HHO-GASOLINE HYBRID MOTORCYCLE

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Abstract - Supplementing HHO into gasoline is an effective solution for improving combustion processes and reducing greenhouse gas emissions in motorcycle engines. When transitioning from pure gasoline to an gasoline-HHO blend with ϕ_H=0.04, engine power increased by 8% at 5000 rpm and by 9.3% at 7500 rpm. Carbon monoxide (CO) concentration in engine exhaust decreased by approximately 8.5%, while nitrogen oxide (NOx) concentration increased by an average of 14% compared to gasoline operation. When engine speed decreased from 7500 rpm to 5000 rpm, NOx emissions increased by 60% for pure gasoline and by 40% for the HHO-gasoline blend with ϕ_H=0.04. At full-load conditions and 7500 rpm, CO_2 emission levels decreased by 13.5% when HHO was added to gasoline with ϕ_H=0.08 compared to gasoline operation.

Key words - HHO; Hydrogen; Renewable fuels; Greenhouse gas emissions; Hybrid motorcycles.

1. Introduction

COP 29 is the United Nations Climate Change Conference taking place in Baku, Azerbaijan from 11 to 22 November 2024 continued to call for global cooperation to reduce greenhouse gas (GHG) emissions. This effort aims to limit the increase in atmospheric temperature to below 2°C by the end of this century, compared to pre-industrial levels, in line with the Paris Agreement. Vietnam currently has over 72 million motorbikes in circulation, making it the second-largest motorbike market in ASEAN, only behind Indonesia, which has the largest number of motorbikes globally with 125 million units [1]. The transition from gasoline-powered motorbikes to electric motorbikes heavily relies on advancements in energy storage technology and the development of adequate infrastructure. Therefore, research into reducing GHG emissions from traditional motorbikes through the use of renewable fuels is crucial before a complete shift to electric power.

Among renewable fuels, hydrogen is considered an ideal fuel because it contains no carbon, and its primary combustion product is water vapor [2]. Hydrogen has a high autoignition temperature (576°C), which allows for an increased compression ratio in spark-ignition engines, thereby improving thermal efficiency and reducing pollutant emissions [3]. However, hydrogen storage on vehicles remains a significant challenge. Hydrogen has a low volumetric energy density and is difficult to liquefy, requiring specialized storage equipment. For automotive applications, hydrogen typically needs to be compressed in tanks at a pressure of 700 bar to achieve a driving range comparable to conventional cars. Integrating an onboard water electrolyzer to produce hydrogen directly in a car is not economically viable [4]. HHO is a mixture consisting of two-thirds hydrogen and one-third oxygen by volume. HHO electrolyzers are simpler and cheaper than pure hydrogen electrolyzers. Consequently, the use of HHO has gained increasing attention from the scientific community in recent years [5].

HHO can be used in combination with conventional fuels in internal combustion engines to improve efficiency and reduce polluting emissions [6], [7]. On motorbikes, HHO is produced by a water electrolyzer and fed into the engine's intake manifold. The power supply to the electrolyzer is regulated to ensure a stable HHO flow, matching the engine's load conditions. Unlike hydrogen, HHO is an explosive mixture, so it's not stored. The HHO electrolyzer operates when the engine is running and shuts off when the engine is turned off. HHO production units are compact, inexpensive, and can be integrated into motorbikes, overcoming the disadvantages associated with hydrogen storage on motorcycles.

Recent studies indicate that supplementing gasoline with HHO can improve the performance and reduce emissions of motorbike engines. Sudarmanta et al. [8] reported a decrease in fuel consumption and an increase in efficiency in a 150cc engine. Hung et al. [9] observed similar positive effects with a 10% HHO supplement. Nabil et al. [10] emphasized the feasibility and practicality of integrating compact HHO electrolyzers into motorbikes.

