



Experimental study of the effect of HHO (oxyhydrogen) electrolyzer installation location on fuel mass flow rate in a four-stroke gasoline motorcycle engine

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Abstract

The surge in motorcycle utilization in Indonesia presents significant challenges concerning fossil fuel dependency and environmental pollution from exhaust emissions. This study explores the efficacy of supplementing a four-stroke motorcycle engine with oxyhydrogen (HHO) gas, generated via a wet-cell electrolyzer, to enhance fuel efficiency. The primary focus is to evaluate the influence of two distinct electrolyzer installation points, the air filter and the intake manifold, on the fuel mass flow rate across a range of engine speeds (1500, 2000, 2500, and 3000 rpm). Experimental results demonstrated consistent reductions in fuel consumption at all tested speeds, with savings ranging from 5.46% to 23.90%. The most substantial improvement, a 23.90% reduction, was achieved at 2000 rpm with the electrolyzer mounted on the intake manifold. These findings suggest that HHO enrichment promotes a more homogeneous air-fuel mixture and more complete combustion. The variation in performance based on installation location underscores the necessity of optimizing system integration to balance HHO yield against electrical input. This work provides empirical support for HHO supplementation as a viable auxiliary technology to improve the efficiency of small-scale internal combustion engines, potentially reducing both fuel costs and emissions. Further investigations into long-term engine effects, emission profiles, and electrolyzer design optimization are recommended to advance practical applications.

Keywords

HHO gas, Electrolyzer, Installation location, Fuel mass flow rate, Motorcycle

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Introduction

Indonesia's economic expansion has been accompanied by a marked increase in personal mobility, predominantly through motorcycle adoption. For instance, registered motorcycles in West Sumatra Province rose from 1,979,526 in 2019 to 2,188,305 in 2021 [1]. This growth intensifies fuel consumption and exacerbates air pollution, as conventional gasoline engines emit carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) [2]. Moreover, the persistent reliance on finite fossil fuels accelerates resource depletion [3]. In response, alternative energy strategies are being actively pursued. One promising avenue is the enrichment of standard gasoline with oxyhydrogen (HHO) gas produced through water electrolysis. Prior research indicates that introducing HHO into the combustion process can enhance efficiency and lower emissions. For example, Vu et al. [4] reported improved combustion in motorcycle engines with HHO supplementation. Mahmood et al. [5] further highlighted hydrogen's role in sustainable transport through techno-economic analyses of renewable-powered electrolysis. Collectively, these studies position hydrogen-based solutions as both an immediate performance enhancer for existing engines and a long-term component of decarbonized transport.

Recent applications in vehicles show tangible benefits. Wahyudi et al. [6] observed significant drops in fuel consumption and emissions for a modified injection motorcycle fitted with a mini-electrolyzer. Devrim and Öztürk [7] confirmed the techno-economic feasibility of such integrated systems, though noting the added electrical energy demands [8]. Subsequent studies have expanded the scope, examining emission reductions in two-stroke engines [9], performance gains in larger SI engines [10], comprehensive assessments of hydrogen fuel [11], and optimized HHO generator designs [12]. Motorcycle-specific applications, including compact HHO devices [13] and systems utilizing regenerative braking [14], along with research on electrode and electrolyte optimization [15, 16], have further enriched the field.

Recent scholarly investigations have substantiated the potential of HHO supplementation across diverse propulsion systems. Research specifically targeting optimal deployment configurations for modest-displacement motorcycle powerplants, however, remains comparatively scarce. Contemporary motorcycle-centric studies have examined condensed electrolyzer implementations [13] and documented performance enhancements [6], while emerging scholarship underscores the criticality of injection methodology in combustion process refinement [21]. A comprehensive review of recent advancements in hydrogen-enriched combustion further emphasizes the need for precise system integration [24]. A conspicuous void exists, nevertheless, in the systematic juxtaposition of distinct installation loci, specifically the air filter housing versus the intake manifold, under regimented operational parameters within recent academic discourse. This gap necessitates a focused empirical inquiry to elucidate the optimal configuration for efficiency gains in small-scale engine applications.

Addressing these gaps, this study experimentally investigates the impact of a wet-cell electrolyzer on the fuel consumption of a four-stroke motorcycle. It specifically evaluates how installing the electrolyzer at two different locations—the air filter and the intake manifold—affects the fuel mass flow rate across multiple engine speeds. The objective is to quantify the potential fuel savings and determine the most effective installation strategy for enhancing efficiency in small-engine applications.

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 electrolyzer placement on fuel consumption (mass flow rate).

Testing was performed under several steady-state engine conditions: idle, 1500, 2000, 2500, and 3000 rpm. The electrolyzer 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 respectively. Research experimental design and specifications shows in Table 1 and Table 2.

