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The Impact Of Introducing Brown Gas Into The Incoming Air Flow On The Performance Of An Internal Combustion Engine

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Abstract

The increase in the number of motorized vehicles has led to challenges in maintaining environmental air quality, combustion efficiency, and the sustainability of fossil fuels. An innovative solution to address these issues is the utilization of brown gas. This study aims to investigate the impact of introducing brown gas into the incoming air flow on the performance of an internal combustion engine. The brown gas flow rate varies based on the gas production rate resulting from variations in the addition of NaOH (10 g/l, 20 g/l, and 30 g/l) to every 1 liter of water in the generator. Gas production rates are measured using a flow meter. The influence of brown gas on gasoline engine performance is assessed through power testing with a chassis dyno test engine and exhaust emissions testing with a gas analyzer. The findings reveal that the highest flow rate of brown gas is achieved with the addition of 30 g/l NaOH during the electrolysis process. Introducing brown gas into the incoming air flow can increase maximum engine power by 15.5% and reduce CO exhaust emissions by 23.37%.

Keywords:

Brown gas, electrolysis, emission, performance, power.

1 Introduction

Motorized vehicles are considered one of the essential human needs today. According to available data, the number of motorized vehicles continues to rise annually. However, this increasing number of motorized vehicles brings about potential issues. There are three issues as discussion points concerning the sustainability of internal combustion engines. These problematic arguments include cleanliness of environmental air, combustion efficiency, and the availability of fossil fuels [1]. Some even argue that its issues can lead irraparable to public health and the environment [2]. So, this issues becomes a collective challenge for all countries to address [3].

This problematic argument is currently a serious concern for every vehicle manufacturer in an effort to maintain internal combustion engine existence amid the potential threat of competition from electric and hybrid cars. One of the product standards that continues to be the concern of researchers to produce an internal combustion engine as clean as possible, has high combustion efficiency and is economical in fuel use. One approach is to introduce brown gas or HHO (Hydrogen Hydrogen Oxygen) into the incoming air oxygen stream. Brown gas itself is a mixture of hydrogen and oxygen gases which produced through electrolysis techniques with water as raw material [4][5]. This gas has received attention because of its potential becoming a cleaner alternative fuel [6]. While theoretically electrolysis is the process of decomposition of water into hydrogen and oxygen by passing direct electric current [7].

There are various research that have revealed the benefits of using brown gas in overcoming problems of air cleanliness or emissions, combustion efficiency and efficiency in the use of fossil fuels. Several studies concluded that brown gas which is added to the combustion of a four stroke gasoline engine was able to reduce CO gas emissions produced at various engine speeds [8][9]. In research with super small brown gas flow of 0.126 LPM, concluded that brown gas was also able to reduce CO gas emission levels by 98% in engine test conditions at speed [10].

The addition of brown gas to diesel engine combustion could also improve engine combustion. The heat of combustion becomes higher and the duration of the combustion process becomes shorter. Peak pressure generally in diesel engines occurs at 9° after Top Dead Point (TDC). Meanwhile, by the addition of 5% brown gas, peak pressure occurs at 7° after TDC [11]. These results were in accordance with the results of other studies which state that the addition of brown gas could increase the rate of heat release in the cylinder, increase combustion temperature, expanding the radius the fire core, increase flame peak surface density, and accelerate of flame propagation [12].

Furthermore, the performance results of diesel engines or compression engines without and with the addition of brown gas also have been studied. The specific fuel consumption value or is also known as the SFC (Specific Fuel Consumption) value decreased by 27% with the addition of brown gas [13]. The average decrease in SFC values with this treatment is 20-30% [14]. More specifically, the results of other studies state that in diesel engines with constant brown gas flow at 0.73 LPM, the SFC value decreases by 7% at speed and decreases by 16% at maximum engine speed [15].

Brown gas can be produced practically from dry cell and wet cell type generators. Dry cell type generators have many advantages, including being smaller in size and easy to apply to machines [16]. Dry cell type generators are also more cost efficient to manufacture and more effectively applied in machines [17]. Meanwhile, the wet cell type also has the advantage of producing more gas. When adding 5 g/l NaOH in the electrolysis process, the dry cell type only produces 866 ml/min gas, while the wet cell type can produce 975 ml/min gas [18].

Likewise the effect on engine performance, the dry cell type generator has a lower effect compared to the wet cell type. Ibrown gas in the range of 0.5-0.75 LPM, in the dry cell type was only able to reduce CO gas emissions by 15%. While the wet cell type could reduce CO levels up to 22% [19].

