10-11], but a limited number of authors have studied serial HEVs and experiments with serial HEV models.

Continuing the previous study [12], this paper presents the research process of manufacturing and experimenting with a HEV series truck model, in order to investigate the operating characteristics and evaluate energy efficiency. Kia Frontier, manufactured by Thaco, was the best-selling diesel light truck under 2 tons in 2019, accounting for 89% of the market share, making it a strong candidate for hybrid conversion as Vietnam tightens emission standards [12]. The model allows simulation of actual operating modes, thereby providing a basis for quantitative analysis of fuel economy, emission reduction, and overall system efficiency. The research results will contribute to the orientation of HEV technology application in Vietnam, while supporting the training and development of human resources in the field of clean energy vehicles.

2. Experimental methods

2.1. Model specifications

In a series hybrid electric vehicle (HEV), the generator, electric motor, and control system form an interdependent network whose coordinated operation directly affects fuel consumption and emissions performance. The generator, driven by the internal combustion engine (ICE), determines the efficiency of converting chemical energy from the fuel into electrical energy. Its size, performance, and operating strategy determine the load profile on the ICE, which in turn affects fuel consumption and emissions characteristics, as engines operating in suboptimal regions tend to produce higher pollution levels.

The electric motor converts electrical energy into mechanical propulsion, controlling the torque transmitted to the wheels. Its performance, performance map, and response to transient loads affect the energy drawn from the battery and the extent to which regenerative braking is used, both of which affect net energy efficiency and the ability to recover wasted kinetic energy.

Crucially, the control system acts as the powertrain's coordinated intelligence, managing the flow of energy between the ICE, generator, battery, and electric motor. Through energy management algorithms, the system determines when the ICE should operate, how much power should be drawn from the battery, and when regenerative braking should be used. Optimized control strategies ensure that the ICE operates primarily in the high-performance zone, the battery maintains a consistent state of charge (SOC), and the engine delivers smooth torque, resulting in reduced fuel consumption and emissions across different driving cycles.

To measure and analyze fuel consumption and pollution emissions, the authors designed and installed an experimental model of the HEV vehicle according to the diagram in Figure 1. The HEV truck model design is based on the authors' previous study [12]. It includes the main assemblies: ICE, generator, charger, electric motor, and control circuits: Internal combustion engine on/off control circuit, battery system cooling circuit, battery balancing circuit, electric motor excitation circuit, and sensors measuring internal combustion engine speed and wheel speed. The main parameters of the experimental HEV truck model:

- ICE: diesel engine, model 4A1-68C40.

- Generator: TECHNANO generator with 13.6A of current intensity; 220V of voltage; 50Hz of frequency; 3 kW of capacity; 1,500 rpm of rotation speed.

- Charger: Converts 220V AC to 48V DC.

- Electric motor: 15A of current intensity; 48V of voltage; 1 KW of capacity.

To measure and analyze fuel consumption and pollution emissions, we designed and installed an experimental model according to the diagram in Figure 1 as follows:

