# RESEARCH ON EFFECTS OF ADDITIONAL BROWN'S GAS ON THE WORKING EMISSION CHARACTERISTICS OF DIESEL ENGINE

BUI NGUYEN HAO[1,a], NGUYEN THANH TUNG[2]
[1]*Kien Giang College,*
[2]*Vinh Long University of Technology Education*
[a]*Corresponding author: bnhao@kgc.edu.vn*

*Reviewed:22/11/2025; Accepted:25/01/2026*

**ABSTRACT**

*The paper presents simulation results aimed at determining the effects of Brown's gas addition into the intake manifold of a diesel engine on operating characteristics and exhaust emissions along the external characteristic curve. The investigated engine is the IVECO 8140.43R, and the simulation tool employed is AVL Boost. The results indicate that with a Brown's gas substitution rate of 10÷20% of the torque, the average torque increases by 17%, power output increases by 25%, brake specific fuel consumption decreases by 20%, NOx emissions increase by 11,3% on average, soot emissions decrease by 13,7%, and CO emissions decrease by 25% on average.*

***Keywords:*** *Brown's gas, Diese engine, emissions, simulation, AVL Boost.*

## 1. INTRODUCTION

In the current context, environmental pollution caused by emissions from transportation and the depletion of fossil fuel resources have become global challenges. Diesel engines, while known for their high thermal efficiency, emit significant amounts of pollutants such as NOx, CO, HC, and particulate matter (PM), all of which have serious impacts on air quality, the environment, and human health. At the same time, emission regulations are becoming increasingly stringent worldwide, including in Vietnam. These regulations require manufacturers and researchers to develop technological solutions that minimize environmental impacts while maintaining engine performance and fuel efficiency. To address these challenges, the use of alternative or supplementary fuels has emerged as a prominent research direction. Hydrogen is widely regarded as a promising fuel of the future; however, its major drawback lies in the difficulty of storage, particularly for transportation applications. Designing and developing systems for hydrogen generation and storage in vehicles remains a significant technical challenge [1]. As a result, many studies have focused on the use of hydrogen–oxygen mixtures, commonly known as Brown's gas or HHO, as a practical alternative. HHO is a mixture of hydrogen and oxygen used as a supplementary fuel in Diesel engines. Its combustion primarily produces water vapor, thereby reducing carbon-based emissions. The application of HHO injection through the intake system to reduce emissions has been implemented in Europe and the Americas since the mid-1990s for engines equipped with mechanical fuel injection systems, and later extended to

ISSN: 3126-2953
E-ISSN: 3126-3097

electronically controlled injection systems around 2009. According to previous studies [2], this technology can reduce fuel consumption by 16% to 35% and decrease harmful emissions by up to 46%. Several notable studies have been reported. Trinh Xuan Phong et al. [3] investigated the use of HHO in a Diesel R180 engine. Their results showed an average reduction in fuel consumption of 9.1%, along with decreases in smoke emissions (31%), CO (28%), and HC (13%), while NOx emissions increased slightly by about 2.5%. Similarly, Tran Trong Tuan et al. [4] conducted experiments on an Isuzu 4BD1T engine. The results indicated that HHO supplementation reduced fuel consumption by 0.57% to 3.35% and decreased smoke emissions by 0.94% to 6.39%, but increased NOx emissions by 0.47% to 9.1% compared to operation without HHO supply.

Fujidenki Company has installed and tested a water electrolysis system for generating HHO gas on fishing vessels to reduce fuel consumption and exhaust emissions. Experimental results on fishing boats in Binh Dinh province showed that fuel consumption decreased by 4.98 liters per hour (16.6%). When calculated per nautical mile, fuel consumption was reduced by 0.56 liters per nautical mile (17.5%), and the total fuel consumption over the same voyage decreased by 22 liters (approximately 17.6%) [5]. These findings, along with previous studies, reveal noticeable variations due to differences in engine types, fuel supply conditions, and operating regimes. Therefore, this study presents simulation results on the effects of supplying Brown's gas into the intake system on the performance characteristics and emission behavior of the IVECO 8140.43R engine. The study aims to provide a theoretical foundation for the adoption of alternative fuels in currently operating vehicles in Vietnam. Its results also contribute to addressing a pressing practical issue: reducing environmental pollution from Diesel engine emissions without requiring major modifications to engine design.