The addition of HHO gas to conventional fuels is considered a potential solution for improving engine performance and reducing polluting emissions. However, most current research primarily focuses on CO, HC, and NOx emissions, without fully evaluating the impact on CO_2 emissions or the power supply for the HHO electrolysis process. This study proposes using regenerative energy from a regenerative braking system to power a dry-type water electrolyzer installed on a motorbike. Through simulation and experimentation, the research assesses the effectiveness of HHO supplementation on operational performance, emissions, and particularly, the potential for CO_2 reduction. The goal is to develop a feasible technical solution that can transform traditional motorbikes into low-CO_2 emission vehicles, aligning with the net-zero roadmap in developing countries.

2. Research objects and methods

The object of this study is a Honda Lead 110cc gasoline-powered motorbike, supplemented with HHO to improve the combustion process and enhance energy efficiency. This motorbike engine has a cylinder bore of 50mm, a piston stroke of 55mm, and a compression ratio of 9:1. Its engine power is 6.4kW at 7500 rpm when running on gasoline.

The research methodology combines simulation with experimentation. Simulation is performed using Ansys Fluent software. The computational domain includes the intake manifold, combustion chamber, and cylinder. The setup of the computational model for the engine's intake and combustion processes has been detailed in previous works [11], [12]. A dynamic mesh is applied within the cylinder volume due to its changing volume.

Boundary conditions include pressure, temperature, and gas mixture composition at the intake port and at the HHO fuel injector. Turbulence in the gas mixture is modeled using the k-ε model. The main combustion products are determined based on thermochemical equilibrium using the Partially Premixed Combustion model.

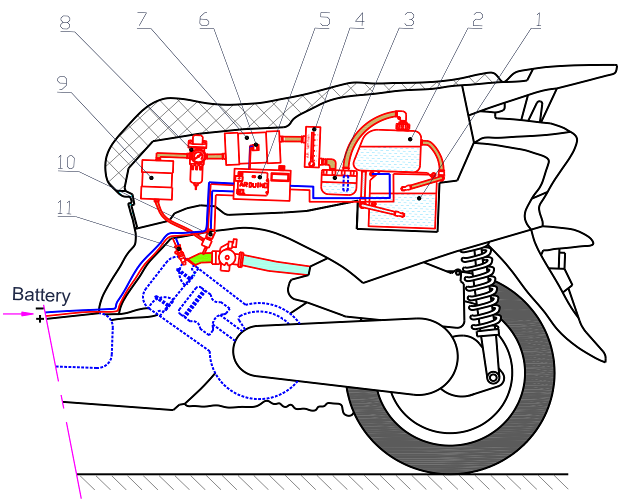


Figure 1. *Schematic diagram of the HHO system layout on the G-HHO hybrid motorcycle*

1. HHO electrolyzer, 2. NaOH solution reservoir, 3. Flashback arrestor, 4. Flow meter, 5. Control circuit, 6. Pressure sensor, 7. Pressure stabilizer tank, 8. Pressure regulating valve, 9. HHO buffer tank, 10. HHO injector, 11. Gasoline injector

The experimental research was conducted on a motorbike dynamometer equipped with power measurement and exhaust gas analysis devices. When converting this motorbike to run on G-HHO, the engine's basic structure remains unchanged. The engine's intake manifold is fitted with a 5mm diameter injector tube to supply HHO. Figure 1 illustrates the structural diagram of the Honda Lead G-HHO motorbike, converted from a conventional gasoline-powered motorbike. HHO is produced by a dry-type water electrolyzer powered by a 24V battery. Initially, the battery is charged via the electrical grid. As the motorbike operates, the battery receives additional charging from the surplus power of the internal combustion engine and from a regenerative braking system integrated into the front wheel of the bike [13]. In principle, this can be considered a novel model of a plug-in hybrid motorbike. The key difference compared to a plug-in hybrid car model is that the electrical energy here is supplied to the vehicle indirectly via HHO, rather than directly to an electric motor. This simplification allows for a more straightforward powertrain system for plug-in hybrids, making it feasible for application on motorbikes where space is very limited. The HHO is supplied to the engine via a gas fuel injector controlled by a dedicated ECU [14]. The ECU uses an Arduino microcontroller activated by the gasoline injector control signal. The HHO injector's opening duration is adjusted via a potentiometer. The HHO accessory kit is located in the motorbike's storage compartment.