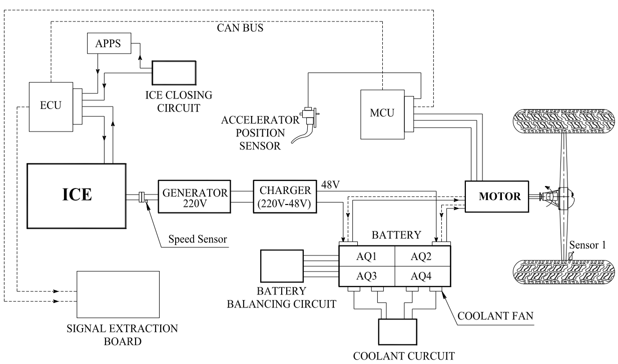


Figure 1. *Serial HEV model diagram*

2.2. HEV control system design

2.2.1. ICE on/off control circuit

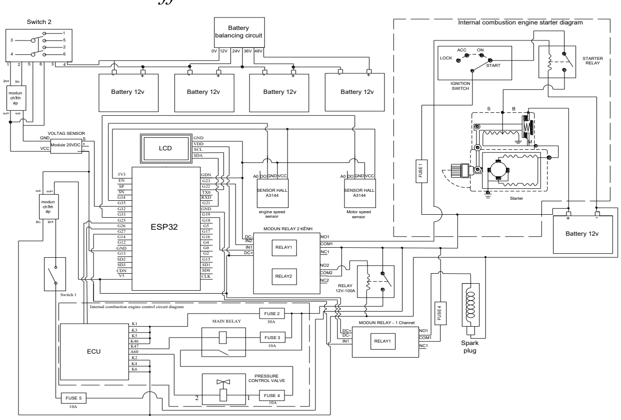


Figure 2. *Internal combustion engine on/off control circuit diagram*

In this study, a microcontroller (ESP 32) is used as a control center to receive signals from sensors and open and close the relay circuit to control the operation of the internal combustion engine. The sensor can measure parameters such as the rotation speed of the crankshaft or the status of the battery in the hybrid system. Based on these signals, the microcontroller will process and decide the appropriate time to activate or deactivate the internal combustion engine, thereby opening and closing the relay to control the current to the ECU and the starter of the internal combustion engine. The control circuit diagram is shown in Figure 2.

The actual circuit fabrication is performed and shown in Figure 3.

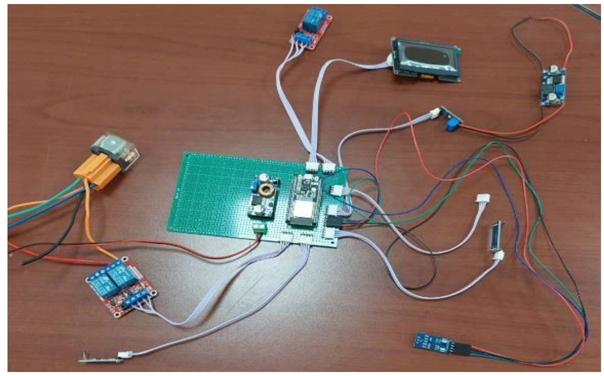


Figure 3. *The circuit controls the on/off of an internal combustion engine in practice*

2.2.2. Battery system cooling control circuit

The battery cooling system uses forced cooling by a fan. The control circuit diagram is shown in Figure 4. The control system uses a microcontroller (ESP 32) for control, using 04 temperature sensors and 04 cooling fans.

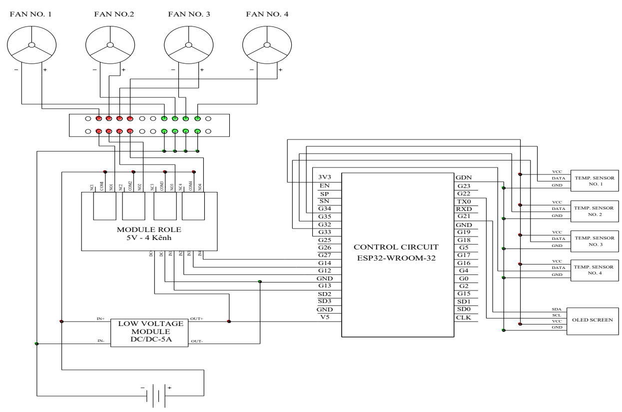


Figure 4. *Battery cooling circuit diagram*

The actual circuit fabrication is performed and shown in Figure 5:

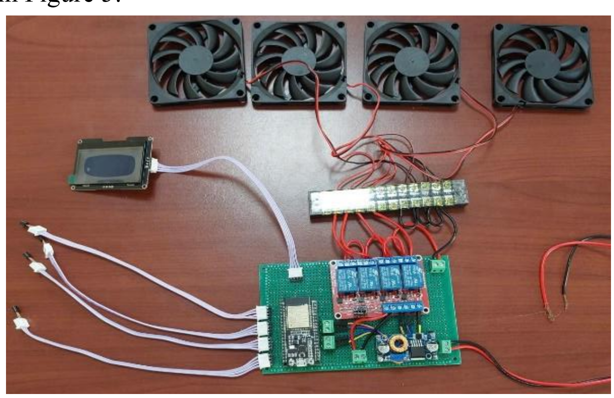


Figure 5. *Battery cooling system control circuit on experimental model*

2.2.3. Generator excitation control circuit

The excitation control circuit diagram for the generator is shown in Figure 6.