## 2. CONTENT

### 2.1. Test engine

The test engine used in this study is the IVECO 8140.43R, supplied by IVECO (Italy). The technical specifications of the engine are presented in Table 1.

*Table 1. Technical specifications of the IVECO 8140.43R engine [6]*

| No | Parameter | Value | Unit |
|---|---|---|---|
| 1 | Engine type | Diesel | - |
| 2 | Rated speed | 4200 | rpm |
| 3 | Number of strokes | 4 | Kỳ |
| 4 | Number of cylinders | 4 in-line cylinders | - |
| 5 | Firing order | 1-3-4-2 | - |
| 6 | Piston stroke | 100 | mm |
| 7 | Connecting rod length | 157 | mm |
| 8 | Cylinder bore | 94.4 | mm |
| 9 | Displacement | 2800 | $cm^3$ |

ISSN: 3126-2953
E-ISSN: 3126-3097

| | | | |
|---|---|---|---|
| 10 | Combustion chamber type | Direct injection (open chamber) | - |
| 11 | Compression ratio | 18:1 | - |
| 12 | Maximum power | 64.7 ÷ 67.3<br>(88 ÷ 91,6) / 3600[rpm] | kW (HP) |
| 13 | Maximum torque | 201,6 ÷ 218,4<br>(20.6 ÷ 22.3) / 1800[rpm] | N.m (kg.m) |
| 14 | Turbocharging | Turbocharged with intake air cooling | - |
| 15 | Cooling system | Water-cooled, cooling starts at 82 ± 2 | $^0C$ |
| 16 | Injection system | Electronic fuel injection | - |
| 17 | Intake and exhaust valve diameter | 7.985 ÷ 8 | mm |
| 18 | Intake valve opening angle $\varphi_1$ | $8^0$ | $^0$ |
| 19 | Intake valve closing angle $\varphi_2$ | $37^0$ | $^0$ |
| 20 | Exhaust valve opening angle $\varphi_3$ | $48^0$ | $^0$ |
| 21 | Exhaust valve closing angle $\varphi_4$ | $8^0$ | $^0$ |
| 22 | Fuel injection pressure | 1350 | bar |

### 2.2. Test fuel

Hydrogen is the primary component of the gas; therefore, the physical and chemical properties of Brown's gas are similar to those of hydrogen. As a result, Brown's gas can be used in internal combustion engines by supplying a small amount into the intake system. In essence, the combustion process of Brown's gas is similar to that of hydrogen.

*Table 2. Basic properties of hydrogen compared with Diesel fuel [7]*

| Property | Hydrogen | Diesel ($C_{10}H_{22}$) |
|---|---|---|
| Auto-ignition temperature (K) | 858 | 553 |
| Minimum ignition energy (mJ) | 0.02 | 20 |
| Flammability limits (% vol. in air) | 4 ÷ 75 | 0.6 ÷ 5.5 |
| Molecular weight (g/mol) | 2.016 | 170 |
| Density (kg/m³) | 0.0899 | 850 |
| Stoichiometric air–fuel ratio | 34.4 | 15,2 |
| Flame propagation speed (cm/s) | 270 | 22 ÷ 25 |
| Quenching distance (cm) | 0.064 | 0.21 |

### 2.3. Simulation model

In the simulation study, combustion, heat transfer, and emission models were employed. The combustion process of the studied engine was modeled using the AVL MCC model. This model accounts for both premixed combustion, corresponding to the rapid combustion phase (PMC – Premixed Mixture Combustion), and mixing-controlled combustion, corresponding to the main combustion phase (MCC – Mixing Controlled Combustion). The model can be applied to Diesel fuel as well as dual-fuel operation involving Diesel and

ISSN: 3126-2953
E-ISSN: 3126-3097

another supplementary fuel. It is capable of predicting the heat release rate in engines with non-homogeneous mixture formation, capturing the effects of recirculation processes, and estimating the formation of emissions such as NOx, CO, and soot. The theoretical background and models used in this study are summarized in Table 3.