From several previous research, it is necessary to further investigate the application of wet cell brown gas in injection gasoline engines and their impact on engine peformance, especially in gasoline engine. Thus, the purpose of this research isto assess the influence of brown gas generated by the wet cell brown gas generator. The generator is manufactured with different NaOH catalyst mixtures. Additionally, the study aimed to investigate the effects of introducing brown gas into the incoming air flow on the performance of a gasoline engine, specifically focusing on power output and CO exhaust emissions.

2 Materials and Methods

This research employed an experimental method, utilizing brown gas generated through the electrolysis process in a wet cell generator. The produced brown gas was introduced into the intake air flow to assess its impact on the performance of the gasoline engine. The first step, researcher manufactured a wet cell brown gas of generator. The schematic arrangement of the components in the wet cell brown gas generator is illustrated in Fig. 1.

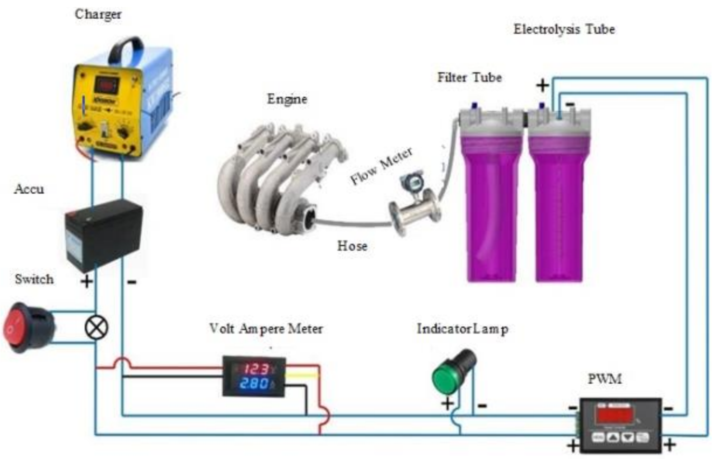

Fig. 1. The schematic components of the wet cell brown gas of generator.

In Fig. 1, the components of the wet cell brown gas generator include a charger, battery, switch, volt ammeter, indicator, Pulse Width Modulation (PWM), test tube, filter tube, flow meter, and hose. Within the test tube, electrodes made of stainless steel plates are present. Table 1 presents the specifications of the components used in the manufactured wet cell brown gas generator.

Table 1. The specifications of the manufactured wet cell brown gas generator

Name of part	Specification
Electrode	Material: stainless steel, thickness: 1 mm
Eectrolysis tube and filter tube	Capacity: 1.5 L and temperature max: 75°C
Nose	Pneumatic nose, diameter: 6 mm
Charger	DC output 12 V, A: 10 Ah
Accu	Voltage: 12 V, capacity: 5Ah
Connecting cable	Stranded cable 2-5 mm
Pulse Width Modulation (PWM)	Ampere value: 0-30 A , volt input: DC 6-60V
Flow meter	Range: 0-0.5 NL/min
Volt ampere meter	Digital, ampere range: 0-20A, volt range: 0-100V

Specifically for the electrodes, their structure follows the arrangement in the manufactured wet cell generator, as illustrated in Fig. 2.

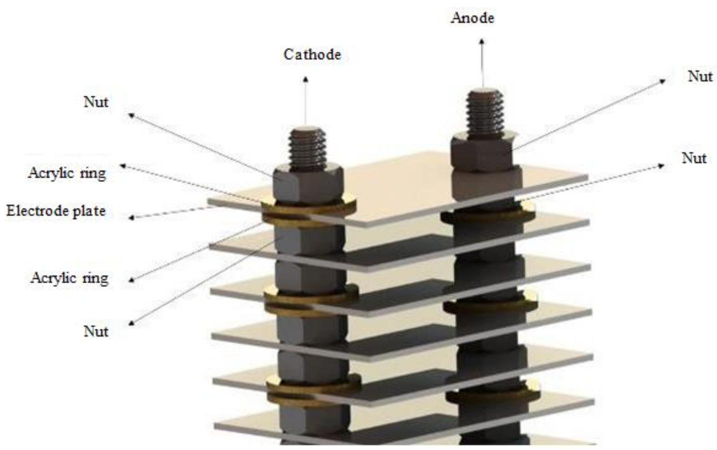

Fig. 2. The structure of the electrodes on the manufactured wet cell brown gas generator.

