

ADDITION OF OXYHYDROGEN FUEL TO REDUCE HYDROCARBON EMISSIONS AND IMPROVE GASOLINE ENGINE PERFORMANCE**M. Paloboran**¹

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¹ Universitas Negeri Makassar, Makassar, Indonesia² Mulawarman University, East Borneo, Indonesia**Abstract**

The threat of global warming is very real before our eyes due to the increasing production of carbon emissions from the use of fossil fuels. Therefore, the use of fossil fuels, especially in the transportation sector, must be stopped immediately and replaced with alternative fuels that are more environmentally friendly. This research aims to apply oxyhydrogen fuel to motorcycles used daily to improve engine performance and reduce hydrocarbon gas emissions in the atmosphere. The test engine used is a 150 cc single-cylinder spark ignition engine. The engine speed varied from 4000 to 8000 rpm, while other parameters were left at standard conditions. The results of engine testing with the addition of oxyhydrogen fuel will be compared with the combustion of gasoline fuel. The results show that all engine performance parameters, including torque, power, and thermal efficiency, increased by an average of 7.65 %. However, the specific fuel consumption decreased by 38.5 kg/(kW · h). Furthermore, combustion emissions, including CO, HC, and CO₂, decreased by an average of 29 %, with the main contributor being a reduction in HC emissions of 45 %. The tool in this research is adaptable and acceptable for application to existing motorcycles, in addition to its small dimensions, good performance, and relatively cheap in manufacturing

Keywords

Oxyhydrogen fuel, HHO generator, dry cell, engine performance, water electrolysis, brown's gas

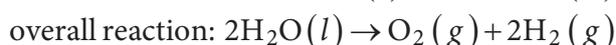
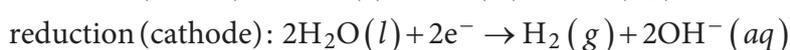
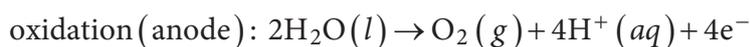
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Introduction. The primary reason for the growing restrictions on the use of fossil energy, particularly in the transportation sector, is the environmental damage caused by the increasing Earth's temperature [1]. In light of this, alternative energy sources for motorized vehicles, such as biofuels, electric fuel, and hydrogen fuel, are being increasingly utilized [2]. Although electric fuels have zero emissions and have become more popular due to advancements in battery technology over the past decade [3], they have not been widely adopted on a large scale in developing countries, even in developed countries, let alone in poorer nations. This is due to the relatively high cost of EVs, the lack of charging infrastructure, and concerns about their performance [4]. As a result, conventional fuels will likely continue to be the primary energy source for vehicles until stricter regulations are imposed on their use [5]. Various methods can be employed on engine motorcycles to reduce hydrocarbon emissions from burning fossil fuels, including adding fuel additives and utilizing synthetic materials and biofuels.

Oxyhydrogen gas utilization in combination with gasoline or diesel fuel is a widely implemented method in existing vehicles. That is due to its relatively inexpensive cost, straightforward construction, easily accessible materials, cost-effective maintenance process, and high energy content [6, 7]. Hydrogen gas is obtained from both renewable and non-renewable sources. However, since 2020, the majority of hydrogen gas (96 %) has been produced from fossil materials, primarily through the steam reforming process of natural gas (49 %), partial oxidation of hydrocarbons (29 %), and coal gasification (18 %). The remaining 4 % is produced through the water electrolysis process [8]. Hydrogen gas was classified into five distinct types based on its color, raw material source, and processing technology. These five types include brown hydrogen, black hydrogen, grey hydrogen, blue hydrogen, and green hydrogen, which are obtained from various raw materials and processed using different technologies, such as brown coal gasification, black coal gasification, natural gas reforming, natural gas reforming with carbon capture, and water electrolysis [9]. Water electrolysis to produce hydrogen gas is accomplished by direct current (DC) flow through a battery into an HHO generator circuit consisting of water and several metal plates acting as the anode and cathode, according to the reaction in equation below [10]:



The hydrogen production in an HHO generator was contingent upon several factors, including the design, voltage, current, the type and material of

the electrodes, and the catalyst utilized [11–13]. Among the types of HHO generators available, the dry-cell variant is the most commonly employed in motorized vehicles today. This is because some of the performance of dry-cells such as energy consumption, energy loss, and construction and maintenance costs are much lower than wet-cells [14].