*Table 3. Theoretical models and approaches used for simulation*

| No | Theory / Model | Test engine |
|---|---|---|
| 1 | *Fundamental theory* | *First law of thermodynamics* |
| 2 | Mixture formation model | Fuel injection model |
| 3 | Combustion model | AVL MCC |
| 4 | Heat transfer model | Woschni model |
| 5 | NOx emission model | Zeldovich model |
| 6 | CO emission model | Onorati model |
| 7 | HC emission model | AVL-MCC model (HC component neglected) |

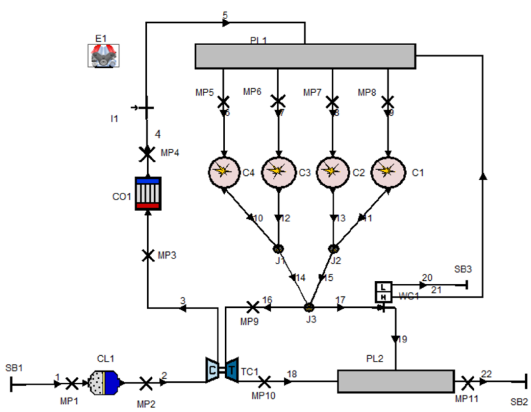



**Figure 1. Simulation model of the IVECO 8140.43R engine**

Figure 1 illustrates the simulation model of the IVECO 8140.43R engine. In the model, E1 represents the engine, while SB1, SB2, and SB3 denote the boundary conditions. CL1 corresponds to the air filter, and C1 to C4 represent the engine cylinders. PL1 and PL2 indicate pressure stabilizing chambers, and I1 represents the Brown's gas injector. CO1 denotes the intercooler, WC1 is the pressure relief valve, and TC1 represents the turbocharger. MP1–MP11 correspond to measurement points, while J1, J2, and J3 are flow junction elements. The system is connected through pipelines labeled from 1 to 22.

## 3. SIMULATION RESULTS

### 3.1 Effect of Brown's gas addition on torque and power

The engine was evaluated under full-load conditions using Diesel fuel supplemented with Brown's gas at levels of 5%, 10%, 20%, and 30% (denoted as HHO5, HHO10, HHO20, and HHO30). Figure 2 presents the variation of torque and power of the baseline engine compared with cases using Brown's gas supplementation. In terms of torque, the results show a clear increasing trend with higher HHO addition. Specifically, torque increased by approximately 2–5% at HHO5, 7–11% at HHO10, 7–17% at HHO20, and 8.6–22% at HHO30. However, at higher engine speeds (around 4200 rpm), although the torque remained higher than that of the baseline engine (Me_nb), the improvement became less significant. This behavior reflects reduced combustion efficiency at high speeds due to shortened combustion duration. Engine power followed a similar trend to torque across all HHO levels, confirming the direct relationship between torque and power. Power increased by about 4% to over 14% at HHO5, 8% to over 22% at HHO10, and 15% to over 25% at HHO20. At HHO30, power continued to increase significantly, with the highest improvement observed at 1800 rpm, where Ne_HHO30 rose by nearly 41% compared to the baseline case (Ne_nb). This improvement indicates more efficient combustion of the Diesel–Brown's gas mixture, resulting in greater work output per cycle.

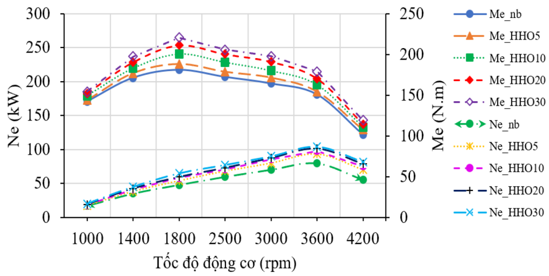



***Figure 2. Engine torque and power under different test conditions***

### 3.2. Effect of Brown's gas addition on specific fuel consumption

Figure 3 shows the variation in specific fuel consumption when the engine operates on Diesel fuel supplemented with Brown's gas. The results indicate that, at all supplementation levels (HHO5, HHO10, HHO20, and HHO30), fuel consumption decreases compared to the baseline case without HHO. The reduction is more pronounced in the engine speed range of 1400 to 3600 rpm, which is also the typical operating range for many Diesel engines. At the HHO5 level, specific fuel consumption decreases by approximately 5-10%. Although Brown's gas improves the combustion process, the low supplementation ratio limits the overall effect. At HHO10 and HHO20, the reduction becomes more significant, reaching 10-20%, representing an optimal range, particularly at medium and high engine speeds. HHO30 shows the greatest fuel savings; however, further evaluation is required to assess its impact on thermal efficiency and combustion stability.