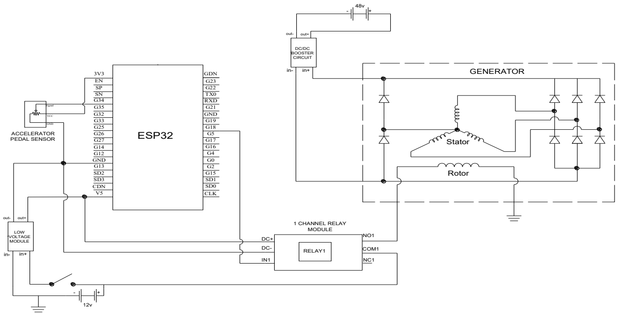


Figure 6. *Generator excitation circuit diagram*

The actual circuit fabricated on the HEV model is shown in Figure 7.

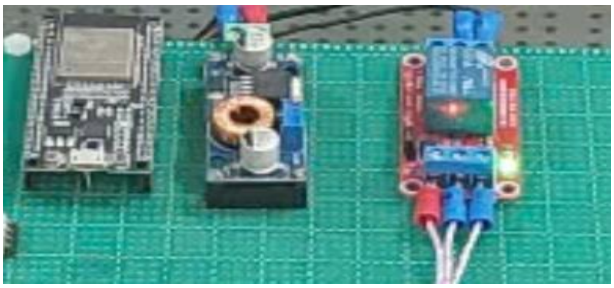


Figure 7. *Generator excitation circuit on experimental model*

2.2.4. Battery system balancing circuit

The voltage balancing circuit is designed to maintain voltage uniformity between batteries by regulating or transferring current from higher voltage batteries to lower voltage batteries. This circuit operates continuously during operation or charging, ensuring that all batteries reach a stable and uniform voltage state.

The generator and charger control circuit diagram is shown in Figure 8.

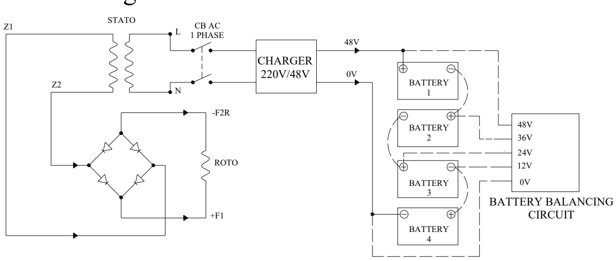


Figure 8. *Generator and charger control circuit diagram*

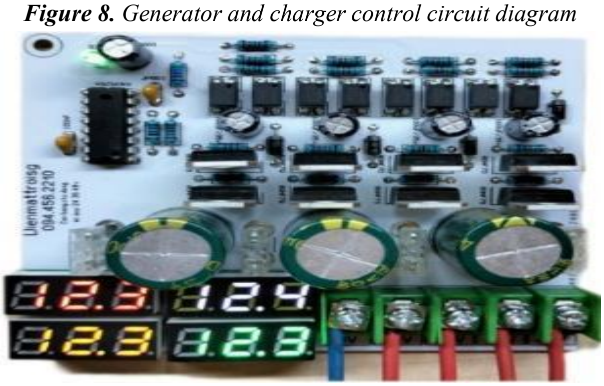


Figure 9. *Active Battery Balancing Circuit 48V/Max 20A on HEV model*

The actual circuit fabricated on the HEV experimental model is shown in Figure 9.

2.3. HEV experimental model

Figures 10 and 11 show the designed HEV model and the model control system, respectively.