Many studies have demonstrated the validity of the findings presented in Table 1, including research conducted by El Soly *et al.* [11]. These studies show that wet cells produce a higher volume of HHO gas, exhibit significant heat loss, cause electrodes to corrode rapidly, and require more space than dry cells. Moreover, research suggests that wet cells can reduce brake-specific fuel consumption (BSFC) more effectively than dry cells in diesel oil-fueled engines. Additionally, wet cells deliver better output power and thermal efficiency than dry cells on the same machine [15].

Table 1

Test fuel properties

Properties	Gasoline	Hydrogen
RON	92	130
Low heating value, MJ/kg	44.791	110.9
AFR stoichiometric	14.7	34.2
Density ($\text{kg}\cdot\text{m}^{-3}$ at 20 °C)	715–770	0.083
Flame speed, ms^{-1}	0.5	1.9

Literature review. The addition of hydrogen gas to internal combustion engines has been practiced for several decades and is currently the focus of research aimed at improving engine efficiency and reliability. Research about the use of HHO gas in diesel engines over the past decade is much more than in gasoline engines. This is because blending HHO gas with diesel engines results in higher combustion efficiency than gasoline engines [16, 17]. Employed HHO gas in biodiesel and diesel-fuelled engines will improve the combustion process, and reduce unburned hydrocarbon, resulting in decreased HC and CO emissions [18, 19]. Additionally, the addition of HHO gas to a diesel engine can compensate for power and torque losses associated with the use of microalgae biodiesel (MB20) or low-sulphur diesel fuel (LSD) while also increasing the engine's thermal efficiency [20–22].

Previous research has demonstrated that a mix of diesel fuel, B20, K5 (kerosene 5 %), and HHO can enhance the brake thermal efficiency (BTE) by 16.4 % and decrease the brake-specific fuel consumption (BSFC) by 25.4 % compared to the conventional B0 fuel. These improvements continue even when

the percentage of kerosene increases to 10 %, resulting in a 17 % increase in BTE and a 26.2 % decrease in BSFC [23]. The result of the research is similar when using a combination of biodiesel, ethanol (bio-diesel), and HHO gas [24]. HHO gas addition also increases peak pressure, BMEP, and BTE, while BSFC is reduced by 5 % when utilizing diesel as the fuel for homogeneous charge compression ignition (HCCI) engines [25]. This outcome was also reported by Al-Dawody *et al.* [26], who found that a diesel engine's shaft power increased by 9 and 16 % at 1500 rpm and 3500 rpm, respectively, when using this mixture. Furthermore, using HHO gas as an additive in diesel and biodiesel engines also causes vibration and noise decrease [27]. HHO gas is commonly applied in compression ignition dual-fuel engines as an additive fuel and results in high engine performance and low hydrocarbon emissions compared to diesel oil or biodiesel fuel [28–31].

The addition of HHO gas was carried out in petrol engines, both for two and four strokes. Kamarudin *et al.* [32] showed that added HHO gas by 0.05 % reduces fuel consumption, CO, and NO_x emissions of 2-stroke petrol engines by 3.23, 3.59, and 1.34 %, respectively. The same phenomenon occurs when HHO gas is used in a 4-cylinder MPI petrol engine, which reduces NO_x, CO, and HC emissions and fuel consumption by 15, 18, 14, and 34 %, respectively, compared to gasoline fuel [33–34]. A few studies have used HHO gas in petrol engines, especially for small-capacity 4-stroke petrol engines, from 100 to 150 cc. Therefore, this research was presented to fill this gap and examine the extent of engine performance improvement with the addition of HHO gas. Moreover, it could be directly used for existing motorcycles in Indonesia.

