



# Experimental study of the effect of oxyhydrogen (HHO) electrolyzer installation location on exhaust emissions (CO and HC) in a four-stroke gasoline motorcycle engine

Hasan Maksum<sup>1</sup>, Martias<sup>1\*</sup>, Wawan Purwanto<sup>1</sup>, M Sadly Firmansyah<sup>1</sup>, Ridho Wahyudi<sup>1,2</sup>, and M Reza<sup>1</sup>

<sup>1</sup> Padang State University, Padang, Indonesia

<sup>2</sup> SMK Hasanah Pekanbaru, Yayasan Amil Hasanah, Pekanbaru, Indonesia

\*Corresponding author email: [martias@ft.unp.ac.id](mailto:martias@ft.unp.ac.id)

## Abstract

The rapid increase in motorcycle usage in Indonesia has intensified air pollution, particularly from carbon monoxide (CO) and hydrocarbon (HC) emissions generated by carbureted spark ignition engines. One practical retrofit approach to improve combustion efficiency is oxyhydrogen (HHO) gas supplementation. This study experimentally evaluates the effect of HHO addition on exhaust emissions of a four-stroke motorcycle, with emphasis on the influence of installation location at the air filter and intake manifold. Emission tests were conducted at engine speeds of 1500, 2000, 2500, and 3000 rpm using a four-gas analyzer. Baseline measurements indicated HC emissions ranging from 2060.33 to 2218.33 ppm and CO concentrations between 4.20% and 4.33%, reflecting incomplete combustion characteristics. The introduction of HHO reduced emissions at all tested speeds. Air-filter installation resulted in HC reductions of 10.87–63.80% (mean 43.51%) and CO reductions of 68.00–88.34% (mean 77.24%). In comparison, intake-manifold installation yielded higher average HC reduction of 52.86% (47.97–73.63%), while CO reductions were more variable at 21.48–110.02% (mean 14.51%). Statistical analysis confirmed that these reductions were significant at the 95% confidence level. The results demonstrate that HHO supplementation effectively improves emission performance, with installation location determining the dominant reduction in CO or HC emissions.

## Keywords

HHO, Electrolyzer, Installation location, Exhaust emission, Motorcycle

## Introduction

Over the past decade, motorcycle ownership in Indonesia has increased substantially, as documented in provincial transportation statistics published by BPS Province Sumatera Barat [1]. This rapid growth reflects the central role of motorcycles in

Published:  
May 04, 2026

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BIS-STE 2025 Committee

supporting daily mobility and economic activity. However, the expansion of fossil fuel-based transportation has intensified environmental concerns, particularly air pollution resulting from combustion emissions [2]. Among various technological interventions, the application of oxyhydrogen gas in internal combustion engines has been investigated as a potential method to enhance combustion efficiency and reduce pollutant formation [3]. Experimental and simulation studies on motorcycles fueled with HHO-enriched gasoline have demonstrated measurable changes in combustion characteristics and exhaust emission profiles [4], even as hydrogen-based systems such as on-site electrolysis continue to be developed for broader energy applications [5].

Despite these technological advancements, conventional gasoline motorcycles remain dominant, and many still operate using carburetor systems. Such systems are susceptible to deviations from the optimal air-fuel ratio, leading to incomplete combustion and increased emissions of carbon monoxide (CO) and hydrocarbons (HC) [6]. The technical feasibility of producing hydrogen through electrolysis, including renewable-integrated configurations, provides the foundation for HHO implementation in retrofit applications [7]. Parametric investigations of dry-cell hydroxy generators have identified operational variables affecting gas production rate and efficiency [8], while experimental retrofitting in small engines, including two-stroke configurations, has shown emission reductions and variations in exhaust temperature [9]. Controlled testing in spark ignition engines further confirms decreases in CO and HC emissions with HHO supplementation under different load conditions [10].

The emission reduction potential of HHO is closely related to the physicochemical properties of hydrogen. Hydrogen exhibits a wide flammability range and high flame propagation speed, enabling stable and rapid combustion even under lean mixture conditions [11]. Additionally, the oxygen component contained in HHO enhances oxidation reactions, promoting more complete conversion of CO into CO<sub>2</sub> during combustion [12]. Experimental development of compact electrolysis devices for auxiliary HHO supply in motorcycle engines has demonstrated improvements in emission performance [13], and integration with regenerative energy systems has been explored to support sustainable gas production [14]. The stability and efficiency of HHO generation are influenced by electrode configuration and electrolyte composition [15], with wet-cell experimental designs providing further insights into generator optimization [16].