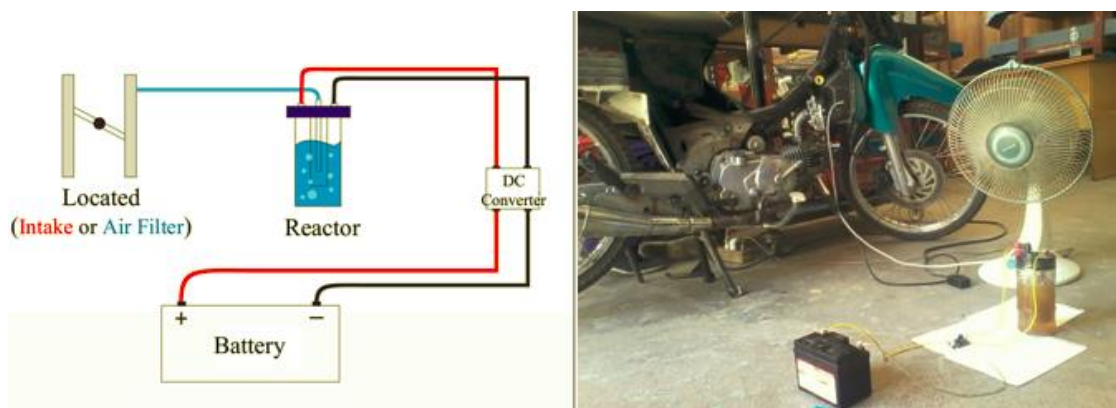


Figure 1. Schematic of the electrolyzer installation on the intake of motorcycle used in the experiment

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

The fuel mass flow rate (M_f) was calculated using Equation (1):

$$M_f = \frac{V}{\Delta t} \cdot \rho_{\text{fuel}} \cdot \frac{3600}{1000} \text{ (kg/h)} \quad (1)$$

Where:

M_f	= Fuel mass flow rate (kg/h)
V	= Volume (ml)
Δt	= Duration (s)
ρ_{fuel}	= Fuel density (0.7329 gr/ml)
$\frac{3600}{1000}$	= Conversion number

Result and discussion

The fuel consumption results under baseline conditions and with the electrolyzer installed at two locations are summarized in Tables 3, 4, and 5. As expected, baseline fuel consumption increased with engine speed, with 10 ml of fuel consumed in 108.18 s at 1500 rpm, decreasing to 58.08 s at 3000 rpm.

Table 3. Fuel consumption test results (baseline, no electrolyzer)

Without Electrolyzer							
No.	Engine Revolutions (RPM)	Volume of Fuel (ml)	Timing Test (s)				Average fuel consumption (ml/s)
			I	II	III	Average	
1	1500	10	108.25	108.00	108.30	108.18	0.0924
2	2000	10	88.14	89.05	88.5	88.56	0.1129
3	2500	10	70.32	71.00	70.85	70.72	0.1414
4	3000	10	57.99	58.00	58.25	58.08	0.1722

Table 4. Fuel consumption with electrolyzer at air filter

With Electrolyzer Installed on Air Filter							
No.	Engine Revolutions (RPM)	Volume of Fuel (ml)	Timing Test (s)				Average fuel consumption (ml/s)
			I	II	III	Average	
1	1500	10	129.15	129.55	129.50	129.40	0.0773
2	2000	10	107.25	107.00	107.15	107.13	0.0933
3	2500	10	80.55	80.20	80.15	80.30	0.1245
4	3000	10	61.23	61.74	61.33	61.43	0.1628

Table 5. Fuel consumption with electrolyzer at intake manifold

With Electrolyzer Installed on Intake Manifold							
No.	Engine Revolutions (RPM)	Volume of Fuel (ml)	Timing Test (s)				Average fuel consumption (ml/s)
			I	II	III	Average	
1	1500	10	139.05	139.35	139.30	139.23	0.0718
2	2000	10	116.85	116.28	116.00	116.38	0.0859
3	2500	10	83.43	83.45	83.55	83.48	0.1198
4	3000	10	62.95	62.90	63.55	63.13	0.1584

The corresponding fuel mass flow rates are consolidated in Table 6 and Figure 2. A clear reduction in flow rate is observed when the electrolyzer is active, with the intake manifold installation consistently yielding the lowest consumption.

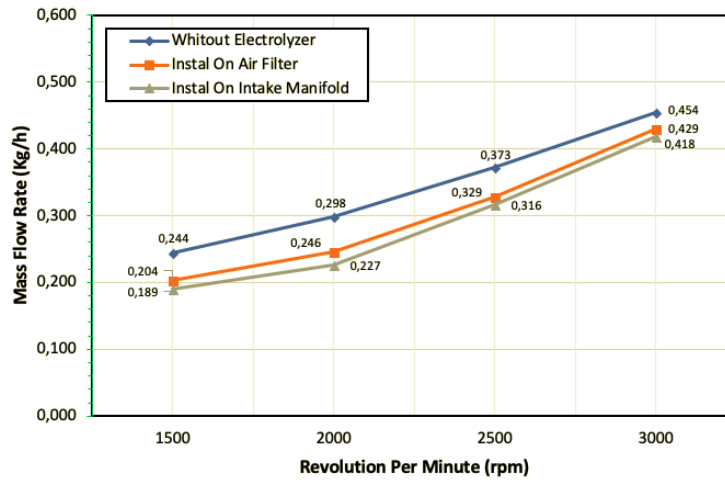


Figure 2. Chart of mass flow rate

The percentage reduction in fuel consumption, calculated from the mass flow rates, is presented in Table 7. The results show that HHO supplementation effectively lowers fuel use across all speeds. The most significant saving of 23.90% was recorded at 2000 rpm with the electrolyzer on the intake manifold. On average, installation at the air filter reduced consumption by 12.78%, while the intake manifold location achieved a 17.37% reduction.