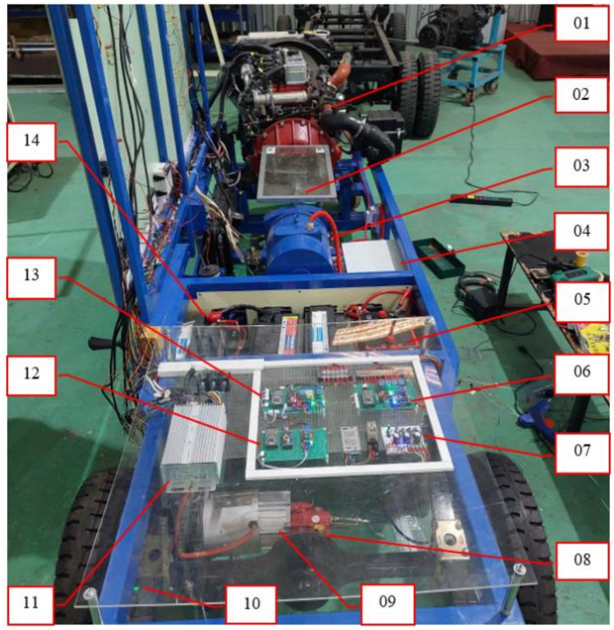


Figure 10. *Serial HEV model*

01- Thermal engine; 02- Engine speed sensor; 03- Generator; 04- Charger; 05- Battery; 06- Battery cooling circuit; 07 – Battery balancing circuit; 08- Rear axle; 09- Electric motor; 10- Wheel speed sensor; 11- Electric motor controller; 12 – Excitation circuit; 13- Thermal engine switching circuit; 14- Battery temperature sensor

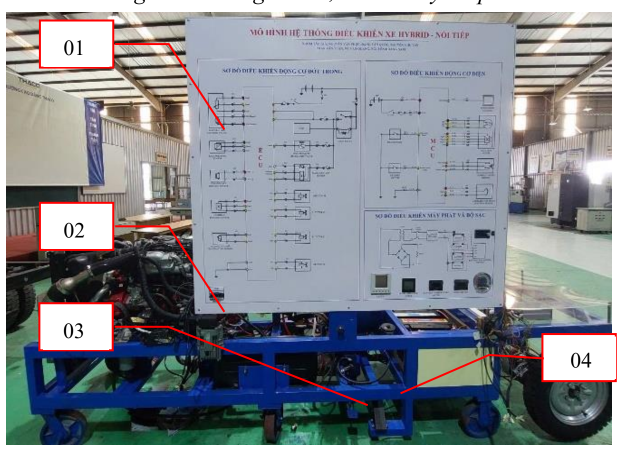


Figure 11. *Front view of HEV model:*
01- Control panel; 02- ECU; 03- Brake pedal; 04 - Accelerator pedal

3. Results and discussion

To experimentally measure fuel consumption and pollutant emissions on the serial HEV model, the experiment is arranged as shown in Figure 1. To evaluate the performance of the HEV model, the model is run in two cycles, i.e., (a) the internal combustion engine cycle and (b) the HEV cycle.

To compare the performance of the serial HEV mode with the ICE mode, we conduct experiments on the serial HEV model according to a certain operating cycle.

Determine the experimental cycles:

- Battery discharge time (t_1):

The battery discharge time (t_1) is determined as:

$$t_1\ (\text{h}) = \frac{\text{Remaining battery capacity (Ah)}}{\text{Current consumption of the electric motor (A)}}$$

Assuming the electric motor operates at maximum power and uses up to 45% of the battery capacity, then the discharge time is as follows:

$$t_1(\text{h}) = \frac{80*45\%}{15} = 2.4\ (\text{h}) = 144\ (\text{mins})$$

Where:

+ Electric motor current consumption: 15 A;

+ Battery capacity: 80 Ah;

- Battery charging time (t_2):

With the battery capacity remaining at 45%, the charging time to fully charge the battery (t_2) is determined as:

$$t_2\ (\text{h}) = \frac{\text{Battery capacity (Ah)} \times 1.2}{\text{Charging current (A)}}$$

Where:

+ Battery capacity (Ah) is the capacity written on the battery.