From a methodological standpoint, rigorous quantitative research design is essential to ensure the validity and reliability of experimental findings [17]. Engine configuration variables, particularly within the intake system, significantly influence combustion and emission outcomes. Intake modifications have been shown to affect fuel consumption and exhaust emissions in four-stroke motorcycles [18], while variations in ignition timing, injector timing, and fuel parameters directly impact CO and HC emission levels in fuel-injected engines [19], [20].

Recent experimental investigations on hydrogen-enriched air combustion consistently report reductions in regulated emissions alongside performance improvements [21]. Studies evaluating hydroxy gas addition across different engine speeds confirm speed-dependent effects on combustion and pollutant formation [22]. Optimization research highlights the importance of controlling HHO generator parameters to maximize emission reduction effectiveness [23], and comprehensive reviews identify hydrogen-enriched combustion as a promising retrofit strategy for internal combustion engines [24]. Comparable improvements in combustion behavior and emission performance have also been observed in other engine platforms supplemented with HHO gas [25]. Nevertheless, systematic comparative studies examining the influence of HHO installation location within the intake system of small-displacement four-stroke motorcycles remain limited. Therefore, this study experimentally evaluates the effects of installing an HHO generator at the air filter and at the intake manifold on CO and HC emissions across a range of engine speeds.

## Method

The experiments were conducted at the Vehicle Testing Laboratory, Faculty of Engineering, Universitas Negeri Padang. A pretest-posttest control group design was employed, using a standard four-stroke motorcycle as the test subject [14], [16], [17]. The core aim was to analyze the effect of electrolyzed placement on exhaust emission. Research experimental design shown in Table 1 and specification of the test motorcycle shown in Table 2.

Testing was performed under several steady-state engine conditions: 1500, 2000, 2500, and 3000 rpm. The electrolyzed was tested at two installation points to assess its influence. Each test condition was replicated three times to ensure data reliability and validity [18], [19], [20]. The experimental schematic and setup are depicted in Figure 1 and Figure 2, respectively.

Table 1. Research experimental design

Research Pattern			
Group	Treatment	Experimental results	Description
R1	X1	Y1	Baseline (without electrolyzer)
R2	X2	Y2	Electrolyzer installed at Air Filter
R3	X3	Y3	Electrolyzer installed at Intake Manifold

Table 2. Specifications of the test motorcycle

Item	Specification
Type	: 4-Stroke, SOHC
Engine	: 109.1 cc Gasoline
Bore x Stroke	: 53.5 mm x 48.9 mm
Transmission	: 4-speed manual transmission
Maximum torque	: 0.81 kg-m / 5.500 rpm
Maximum Power	: 7.7 ps / 7.000 rpm
Fuel system	: Carburetor

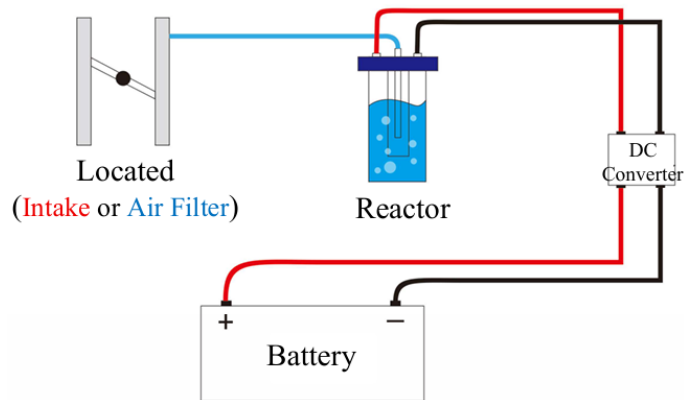


Figure 1. Schematic of the electrolyzer installation on the intake of motorcycle used in the experiment

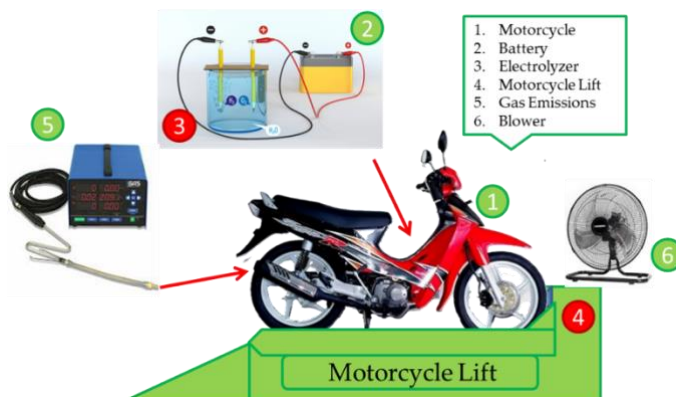


Figure 2. Setup of the electrolyzer installation on the intake of motorcycle used in the experiment

## Results and discussion

The exhaust emission results under baseline conditions and with the electrolyzer installed at two locations are summarized in [Tables 3](#), [Table 4](#), and [Table 5](#). Under baseline conditions, exhaust emissions varied with engine speed, reaching 2060.33 ppm (HC) and 4.32% (CO) at 1500 rpm and 2178.00 ppm (HC) and 4.20% (CO) at 3000 rpm.