The energy of gasoline and HHO entering the engine is determined based on their individual equivalence ratios within the mixture. The overall equivalence ratio of the mixture, denoted as ϕ, is the sum of the partial equivalence ratio for gasoline (ϕ_G) and for HHO (ϕ_H): $\phi=\phi_G+\phi_H$. Fuel with HHO supplementation is denoted as G-HHO.

3. Results and discussion

3.1. Gasoline-HHO intake process simulation

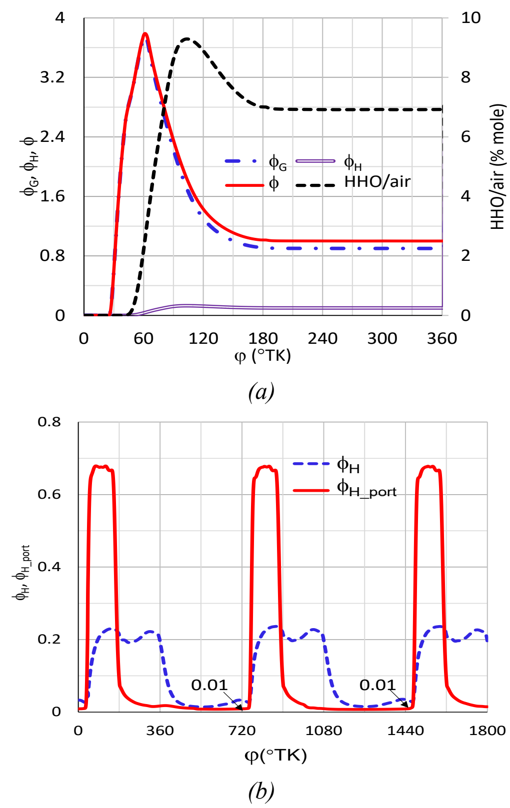


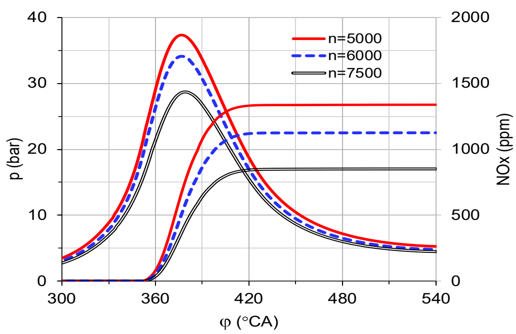
Figure 2. *Variation of ϕ_G, ϕ_H, ϕ, and HHO/air with crankshaft angle (a); Variation of ϕ_H and ϕ_{H_port} with crankshaft angle (b)*

The simulation results show that the overall equivalence ratio of the mixture (ϕ) is primarily determined by gasoline. During fuel injection, a high equivalence ratio is concentrated near the gasoline injector. By the end of the intake stroke, the gasoline has almost completely vaporized, mixing with H_2 and air to form the fuel-air mixture. At the beginning of the compression stroke, the mixture in the cylinder is non-uniform, with a higher equivalence ratio in the region near the cylinder bottom. During compression, the swirling motion of the gas pushes this rich mixture towards the exhaust valve. The overall equivalence ratio in the combustion chamber dome, where the spark plug is located, is approximately 1. This creates favorable conditions for ignition.