Methods and experiment set-up. The type of gasoline fuel used in this study is C₈H₁₅, in Indonesia it is called Pertamina, RON 92, and its calorific value (LHV) is 44.8 MJ/kg. The characteristics of gasoline and hydrogen fuels are thoroughly outlined in Table 1. Meanwhile, the engine test is a 4-stroke, 1-cylinder, spark ignition engine with a 9.2:1 compression ratio, and the fuel system is a carburetor. The specifications of the test engine used in the research are presented in Table 2. This research compares the engine performance with gasoline fuel and gasoline + HHO under the same test conditions. The type of HHO generator used was the dry cell, with the specifications in Table 3.

The test engine was run at 4000–8000 rpm (increment of 500 rpm) with a dyno test load, and gasoline fuel consumption time was recorded per 20 mL. The supply of the HHO gas into the engine flows at a constant current and voltage of 3.6 A and 12 V, respectively. The trial was repeated at least three times after the steady condition was achieved for each engine rpm.

Table 2

Test engine specification

Engine type	Single cylinder, 4-stroke, SOCH
Compression ratio	9.2:1
Displacement, cc	108
Fuel system	Carburetor
Power maximum, kW	6.05 / (8000 rpm)
Torque maximum, Nm	8.4 (6000 rpm)
HHO supply	Venturi
Spark system	Spark plug / DC-CDI

Table 3

HHO generator specification

Body of generator	Acrylic
Electrode material	Fe
Size (width × length × thickness), mm	70×70×0.5
Number of electrodes	9 (2 anodes, 2 cathodes, 5 neutral)
Type of isolator	Rubber
Voltage supply, V	12
Current supply, A	3,6
Volume of water, ml	350
Type of catalyst	Potassium hydroxide KOH
Catalyst concentration, %	4,5
Mass of generator, kg:	
full	1.3
empty	0.925

Results and discussions. The effect of adding HHO gas to gasoline fuel on engine torque and power is shown in Fig. 1, *a, b*. This figure shows that engine torque will increase with increasing engine speed, but will continue to decrease if it has passed a speed of 4500 rpm, both for gasoline or gasoline + HHO fuel. There was an increase in engine torque using gasoline fuel + HHO was an average of 6.35 % compared to gasoline fuel. Meanwhile, the average increase in power for engines fueled by gasoline + HHO is 7.06 % compared to gasoline fuel. Both show a trend that continues to increase as engine speed increases.

The maximum engine torque with gasoline fuel is 10.30 Nm, while 10.42 will be obtained when gasoline + HHO is applied (increase by 1.17 %) and it was reached at an engine speed of 4500 rpm. Therefore, the maximum brake

power is 4.92 kW and will increase to 5.09 kW at 6500 rpm when the fuel changes from gasoline to gasoline + HHO gas (increase by 3.46 %). This result advanced compared to Ummi Kultsum's research [35] which produces torque and brake power only by 0.7, and 1.38 %, respectively, even though the research employed varying battery voltages of 15, 25, and 30 V.