Table 3. Exhaust emission test results (Baseline, No Electrolyzer)

Without Electrolyzer									
No.	Engine Revolutions (RPM)	HC (ppm)				CO (%)			
		I	II	III	Average	I	II	III	Average
1	1500	2161	1859	2161	2060.33	4.11	4.11	4.75	4.32
2	2000	1880	1819	1880	1859.67	1.3	1.69	1.30	1.43
3	2500	2270	2277	2108	2218.33	4.42	4.23	4.34	4.33
4	3000	2087	2210	2237	2178.00	4.12	4.17	4.32	4.20

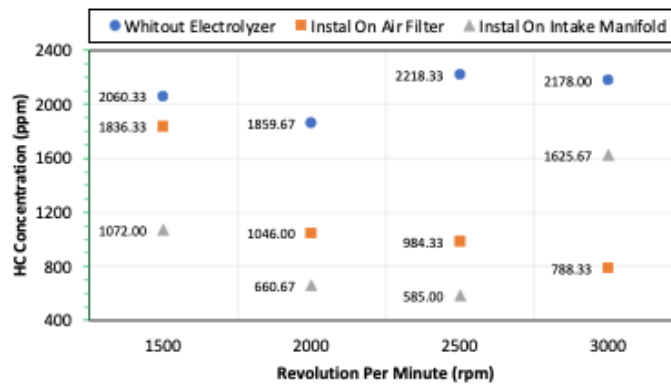
Table 4. Exhaust emission with electrolyzer at air filter

With Electrolyzer Installed on Air Filter									
No.	Engine Revolutions (RPM)	HC (ppm)				CO (%)			
		I	II	III	Average	I	II	III	Average
1	1500	1733	1809	1967	1836.33	1.36	1.44	1.35	1.38
2	2000	964	1087	1087	1046.00	0.19	0.12	0.19	0.17
3	2500	1016	1016	921	984.33	0.91	0.91	0.75	0.86
4	3000	733	816	816	788.33	0.98	1.25	1.25	1.16

**Table 5.** Exhaust emission with Electrolyzer at Intake Manifold

With Electrolyzer Installed on Air Filter									
No.	Engine Revolutions (RPM)	HC (ppm)				CO (%)			
		I	II	III	Average	I	II	III	Average
1	1500	1733	265	1218	1072.00	1.36	2.55	1.700	1.87
2	2000	1163	275	544	660.67	2.54	3.15	3.320	3.00
3	2500	824	700	231	585.00	3.18	2.85	4.170	3.40
4	3000	1576	1799	1502	1625.67	0.55	0.45	0.280	0.43

The corresponding fuel exhaust emissions are consolidated in [Figure 3](#) and [Figure 4](#). A clear influence on exhaust emissions is observed when the electrolyzer is active, with the intake manifold installation consistently yielding the lowest emission levels.



**Figure 3.** Chart of HC

**Table 6.** Percentage reduction in exhaust emission with electrolyzer

RPM	Instal on Air Filter		Instal on Intake Manifold	
	HC	CO	HC	CO
1500	10.87%	68.00%	47.97%	56.75%
2000	43.75%	88.34%	64.47%	110.02%
2500	55.63%	80.22%	73.63%	21.48%
3000	63.80%	72.40%	25.36%	89.85%
Mean	43.51%	77.24%	52.86%	14.51%

[Table 6](#) summarizes the percentage variations in HC and CO emissions resulting from electrolyzed installation at two different intake positions over four engine speeds. In the air-filter configuration, HC emissions showed a gradual increase in effectiveness with rising engine speed, beginning at 10.87% at 1500 rpm and reaching 63.80% at 3000 rpm, with an average decrease of 43.51%. For CO emissions, the reduction ranged from 68.00% at 1500 rpm to a maximum of 88.34% at 2000 rpm, producing a mean decrease of 77.24% across the tested speeds.