Table 6. Mass flow rate of engine at various RPM with and without electrolyzer

RPM	Mass Flow Rate (Kg/h)		
	Without Electrolyzer	With Electrolyzer	
		Instal on Air Filter	Instal on Intake Manifold
1500	0.244	0.204	0.189
2000	0.298	0.246	0.227
2500	0.373	0.329	0.316
3000	0.454	0.429	0.418

Table 7. Percentage reduction in fuel consumption with electrolyzer

RPM	Percentage Reduction in Fuel Consumption	
	Instal on Air Filter	Instal on Intake Manifold
1500	16.40%	22.30%
2000	17.33%	23.90%
2500	11.93%	15.28%
3000	5.46%	8.00%
Mean	12.78%	17.37%

The observed improvements can be attributed to the properties of HHO gas. Its introduction into the intake charge likely creates a more homogeneous and reactive air-fuel mixture. Hydrogen’s high flame speed and wide flammability range promote more complete oxidation of the gasoline, reducing unburned hydrocarbons and improving thermal efficiency [11]. The superior performance of the intake manifold location suggests that introducing HHO closer to the combustion chamber minimizes losses and allows for better mixing, compared to the air filter location where the gas may have more time to disperse or interact with components in the airbox. The demonstrably superior efficacy associated with the intake manifold mounting configuration intimates that introducing HHO in closer proximity to the combustion chamber reduces transit

duration within the intake tract. This minimization of residence time likely mitigates potential charge dilution effects and fosters more immediate homogenization with the primary air-fuel mixture. This empirical observation finds congruence with recent experimental findings that emphasize the pivotal influence of injection proximity in optimizing the combustion-enhancing attributes of hydrogen supplementation [21] and aligns with documented combustion characteristic improvements from HHO addition in other engine platforms [25]. The comparative advantage over the air filter location—where premature homogenization and potential interfacial interactions with filtration media may transpire—accentuates the imperative of strategic installation site selection for maximizing system efficacy.

The magnitude of savings, particularly the peak 23.90% reduction, exceeds the 14–18% range often cited in earlier studies [7]. This may be due to the specific integration parameters and the controlled experimental conditions of this work, highlighting the importance of system optimization. The diminishing relative savings at higher engine speeds (3000 rpm) could indicate a limit where the energy demand of the electrolyzer or the volumetric displacement of HHO becomes less significant relative to the high primary fuel flow rate. This attenuation of relative savings at elevated engine speeds may signify a systemic constraint wherein the fixed HHO production rate becomes proportionally less consequential against the substantially amplified primary fuel requisition. This observed trend resonates with contemporary analytical treatments of auxiliary fuel systems, which delineate the inherent challenge of sustaining efficiency gains across broad operational spectra [22]. The necessity to balance HHO yield with system parasitics underscores the importance of holistic optimization, a principle echoed in recent studies focusing on parameter optimization for automotive HHO applications [23].

These findings align with and extend previous research. They corroborate studies reporting emission benefits from HHO in two-stroke [9] and SI engines [10], and support motorcycle-specific applications demonstrating efficiency gains [13, 14]. The location-contingent performance variations documented in this study contribute novel empirical data to ongoing scholarly dialogues concerning optimal HHO integration methodologies, as highlighted in recent comprehensive reviews [24]. This investigation furnishes timely experimental substantiation that complements recent scholarly inquiries into wet-cell electrolyzer architectures [16] and electrode material optimization [15], collectively propelling the practical deployment of HHO technology for small-scale propulsion applications.

Conclusion

This experimental study confirms that integrating a wet-cell HHO electrolyzer into a four-stroke motorcycle engine significantly reduces fuel consumption. Testing across 1500–3000 rpm demonstrated reductions from 5.46% to 23.90%, with the highest efficiency gain of 23.90% achieved at 2000 rpm when the electrolyzer was installed

directly on the intake manifold. The consistent savings are attributed to HHO gas improving combustion homogeneity and completeness. The results underscore that the installation location is a critical factor for optimizing system performance, with the intake manifold proving more effective than the air filter. This work substantiates the potential of HHO supplementation as a viable auxiliary technology for improving fuel efficiency in small-scale internal combustion engines, contributing to reduced fossil fuel use and lower emissions.

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