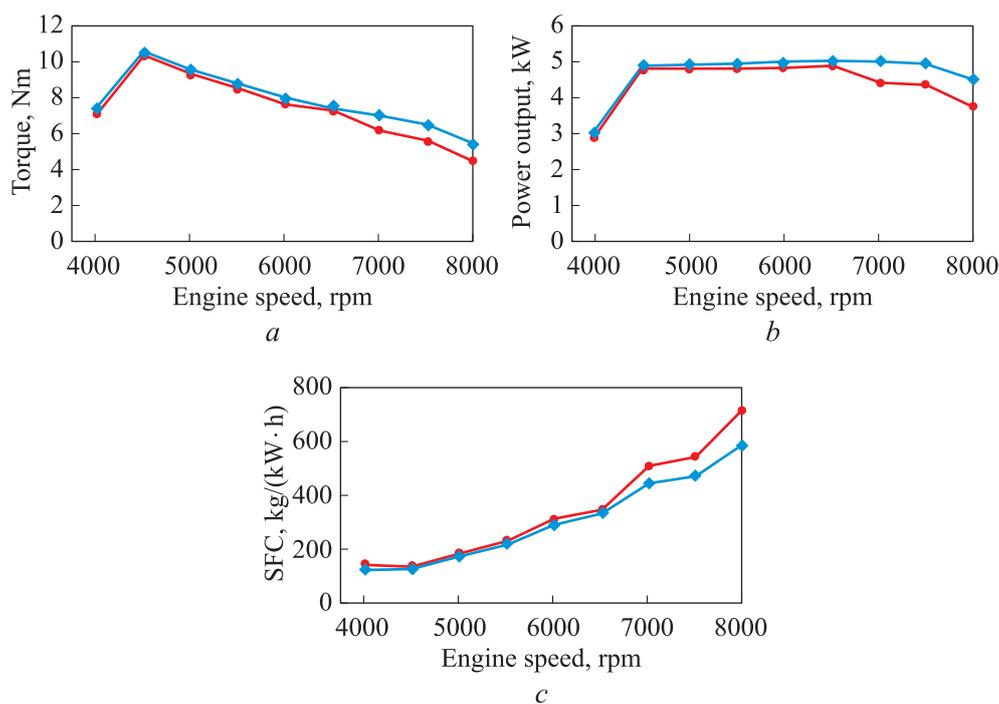


Fig. 1. Influence of HHO gas addition on engine torque (a), brake power (b), SFC of engine (c) (gasoline (•), gasoline + HHO (♦))

Meanwhile, the research by Ali Hussain Kazim [16] shows that the torque and brake power increase with an increase in the flow rate of diesel + HHO gas compared to diesel fuel. The brake power increases by 12 % when the rate of HHO on 6 standard cubic feet per hour (SCFH), and continues to increase by 22.4 % for 10 SCFH. The increase in brake power is relatively similar to an increase in engine torque. This research used potassium hydroxide as an electrolyte with 24 electrodes, $165 \times 165 \times 10$ mm in size, and the supply current is 60 A at 35 V.

The effect of adding HHO to small-capacity gasoline engines on engine-specific fuel consumption is shown in Fig. 1, c. This figure also shows the tendency for SFC to increase with increasing engine speed, both for gasoline and gasoline + HHO. Meanwhile, there was a significant decrease in specific fuel consumption from an average of 343.8 kg/(kW·h) to 305.3 kg/(kW·h) or an

average of 11.20 % from gasoline to gasoline + HHO. It indicates that the addition of HHO gas will improve the combustion process, thereby reducing the engine SFC. It is due to H₂ and O₂ gases directly interacting with the heat of combustion and does not require energy to break down the atoms. Meanwhile, gasoline fuel that consists of thousands of hydrocarbon molecules still requires heat to separate the bonds of its atoms [33].

Figure 1, *c* also shows that the decrease in SFC with HHO will continue as increase engine speed. It is due to an increase in engine temperature causes the fuel supply to the combustion chamber to decrease because the cylinder pressure increases, so the flow of gasoline in the combustion chamber decreases. Therefore, the combustion chamber is predominantly filled by HHO which is more easily atomized than gasoline. This has been proven by Shahid Farooq's research [36] which used CNG fuel and HHO as an additive fuel. The results show that using CNG + HHO fuel can reduce SFC compared to using only gasoline, CNG, or gasoline + HHO fuel. The results of this study are almost similar to Thin Quynh's research [37], where the addition of HHO can reduce BSFC on average by 13.7 % compared to using pure diesel alone. This research used stainless steel metal as the electrode and NaOH as the electrolyte, as well as the size of the HHO generator, was 140 × 140 × 1 mm (width-length-thickness).