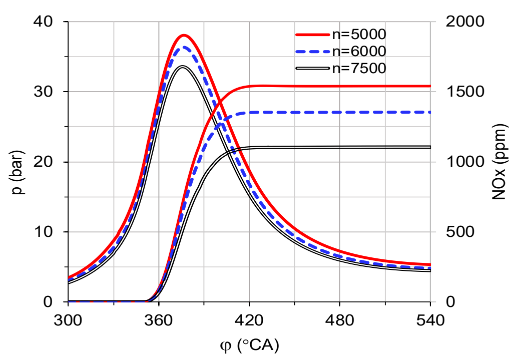
Figure 2a illustrates the variation of ϕ_G, ϕ_H, ϕ, and HHO/air with crankshaft angle. At the beginning of the intake stroke, the values of ϕ_G, ϕ_H, and ϕ increase to a maximum before gradually decreasing to a stable value. This occurs because the initial amount of air in the cylinder is negligible, leading to a high fuel-to-air ratio (F/A). As the intake stroke progresses, the amount of air drawn into the cylinder increases, causing the F/A value to decrease and stabilize after fuel injection ceases.

Figure 2b shows the hydrogen-air equivalence ratio at the intake port (ϕ_{H_port}), a parameter that influences backfire phenomena. When HHO is supplied via the ECU-controlled method, this parameter drops sharply when HHO injection stops. By the time the intake valve opens for the next cycle, ϕ_{H_port} is approximately 0.01. In the design of hydrogen or HHO fuel supply systems, particular attention must be paid to this parameter, ensuring its value is as low as possible when the intake valve opens to prevent backfire in the intake manifold.

3.2. Gasoline-HHO fuel combustion process simulation



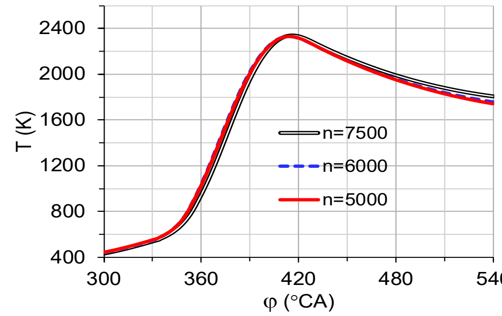
(a)



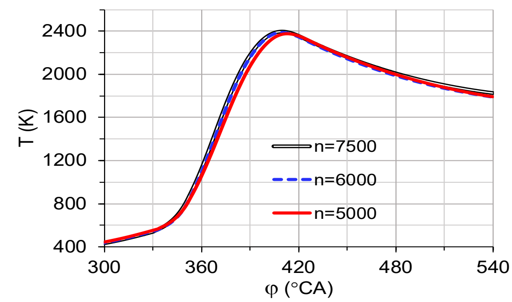
(b)

***Figure 3.** The effect of engine speed on the variation of in-cylinder pressure and NOx concentration in exhaust gas when the engine runs on gasoline (a) and G-HHO with ϕ_H=0.04, ϕ_G=0.96 (b)*

Figures 3a and Figures 3b illustrate the effect of engine speed on in-cylinder pressure variation and NOx concentration in exhaust gas when the engine operates on gasoline and on G-HHO with a ϕ_H of 0.04. The optimal spark advance angle for the engine changes with engine speed. In the simulation calculations, the optimal spark advance angles chosen were 22ºCA, 25ºCA, and 28ºCA, corresponding to engine speeds of 5000 rpm, 6000 rpm, and 7500 rpm, respectively.