+ Charging current (A) is the actual current of the charger.

+ Factor 1.2 to compensate for charging efficiency losses (usually around 80%).

$$t_2\ (\text{h}) = \frac{1.2\times 80\times 45\%}{20} = 2.16\ (\text{h}) = 130\ (\text{mins})$$

The ICE speed and electric motor speed values in the cycle are calculated and selected so that the speed at the rear wheel is the same.

From the battery discharge time and charging time, we built an experimental cycle with a total cycle time of 270 minutes on the engine test bench system. The ICE speed considered as the load condition was operated in the range of 800 rpm to1500 rpm, while the electric motor speed was about 50 rpm to 490 rpm. The experimental cycles of the ICE and the HEV cycles, respectively, are shown in Figure 12.

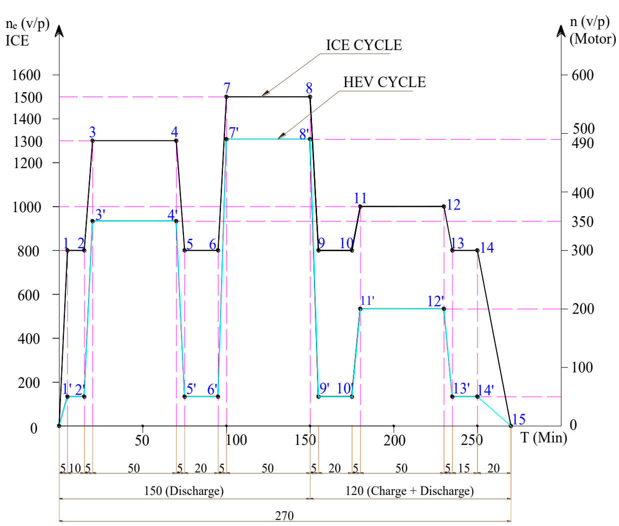


***Figure 12.** Experimental cycles*

3.1. Fuel consumption evaluation in ICE mode and HEV mode

3.1.1. Experimental procedure for measuring fuel consumption

The experiments were conducted at the THACO College under the conditions of a temperature of 32 °C and humidity of 80%. The experimental procedure is shown in Table 1, while the technical specifications of the instruments are presented in Table 2.

***Table 1.** Fuel consumption experimental procedure*

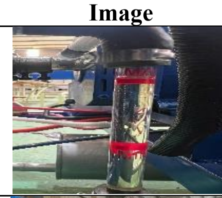
Step	Action	Image
01	Fill the fuel tank to the Max level.	
02	For internal combustion engines operating in cycles, determine the engine speed running in cycles using a HIOKI tachometer.	
03	Measure the fuel consumption, and use the burette to refill the used fuel in the tank up to the Max line.	
04	Record fuel consumption data.	

***Table 2.** Technical Specifications of Instruments*

Diesel Engine Exhaust Gas Analyzer – HESHBON HD-410	
Specification	**Details**
Operating Power Supply	220 V AC / 110 V AC, 60 Hz
Power	100 W
Probe Length	760 mm
Probe Diameter	10 mm
Smoke Density	0 – 100 % (Resolution: 0.1%)
K-value	0.00 – 21.42 m⁻¹ (Resolution: 0.01 m⁻¹)
Engine Speed	0 – 8000 rpm (Resolution: 10 rpm)
Oil Temperature	0 – 150°C (Resolution: ±1°C)
Accuracy	±1 % (RPM: ±80 rpm)
Tachometer – HIOKI FT3405	
Specification	**Details**
Measurement Methods	Non-contact (optical reflection), Contact (optional adapter)
Engine Speed	30.00–199.99 rpm up to 20,000–99,990 rpm
Frequency Range	0.5000–1.9999 rps up to 200.0–1600.0 rps
Cycle Time Range	0.6000–1.9999 ms up to 200.0–1999.9 ms
Count Range	0 – 999,999
Accuracy	±1 digit to ±100 digits depending on range
Detection Distance	50 – 500 mm
Buret	
Specification	**Details**
Nominal Capacity	100 ml
Scale Division	0.2 ml
Max. Error	±0.1 ml