In the intake-manifold configuration, HC reductions were recorded at 47.97%, 64.47%, 73.63%, and 25.36% for 1500, 2000, 2500, and 3000 rpm, respectively, resulting in a higher mean HC decrease of 52.86% compared to the air-filter setup. However, CO emissions in this configuration exhibited greater fluctuation, with percentage decreases of 56.75%, 110.02%, 21.48%, and 89.85% across the respective engine speeds, and an overall average decrease of 14.51%. These findings indicate that both installation locations affect exhaust emission behavior, with the intake-manifold position yielding stronger average HC

improvement, while the CO response demonstrates substantial sensitivity to engine speed variations.

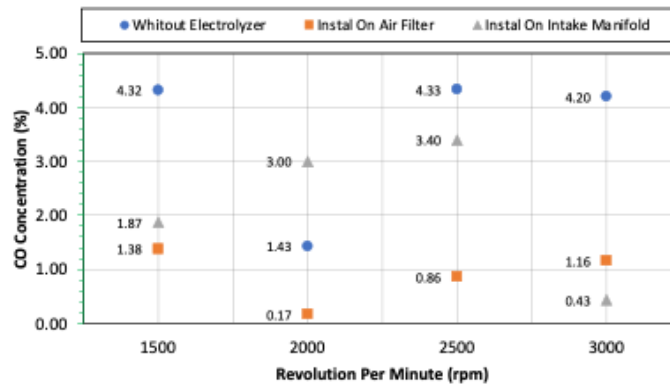


Figure 4. Chart of CO

The experimental findings indicate that, under baseline operating conditions, HC concentrations remained above 2000 ppm and CO levels were consistently within the range of 4.20–4.33% across all tested engine speeds. These emission levels reflect incomplete combustion behavior typically associated with carbureted spark ignition engines operating under relatively rich air–fuel ratio conditions, as documented in previous studies [6], [19], [20]. The activation of the HHO electrolyzed clearly altered exhaust emission characteristics, confirming that hydrogen enrichment significantly influences combustion dynamics [24], [25].

When the electrolyzed was installed at the air filter, HC emissions exhibited a progressive decline with increasing engine speed, reaching 788.33 ppm at 3000 rpm. This trend suggests that introducing HHO upstream of the carburetor enhances premixing with intake air, thereby improving charge homogeneity and promoting more complete oxidation of hydrocarbons. Comparable improvements in HC reduction due to auxiliary HHO systems in motorcycle engines have been reported in earlier investigations [13], [14]. This behavior is consistent with the intrinsic combustion properties of hydrogen, particularly its high flame propagation speed and wide flammability limits, which contribute to more stable and efficient combustion [11].

In contrast, installation at the intake manifold produced more substantial HC improvement at low and intermediate engine speeds, with the lowest concentration observed at 2500 rpm. This outcome aligns with findings indicating that localized hydrogen enrichment intensifies combustion reactions and reduces quenching effects within the combustion chamber [9], [10]. However, the observed increase in HC at higher engine speed suggests that reduced residence time and elevated airflow velocity may limit the effectiveness of direct manifold injection under such conditions.

For CO emissions, the air-filter configuration produced substantial and relatively consistent decreases across all engine speeds, with the most pronounced improvement at 2000 rpm. This suggests more effective oxidation of CO to CO<sub>2</sub> due to improved mixture uniformity and the additional oxygen supplied by HHO, as reported in previous studies [12], [16]. In contrast, the intake-manifold configuration showed greater

variability in CO response, supporting findings that hydrogen-enriched combustion is sensitive to engine speed and mixture distribution characteristics [21], [22]. Overall, while HHO supplementation enhances emission performance, the installation location significantly influences the consistency and magnitude of HC and CO improvements.

## Conclusion

The results confirm that HHO supplementation significantly influences the exhaust emission characteristics of a four-stroke motorcycle engine. Under baseline conditions, HC emissions ranged from 2060.33–2218.33 ppm and CO concentrations from 4.20–4.33%, indicating incomplete combustion typical of carbureted systems. Activation of the electrolyzed at both installation locations modified emission behavior across all tested engine speeds.

The air-filter configuration produced HC reductions of 10.87–63.80% (mean 43.51%) and CO reductions of 68.00–88.34% (mean 77.24%). In contrast, the intake-manifold configuration yielded higher average HC reduction of 52.86% (47.97–73.63%), but more variable CO reductions of 56.75–110.02% (mean 14.51%). These findings indicate that while both configurations enhance emission performance, the intake-manifold installation improves HC more effectively, whereas the air-filter configuration provides more consistent CO reduction, highlighting the importance of installation location in determining emission outcomes.

## Acknowledgement

The authors gratefully acknowledge the support and facilities provided by Universitas Negeri Padang, which were instrumental in conducting this research.

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