The findings related to the influence of HHO gas on CO and HC emissions are illustrated in Fig. 2. In most cases, HC emissions experienced a slight rise as engine speed increased, while CO emissions exhibited a substantial increase as engine rpm rose for both types of fuel. The outcomes of this research indicate that the average HC emissions for gasoline fuel were 175.6 ppm, whereas those for gasoline + HHO fuel amounted to 98.1 ppm, reflecting a decrease of 44.15 %. The results reported in this study are consistent with those of Muhammad Usman *et al.* [38], who found that the use of LPG + HHO fuel led to an average reduction of 44.9 % in HC emissions compared to using gasoline alone. This indicates that adding oxyhydrogen to the combustion chamber can increase the homogeneous mixture and cylinder temperature, resulting in improved combustion and reduced unburnt hydrocarbons.

While carbon monoxide (CO) emissions result from the high viscosity of the air and fuel mixture, which makes it difficult to atomize and decrease the homogeneous mixture, it is challenging for hydrocarbon compounds to bind oxygen atoms [39, 40]. The study revealed that adding hydrogen gas (HHO) to gasoline fuel led to a 24.45 % reduction in CO emissions, decreasing from 5.91 to 4.46 %. This finding is consistent with other studies, such as the research by Shajahan *et al.* [41], which achieved a 9.6, 11, 7.8, and 8.9 % reduc-

tion in CO emissions at loads of 1, 2, 3, and 4 kg, respectively, after adding HHO gas to gasoline fuel. Mohan *et al.* [42] reported a significant 56.34 % reduction in CO emissions when using a dry HHO generator on a 4-stroke, single-cylinder petrol engine with a displacement volume of 97.2 cc.

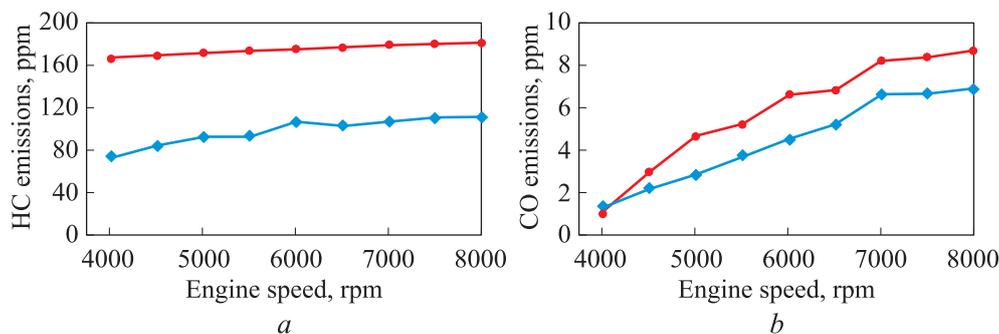
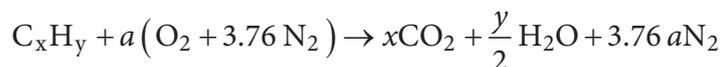
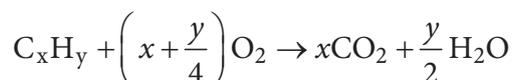


Fig. 2. Influence of HHO gas addition on HC (a) and CO (b) emission (gasoline (•), gasoline + HHO (♦))

The primary products of the stoichiometric combustion of fossil fuels in the presence of pure oxygen (O_2) are water vapor (H_2O) and carbon dioxide (CO_2), as demonstrated in equations below [43]:



In contrast, the combustion of fossil fuels using air as the oxidizer results in the production of nitrogen compounds.

Based on the law of mass conservation, the mass quantity of the reactants must be the same as the mass of the reaction products (products). Therefore, if the mass of carbon atoms in the reactant decreases, the combustion product in the form of CO_2 will also decrease. Adding HHO gas to gasoline fuel causes the mass of gasoline burned to decrease. This is because the HHO gas is easily atomized, so it is more flammable and reduces CO_2 emissions [43].

The effect of the induction of HHO gas into the combustion chamber of a gasoline engine on carbon dioxide emissions is shown in Fig. 3, a. The Figure shows that CO_2 emissions produced from gasoline fuel tend to be steady with an average value of 13.0 %, except that after passing 6000 rpm, it increases slightly. The highest CO_2 emissions with gasoline fuel are 14.43 % at 8000 rpm, and the lowest is 11.95 at 4000 rpm. Meanwhile, CO_2 emissions produced from

burning gasoline + HHO are consistently steady while the engine works with an average value of 10.93 %, where the maximum value is 11.25 % at 6000 rpm and the minimum is 10.40 % at 4000 rpm. Based on this data, there was a reduction in CO₂ emissions with the addition of HHO gas by 15.90 % on average.