3.1.2. Results of fuel consumption measurement

Measure fuel consumption in 2 modes (HEV mode and ICE mode), perform 5 measurements, and the fuel consumption measurement results are shown in Table 3 and Figure 13.

Table 3. *Fuel consumption in HEV mode and ICE mode*

Exp. time	Fuel consumption				
	ICE mode				
	Value (ml)	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$	Std. Dev.	Error
1	2924	0.1	0.01	0.1	0.045
2	2923.8	-0.1	0.01		
3	2923.9	0.0	0.00		
4	2924	0.1	0.01		
5	2923.8	-0.1	0.01		
Exp. time	HEV mode				
1	1850.3	0.10	0.01	0.1	0.045
2	1850.1	-0.10	0.01		
3	1850.2	0.00	0.00		
4	1850.1	-0.10	0.01		
5	1850.3	0.10	0.01		

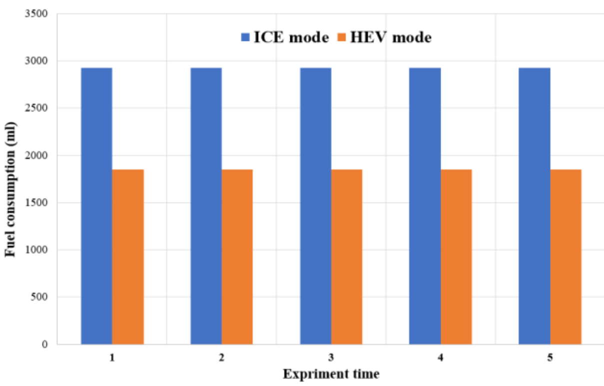


Figure 13. *Fuel consumption measurement results*

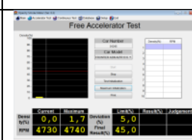
Figure 13 clearly shows the difference in fuel consumption between the two experimental cycles. During the 270-minute experiment, the ICE cycle consumed an average of 2923.9 ml of diesel, while the experimental cycle on the serial HEV model consumed an average of only 1850.2 ml. This shows that the consumption of the serial HEV model cycle is reduced by 36.72%. This is explained by the fact that the serial hybrid system has the ability to operate flexibly, especially effectively in the stages where the internal combustion engine can stop working completely. Operating mainly on electric energy helps to significantly reduce fuel consumption and emissions. At the same time, the control system demonstrates the ability to respond quickly and coordinate well between the components in the experimental cycle. This difference proves the superior fuel economy of the serial HEV system. Consequently, the results confirm that the serial HEV powertrain architecture on the experimental model fully meets the fuel economy target and improves energy efficiency compared to the traditional configuration using only the internal combustion engine (ICE). The significant reduction in fuel consumption in the HEV cycle proves that the model not only works according to the theoretical principle but also demonstrates clear efficiency under real operating conditions.

3.2. Emission index evaluation in ICE mode and HEV mode

3.2.1. Experimental procedure for measuring engine emissions

The experiment procedure is shown in Table 3, while the experimental layout is presented in Figure 14.