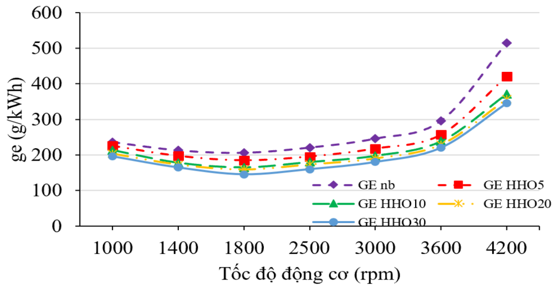



***Figure 3. Specific fuel consumption of the Diesel–Brown's gas mixture under different test conditions***

### 3.3. Effect of Brown's gas addition on NOx emissions

Figure 4 illustrates NOx emissions when the engine operates on Diesel fuel supplemented with Brown's gas under the investigated conditions. The results show that NOx emissions increase with higher levels of HHO supplementation. Specifically, NOx emissions rise by approximately 3.3% to 7.4% at HHO5, 4.3% to 8.7% at HHO10, and more noticeably by 6.6% to 11.3% at HHO20. The highest increase is observed at HHO30, with NOx emissions rising significantly in the range of 9.8% to 14.1%.

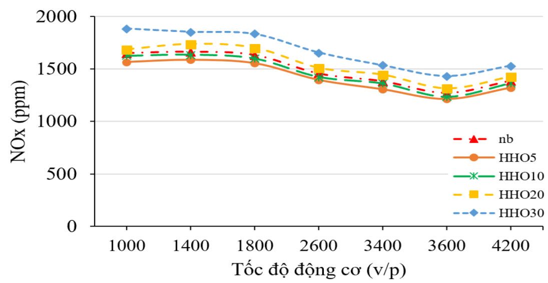
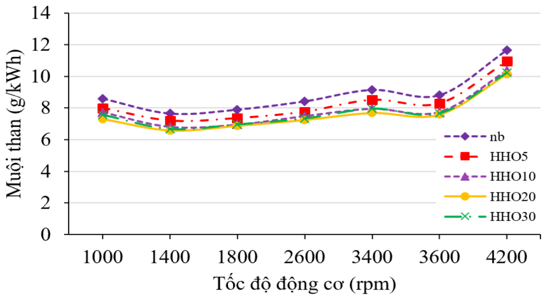



***Figure 4. NOx emissions under different test conditions***

### 3.4. Effect of Brown's gas addition on soot emissions

Figure 5 illustrates soot emissions when the engine operates on Diesel fuel supplemented with Brown's gas under the investigated conditions. The results show a consistent reduction in soot emissions as the HHO supplementation level increases.

Specifically, soot emissions decrease by approximately 4.8% to 6.5% at HHO5 and by 6.5% to 12% at HHO10. A more pronounced reduction is observed at HHO20, with values ranging from 6.5% to 13.7%. The greatest reduction occurs at HHO30, where soot emissions decrease by approximately 7.3% to 14.6%.




***Hình 5. Phát thải muội than ở các trường hợp khảo sát***

### 3.5 Figure 5. Soot emissions under different test conditions

Figure 6 illustrates CO emissions when the engine operates on Diesel fuel supplemented with Brown's gas under the investigated conditions. The results show a consistent decrease in CO emissions with increasing HHO supplementation. Specifically, CO emissions decrease by approximately 7.7% to 11.5% at HHO5 and by 10% to 20% at HHO10. A more significant reduction is observed at HHO20, ranging from 12% to 25%. The greatest reduction occurs at HHO30, where CO emissions decrease in the range of 15% to 28%.