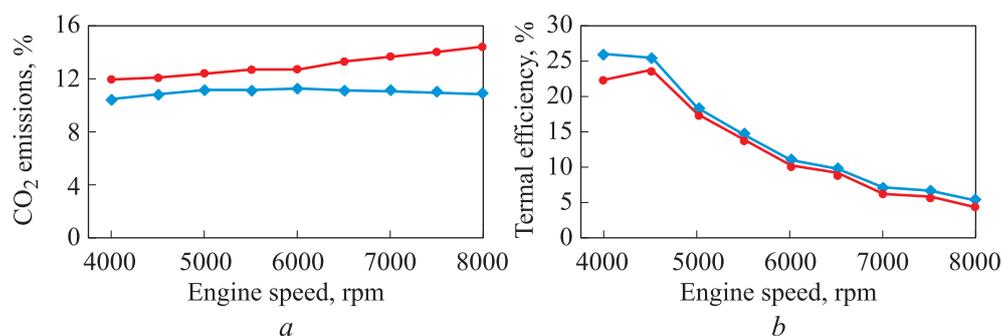


Fig. 3. Influence of HHO gas addition on CO₂ emission (gasoline (•), gasoline + HHO (♦))

A comparison between the thermal efficiency of a 108cc petrol engine fuelled by gasoline and gasoline + HHO is shown in Fig. 3, *b*. The figure described that adding HHO gas can increase the engine's thermal efficiency by an average of 9.55 % from 12.54 % to 13.74 %. The maximum thermal efficiency of gasoline fuel is 23.74 % at an engine speed of 4500 rpm, while gasoline + HHO is 26.04 % at an engine speed of 4000 rpm. The figure also confirms that the engine's thermal efficiency will continue to decrease if the engine speed exceeds 4000–4500 rpm for both fuels. In the HHO compound, hydrogen and oxygen are compounds that easily interact with gasoline compounds, so they are flammable. The combustion results will also produce higher energy than gasoline compounds, causing thermal efficiency to increase [44].

Conclusion. This research has been carried out to curb the production rate of hydrocarbon emissions by using green energy in the form of HHO gas as an additive in gasoline engines. The results of this research also revealed interesting facts about the use of HHO gas to improve engine performance and reduce combustion emissions. The construction of the HHO generator in this research is very flexible and adaptable to existing motorcycles because of its relatively small size, so it is easy to place in empty spaces on the vehicle or motorcycle. Besides that, the efficiency and effectiveness of the HHO generator in this research are very good for improving engine performance and reducing hydrocarbon emissions.

The addition of HHO gas to gasoline fuel can increase engine torque by an average of 6.35 % from 7.31 Nm to 7.78 Nm, while engine power increases

by an average of 7.06 % from 4.42 kW to 4.73 kW when compared to gasoline fuel. Mixing oxyhydrogen and gasoline fuel has an impact on reducing specific fuel consumption of engines by 11.20 %. The SFC of engines is 343.8 kg/kWh when gasoline is applied, while the SFC decreases to 305.3 kg/(kW·h) when the fuel is added with HHO.

This work found that HC and CO emissions decreased drastically by 45 and 25 % if HHO gas was applied to gasoline fuel. This result is better than other studies that used almost similar generator specifications, namely around 10–15 %. The addition of oxyhydrogen gas as a fuel additive to gasoline engines causes the carbon element in the fuel to be reduced. It has an impact on reducing CO₂ emissions on average by almost 16 %, from 13.0 to 10.93 %. This research resulted in an average increase in thermal efficiency of 9.55 % with the addition of HHO gas to gasoline fuel. It indicated that the heat loss when using gasoline + HHO gas fuel is lower than gasoline fuel.

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