Table 3. *Emission measurement procedure [13]*

Step	Procedure	Image
01	Start the device, computer, and test software.	
02	Use the remote or the key combination on the device to press SET twice, then press SELECT to adjust RESET to 0.0 (display PASS is successful).	
03	Clamp the engine rpm signal jack to the battery according to the positive (+) and negative (-) terminals of the tester.	
04	- Depress the accelerator pedal fully to reach the maximum engine speed (to eliminate exhaust gas stagnant in the exhaust pipe). - Clamp the probe into the tail of the exhaust pipe so that the probe is located in the exhaust pipe > 50 mm	
05	Step on the accelerator pedal to accelerate from the minimum rpm to the rpm to be measured. Use the HIOKI FT3405 tachometer to determine the speed value to be measured.	
06	Record measurement results in software	

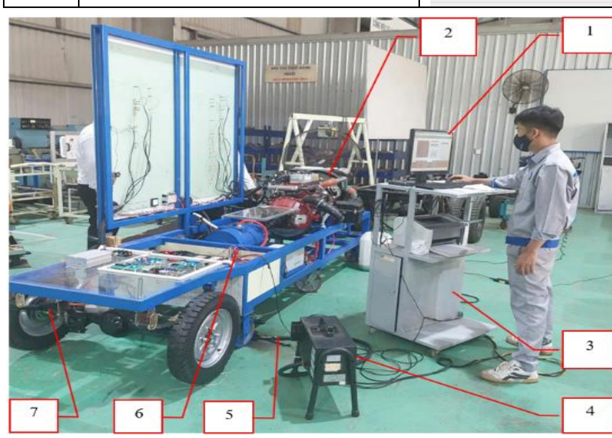


Figure 14. *Experimental setup for measuring diesel engine emissions*

1- Computer; 2- Diesel engine; 3- CPU ;4- HESHBON HD-410 emission meter; 5- Probe; 6- Battery clamp; 7- Speed sensor

3.2.2. Results of emission measurement

The experiments were operated using the THACO testing standard cycle for diesel engine according to the national technical regulation on safety and environmental protection for automobiles - QCVN 09:2024/BGTVT [14]. Figure 15 illustrates the time evolution of Hartridge Smoke Unit (HSU) emissions for the ICE and HEV over a 300-minute operating period. The ICE cycle shows several emission events characterized by low baseline values followed by abrupt spikes. Two prominent peaks appear at approximately 110 and 150 minutes, each reaching values near 1.7%, indicating brief periods of elevated particulate emissions. Between these peaks, the ICE maintains low but not zero emissions, often hovering below 0.3%. In contrast, the HEV cycle remains essentially HSU emission-free throughout the first 150 minutes, reflecting predominantly electric vehicle operation. A sharp emissions spike was observed at around 150 minutes, coinciding with the ignition of the internal combustion engine, but this increase was short-lived. A second spike occurred at around 260 minutes when the engine restarted, again reaching emissions levels equivalent to the ICE peak. This shows a clear difference in the total emission time between the two cycles. Therefore, the smoke coefficient of the entire cycle is within the permissible limits of national standard QCVN 09:2024/BGTVT [14].

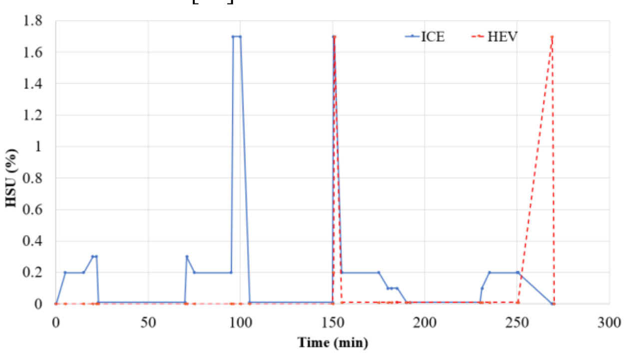


Figure 15. *Smoke level measurement (HSU) of the experimental model in operating modes of ICE and HEV*

In other words, Figure 15 shows that the experimental cycle on the serial HEV model has the potential to significantly reduce emissions, both in terms of intensity and duration of emissions. This demonstrates the effectiveness of the serial hybrid system in reducing pollutant emissions under real operating conditions.