(a)



(b)

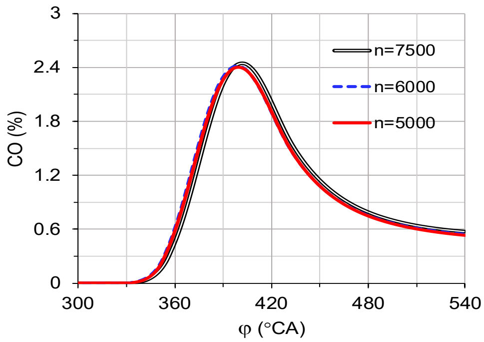
***Figure 4.** The effect of engine speed on the variation of gas temperature in the cylinder when the engine runs on gasoline (a) and G-HHO with ϕ_H=0.04, ϕ_G=0.96 (b)*

In both cases, whether the engine runs on gasoline or G-HHO, as the engine speed increases, the volumetric efficiency decreases due to increased pressure losses in the intake manifold, leading to a reduction in peak pressure. The simulation results indicate that at the same speed, adding HHO to gasoline increases the engine's peak power, consequently increasing the indicated work per cycle. The degree of engine power improvement when switching from gasoline to G-HHO fuel depends on the engine speed. With ϕ_H=0.04, engine power increases by 2.5% at 5000 rpm and by 8% at 7500 rpm. Therefore, for a given ϕ_H value, the engine power improvement is more pronounced at higher speed ranges. This highlights the effectiveness of hydrogen fuel for high-speed engines due to its significantly higher combustion speed compared to traditional fuels.

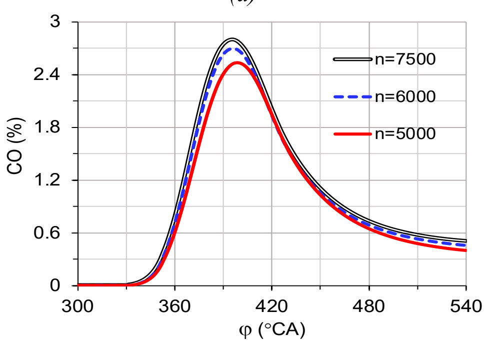
When HHO is added to gasoline, NOx emissions increase under the same engine operating conditions. This is because HHO has a higher combustion temperature than gasoline (Figures 4a, b). Simulation results show that when the engine runs on G-HHO with ϕ_H=0.04, the NOx concentration in the exhaust gas increases by an average of 14% compared to when the engine runs on gasoline alone.

For the same fuel type, NOx emissions decrease as engine speed increases. This is due to a reduction in the time the burning mixture remains in a high-temperature environment. When the engine speed decreases from 7500 rpm to 5000 rpm, NOx emissions increase by 60% for gasoline fuel and by 40% for G-HHO fuel with ϕ_H=0.04. This indicates that HHO reduces the influence of engine speed on NOx emissions.

Figures 5a and Figures 5b illustrate the impact of engine speed on the variation of CO concentration in the combustion products as a function of crankshaft angle when the engine runs on gasoline and on G-HHO with a ϕ_H of 0.04.



(a)



(b)

***Figure 5.** The effect of engine speed on the variation of CO concentration in exhaust gas when the engine runs on gasoline (a) and G-HHO with ϕ_H=0.04, ϕ_G=0.96 (b)*

In both cases, the CO concentration rises to a maximum value corresponding to a crankshaft angle of approximately 400°CA to 410°CA. This position also corresponds to the peak gas temperature in the cylinder (Figures 4a, b). This can be explained by the rapid flame propagation, which leads to incomplete combustion of the mixture, generating a significant amount of CO. Subsequently, this CO continues to combust into CO_2, causing its concentration in the combustion products to decrease.

The CO concentration in the engine exhaust is minimally affected by engine speed. When HHO is added to gasoline, the CO concentration decreases at a given engine speed. This is because the combustion process of the fuel-air mixture is more complete when HHO is present in the fuel. Simulation results show that the CO concentration in the engine exhaust decreases by approximately 8.5% when switching from gasoline to G-HHO fuel with ϕ_H=0.04.

Figure 6 Comparison of CO_2 emissions when the engine runs on gasoline and G-HHO with ϕ_H=0.04, ϕ_G=0.96. Figure 6 compares the CO_2 emissions when the engine runs on gasoline and G-HHO, showing that adding HHO to gasoline helps reduce CO_2 emissions. This occurs because HHO improves combustion efficiency, reducing the formation of incomplete carbon during the combustion process, thereby decreasing CO_2 emissions. HHO also helps burn gasoline more efficiently, reducing harmful gas emissions, which leads to decreased CO_2 emissions.