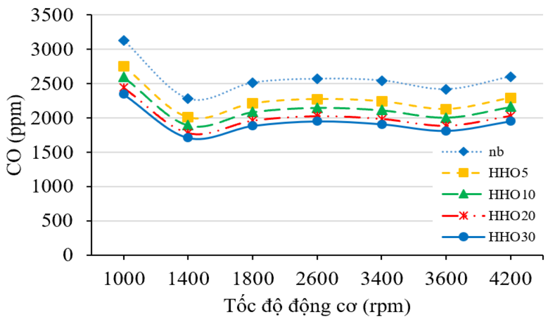



***Figure 6. CO emissions under different test conditions***

## 4. CONCLUSION

Brown's gas (HHO) is considered a clean supplementary fuel. Due to its rapid combustion characteristics and the absence of carbon content, its addition to Diesel fuel enhances the combustion process, leading to faster and more complete burning. In addition, Brown's gas contributes a certain amount of thermal energy to the process, resulting in increased engine power, reduced fuel consumption, and lower emissions of harmful pollutants.

This study evaluated the effects of Brown's gas supplementation on the performance and emissions of the IVECO 8140.43R engine. The HHO10–HHO20 range was identified as the optimal supplementation level. From a techno-economic perspective, engine torque increased by approximately 7–11%, and power improved by 8–25%. Specific fuel consumption decreased by 10–20%. In terms of emissions, NOx increased by approximately 4.3–11.3%, while soot emissions decreased by 6.5–13.7%, and CO emissions decreased by 10–25%. These results indicate that appropriate supplementation of Brown's gas improves combustion efficiency. However, exceeding the optimal level may reduce combustion efficiency and increase the risk of engine knocking. Some limitations remain in this study. In particular, NOx emissions show an increasing trend compared to the baseline engine. Additionally, factors such as engine durability, overall operating cost, and long-term performance under different operating and environmental conditions were not considered. Future work should incorporate NOx control technologies such as EGR and SCR to mitigate emissions when using Brown's gas. Experimental validation on real engines over extended

ISSN: 3126-2953
E-ISSN: 3126-3097

operating periods and under various load and environmental conditions is also necessary to provide a more comprehensive assessment. Overall, the results demonstrate that the use of Brown's gas as a supplementary fuel is a feasible and promising approach. It offers potential for practical application in reducing fossil fuel consumption and mitigating environmental pollution. Supplying Brown's gas through the intake system represents a viable solution for improving fuel efficiency and reducing harmful emissions in Diesel engines without requiring major modifications to engine design.

## REFERENCES

[1] White, CM, Steeper, RR, and Lutz, AE, (2006), *The hydrogen-fueled internal combustion engine: a technical review*, International journal of hydrogen energy. 31(10), pp. 1292-1305.

[2] Reddy, A., et al., (2014), *Improving The Efficiency Of I.C. Engine Using Secondary Fuel,* International Journal of Technology Enhancements and Emerging Engineering Research, Vol.2: pp.52-64.

[3] Trinh Xuan Phong, Hoang Dinh Long, Tran Quoc Dang, Nguyen Duc Khanh, Tran Tuan Anh (2021), *Effect of HHO gas addition on performance and emission formation of a Diesel engine*, Journal of Marine Science and Technology, No. 10, pp. 151–155.

[4] Tran Trong Tuan, Nguyen Cong Doan, Vu Ngoc Khiem (2019), *Study on the effects of HHO gas addition into the intake system on technical and environmental performance of Diesel engines*, Journal of Water Resources and Environmental Engineering, Thuy Loi University, No. 10, pp. 52–57.

[5] Tran Trong Tuan, Lu Thi Yen (2019), *Research on the design and fabrication of an HHO gas generator for supplying to the intake system of internal combustion engines,* Journal of Transport and Communications, No. 4, pp. 97–100.

[6] IVECO (2004), Iveco Daily Repair Manual.

[7] Nguyen Tien Han, Vu Minh Dien, Pham Huu Nam, Le Hoang Long (2017), *Research on the application of HHO technology for automotive Diesel engines*, Hanoi University of Industry, No. 42, pp. 74–76.