4. Conclusion

The serial HEV system model was built to verify the design solutions of serial hybrid powertrains on light truck platforms. The experimental components consist of the internal combustion engine, generator, electric motor, energy storage, and control system, interconnected to simulate real operating conditions. The experimental cycle was designed to assess fuel consumption and emission levels under various modes. Results show that the series hybrid system operates flexibly and efficiently, especially when the engine is completely shut down. Predominant electric operation significantly reduces fuel use and emissions, while the control system ensures quick response and effective coordination among components, maintaining stable performance throughout the tests.

From the results of the experiments, it can be affirmed that the serial HEV structure is a feasible and effective solution for light commercial vehicles, and at the same time, opens up a research direction for developing green and energy-saving powertrains in practice. Future research will focus on enhancing energy management strategies to optimize power distribution between the engine, generator, battery, and motor under different driving conditions. Improving battery performance and reducing energy losses during charging and regenerative braking are also areas of focus. In addition, predictive and multi-objective control methods could further reduce fuel consumption and emissions while maintaining vehicle performance and reliability.

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REFERENCES

[1] T. Denton, *Electric and Hybrid Vehicles,* 2nd edition. London: Routledge, 2020. https://doi.org/10.1201/9780429296109

[2] T. Denton and H. Pells, *Electric and Hybrid Vehicles*, 3rd edition. London: Routledge, 2024. https://doi.org/10.1201/9781003431732

[3] M. Ehsani, Y. Gao, S. Longo, and K. Ebrahimi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, 3rd edition. Boca Raton: CRC Press, 2018. https://doi.org/10.1201/9780429504884

[4] Office of Energy Efficiency and Renewable Energy (EERE), "Hybrid Electric Vehicles", *afdc.energy.gov*, April 10, 2025. [Online]. Available: https://afdc.energy.gov/vehicles/electric-basics-ev, [Accessed April 10, 2025].

[5] K. Ç. Bayindir, M. A. Gözüküçük, and A. Teke, "A comprehensive overview of hybrid electric vehicle: Powertrain configurations, powertrain control techniques and electronic control units", *Energy Conversion and Management*, vol. 52, no. 2, pp.1305-1313, 2011. https://doi.org/10.1016/j.enconman.2010.09.028

[6] T. V. Dang, "*Study on calculation and design of hybrid vehicle's propulsion system*", Ph.D. dissertation, Hanoi University of Science and Technology, 2022.

[7] D. T. Nghia, "*Simulation study of the power system of a two-mode hybrid vehicle*", Master's thesis, University of Industrial Technology, 2023.

[8] D. X. Ha, "*Research on the design of power combination between power sources on hybrid cars*", Master's thesis, Thainguyen University of Technology, 2018.

[9] K. V. Quang, L. D. Duy, T. V. Dang, and T. D. Quoc, "Development of hybrid vehicle power combination system using CVT", *Transport and Communications Science Journal*, vol. 73, no. 6, pp. 647-660, 2022. https://doi.org/10.47869/tcsj.73.6.5

[10] T.V. Dang, K. V. Quang, T. D. Quoc, and N. K. T. An, "Research on design and manufacture of power source coordination controller for hybrid vehicles", *Journal of Marine Science and Technology*, vol. 10, no. 10, pp. 202-210, 2022. https://www.jmst.vimaru.edu.vn/index.php/tckhcnhh/article/view/198.

[11] N. V. L. Giang and L. V. Mien, "Modeling and simulation of hybrid vehicle control system by using MATLAB simulink", *Journal of Technical Education Science*, vol. 18, no. 2, pp. 56–66, 2023. https://doi.org/10.54644/jte.76.2023.1350

[12] L. M. Duc, T. V. Nam, N. V. Phuc, L. C. Tin, and N. Q. Trung. "A solution for converting the propulsion system of light truck". *The University of Danang - Journal of Science and Technology*, vol. 23, no. 6A, pp. 7-13, 2025. https://doi:10.31130/ud-jst.2025.23(6A).539E

[13] *Diesel engine emission testing process*, THACO Group, 2025.

[14] *National technical regulations on technical safety quality and environmental protection for automobiles*, National standards QCVN 09:2024/BGTVT, 2024.