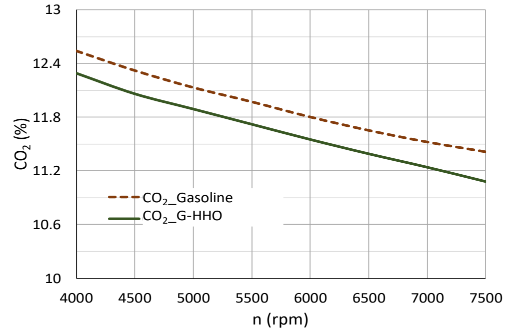


***Figure 6.** Comparison of CO_2 emissions when the engine runs on gasoline and G-HHO with ϕ_H=0.04, ϕ_G=0.96*

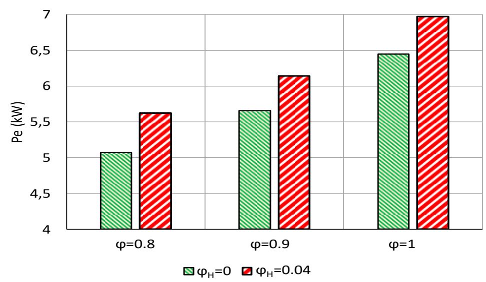


***Figure 7.** Comparison of engine power when running on gasoline and G-HHO with G-HHO with ϕ_H=0.04, ϕ_G=0.96, n=7500 rpm*

Figure 7 illustrates the increase in engine power when HHO is added to gasoline, with ϕH=0.04 and ϕG=0.96. The percentage increase in engine power when running on gasoline-HHO compared to running on gasoline for equivalence ratios of 0.8, 0.9, and 1 is 9%, 7%, and 6%, respectively. The addition of HHO improves combustion efficiency, allowing gasoline to burn more effectively, reducing energy losses and increasing engine power.

3.3. Comparison of simulation and experimental results

Road test results:

***Table 1.** Road test results*

Evaluation riteria	G motorcycle	G-HHO motorcycle	Comparison
Speed at 50% throttle (km/h)	72	78.5	Increase 9.03%
Distance per 1 kg of gasoline at avg. speed of 50km/h (km/kg)	52.5	57	Increase 8.57%
Fuel consumption at avg. speed of 50km/h (kg/100km)	1.90	1.75	Decrease 7.89%
Acceleration time from 0-80km/h (s)	9.8	9.2	Decrease 6.12%

Table 1 shows that at 50% throttle opening, there's a 9.03% increase (in an unstated metric, likely power or acceleration). The distance traveled per kg of gasoline at an average speed of 50 km/h increases by 8.57%. Fuel consumption measured in kg/100km at the same speed decreases by 7.89%, and the acceleration time from 0-80 km/h decreases by 6.12%. These results indicate that vehicles using gasoline-HHO improve speed and travel distance while reducing fuel consumption and shortening acceleration time, thereby enhancing the overall performance of the vehicle.

Super Dyno 50L test bench results: The experimental effective power of the engine was obtained by converting the power measured at the wheels back to the crankshaft, using a transmission efficiency of 0.65.

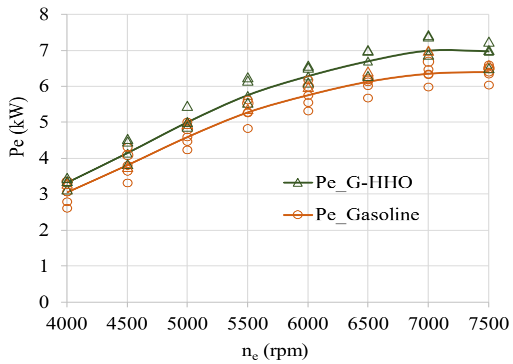


***Figure 9.** Motorcycle test results on Super Dyno 50L test bench*

Figure 9 shows that the engine power when using G-HHO is higher than when using gasoline alone and reaches its maximum earlier. The maximum engine power using gasoline-HHO increased by 9.3%. This indicates that adding HHO to gasoline improves the combustion process because HHO's fast combustion speed helps the engine reach maximum power earlier than with gasoline alone.

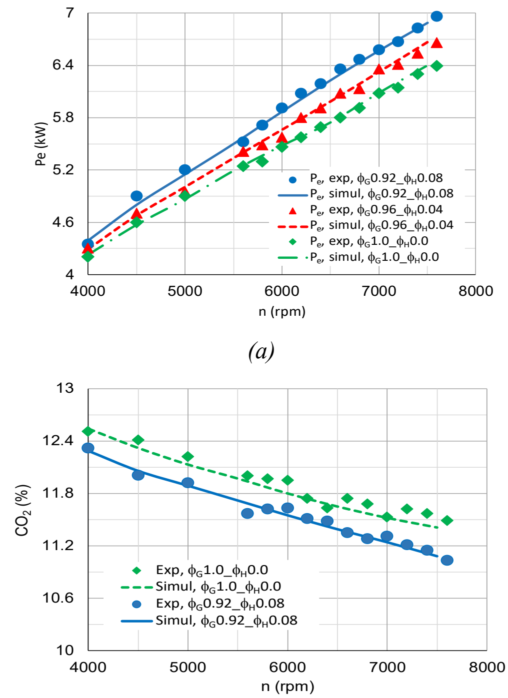
***Table 2.** Exhaust gas emission measurement results using the Sauermann SICA 230-5NDC gas analyze*

n_e (rpm)	4000	5000	6000	7000	7500
CO_G (ppm)	18440	18750	20750	23565	24520
CO_G-HHO (ppm)	16620	16730	17930	20205	21100
HC_G (%)	0.5	0.53	0.74	1.08	1.24
HC_G-HHO (%)	0.47	0.48	0.67	0.99	1.16
CO_2_G (%)	14.3	14.11	13.1	12.4	12.3
CO_2_G-HHO (%)	12.23	12.05	11.21	10.43	10.32
NOx_G (ppm)	1420	1300	1010	880	800
NOx_G-HHO (ppm)	1620	1470	1160	1030	980

Exhaust gas emission test results, conducted using a Sauermann SICA 230-5NDC gas analyzer and displayed in Table 2, demonstrate that using a gasoline-HHO mixture significantly reduces CO and HC emissions at all measured speeds. The percentage reduction for CO ranges from 9.9% to 14.6%, and for HC, it ranges from 6% to 9.9%. This decrease in CO and HC proves HHO's ability to make the combustion process more efficient, thereby reducing the amount of harmful gases released into the environment.

The reduction in CO and HC emissions can primarily be explained by two factors: HHO's high combustion speed promotes more complete combustion of hydrocarbon compounds, thus reducing CO and HC emissions. Its wide flammability limit allows the gasoline-HHO and air mixture to burn stably over a broad range, including oxygen-lean mixtures. This helps reduce CO and HC in situations where the gasoline-air mixture would not burn completely.

The simulated effective power and CO_2 emissions at full load were evaluated against experimental results for three fuel cases: Engine running entirely on gasoline (ϕ_G=1), engine running on G-HHO with ϕ_G=0.96 and ϕ_H=0.04, engine running on G-HHO with ϕ_G=0.92 and ϕ_H=0.08, engine speed varied from 4000 rpm to 7500 rpm.



(a)

(b)

***Figure 10.** Comparison of the variation in effective power Pe (a) and CO_2 emissions (b) versus engine speed given by simulation and experiment when the engine runs on gasoline and on G-HHO with different ϕ_H values*

Figure 10a shows that the simulated engine power Figure 7 aligns well with experimental data Table 2 for both gasoline and G-HHO operation. The discrepancy between simulation and experiment decreases as the proportion of HHO in the mixture increases. As previously discussed, indicated work per cycle decreases with increasing engine speed due to increased losses in the intake manifold. The indicated work per cycle is higher in the low-speed range than in the high-speed range, meaning that indicated work per cycle is a function of engine speed. Therefore, the actual effective power of the engine does not change linearly with speed.

Adding HHO to gasoline fuel reduces CO2 content in the exhaust gas compared to running the engine on gasoline alone. Figure 10b demonstrates that the average reduction in CO_2 emissions when the engine runs on G-HHO with ϕ_H=0.08 is approximately 4% compared to gasoline operation. The percentage reduction in CO_2 emissions can be calculated by assessing the increase in indicated work per cycle when the engine runs on G-HHO fuel compared to gasoline, along with the proportion of gasoline replaced by hydrogen when HHO is added. Consequently, the actual CO_2 emissions when the engine runs on G-HHO fuel with ϕ_H=0.08 at 7500 rpm are reduced by approximately 13.5% compared to gasoline operation.

Figure 11 shows that when the engine is supplemented with HHO at ϕ_H=0.04 and ϕ_H=0.96, the amount of NOx emissions in the exhaust increases, which is consistent with the simulation results. This increase is due to earlier ignition, creating higher combustion rates and increased combustion temperatures. At higher engine speeds, NOx decreases more compared to lower engine speeds. The reason is that combustion occurs faster at high engine speeds, reducing the time the combustion chamber experiences high combustion temperatures, leading to a reduction of NOx during engine operation.

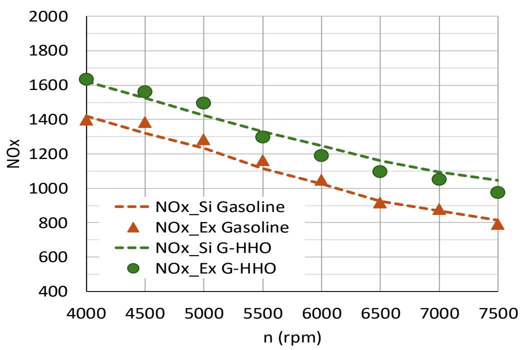


Figure 11. *Comparison of NOx variation by engine speed shown through simulation and experimental results when the engine runs on gasoline and on G-HHO with ϕ_H=0.04 and ϕ_G=0.096*

4. Conclusion

The research results lead to the following key conclusions:

When switching from gasoline to G-HHO fuel with ϕ_H=0.04, engine power increased by 8% at 5000 rpm and by 9.3% at 7500 rpm. Concurrently, the CO concentration in the engine exhaust decreased by approximately 8.5%.

When the engine ran on G-HHO with ϕ_H=0.04, the average NOx concentration in the exhaust increased by 14% compared to running on gasoline. However, as engine speed decreased from 7500 rpm to 5000 rpm, NOx emissions increased by 60% for gasoline but only 40% for G-HHO fuel with ϕ_H=0.04. This suggests HHO reduces the impact of engine speed on NOx emissions.

The reduction in CO_2 emissions is directly proportional to the increase in indicated work per cycle and the proportion of gasoline replaced by HHO when transitioning from gasoline to G-HHO. At full load and an engine speed of 7500 rpm, CO_2 emissions decreased by 13.5% when switching from gasoline to G-HHO with ϕ_H=0.08.

This initial research indicates that adding HHO to gasoline is an effective solution for improving combustion and reducing greenhouse gas emissions from motorcycle engines, aligning with net-zero goals. To enable practical application of G-HHO motorcycles, further research is needed to develop solutions for preventing backfire in the intake manifold and to conduct engine performance measurements directly at the crankshaft output.

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