Fig. 2 illustrates the electrode on the left side (cathode) of 1 cell comprises nut-ring-plate-ring-nut, while the electrode on the right side (anode) consists of nut-plate-nut. These electrodes are constructed from stainless steel 316, chosen for its superior conductivity and corrosion resistance compared to alloy metals or other pure metals. Stainless steel is essentially an alloy of iron (Fe) with main alloying elements including carbon (C), nickel (Ni), and chromium (Cr). The dimensions of the electrode plate are set at 50 mm×35 mm, providing an area of 2,000 mm^2. The wet cell brown gas generator utilizes a total of 6 electrodes.

The second step involved testing the production of brown gas generated from the previously constructed generator. During this process, various electrolytic materials were used for the electrolysis process in the generator, with particular emphasis on the addition of a catalyst. Variations in the volume of brown gas from the generator were examined by adding different amounts of catalyst (NaOH) to the electrolytic material in each test tube. The catalyst amounts used were 10 grams (A10), 20 grams (A20), and 30 grams (A30) of NaOH per 1 liter of water. Electrolysis, a process involving the breakdown of chemical compounds into new molecules with the assistance of an electric current and two electrodes, was employed[20].

Electric current flows to the positive electrode (anode) and negative electrode (cathode). The electrolysis process can be accelerated with the assistance of electrolytes acting as catalysts. Several types of electrolytes, such as NaOH, KOH, and H_2SO_4, can be used as catalysts[21]. The amount of current and voltage settings in the generator is regulated by Pulse Width Modulation (PWM) which is set to remain at 20%.

The flow rate data of brown gas production from the generator is measured using a flow meter with a measuring range of 0-0.5 L/min. The flow meter operates based on the movement of a black ball, which moves up and down in response to the volume of gas passing through it. Theappearanceofmeasuringgas productionusingaflowmetershowninFig.3.

Fig. 3. The appearance of brown gas production in the flow mater.

The third step, the brown gas that has been produced is supplied into the intake air manifold of gasoline engine. The location of the gas supplied is in the air filter box hole. The process of mixing brown gas in the inlet air flow of 1300 cc gasoline engine from avanza 2006 is shown in Fig. 4.

After the gas is supplied, the impact of brown gas on the combustion process is assessed through engine performance tests, focusing on two aspects: engine power and exhaust emissions. Engine power data is measured using a roller chassis dynamometer, specifically the Mainline Dynolog Dynamometer. A chassis dynamometer, also known as a rolling road dynamometer, is a testing tool used to measure the engine's power output by testing the vehicle in its complete form [22].

Fig. 4. The process of introducing brown gas into the incoming air flow of gasoline engine.

The emission data is measured using an exhaust emission test equipment equipped with a gas analyzer tool. The gas analyzer employed is the Heshbon brand, specifically the HG-520 type. Fig. 5 shows the process of collecting power and emission test data.

Fig. 5. The process of collecting power and emission test data.

3 Results and Discussion

The outcomes of brown gas production with different additions of NaOH to the electrolyte and PWM settings at 20% are presented in Table 2.

Table 2. The production of brown gas flow rates was studied under variations in the addition of NaOH electrolyte

Code	Electrolyte type	Flow rate (L/min)
A10	Water 1 L and NaOH 0 gr	0.05
A20	Water 1 L and NaOH 5 gr	0.075
A30	Water 1 L and NaOH 10 gr	0.15

According to Table 2, the addition of NaOH has a noticeable impact on the production rate of brown gas. The highest average volume of brown gas production in L/min is observed when using water electrolyte (H_2O) with the addition of 30 grams of NaOH per 1 liter of water. The observed increase in brown gas production with the addition of NaOH aligns with the theoretical expectation, as NaOH serves as a catalyst[21].The impact of introducing brown gas into the incoming air flow of a 1300 cc gasoline engine from the 2006 Avanza to engine power is shown in Fig. 6. While the result of the impact of introducing brown gas to CO exhaust emission gas of 1300cc gasoline engine from avanza 2006 is shown in Fig. 7.

3.1 Discussion about of the Impact of Introducing Brown Gas in to Engine Power Peformace of Engine

Fig. 6 show the power of a 1300 cc gasoline engine rises with an increase in engine speed. This value reaches a peak point before gradually decreasing. The introduction of the brown gas mixture has a noticeable impact on engine power, as evidenced by the increase in power with the addition of brown gas. The findings of this research align with several studies asserting that brown gas has the potential to enhance engine power[23].

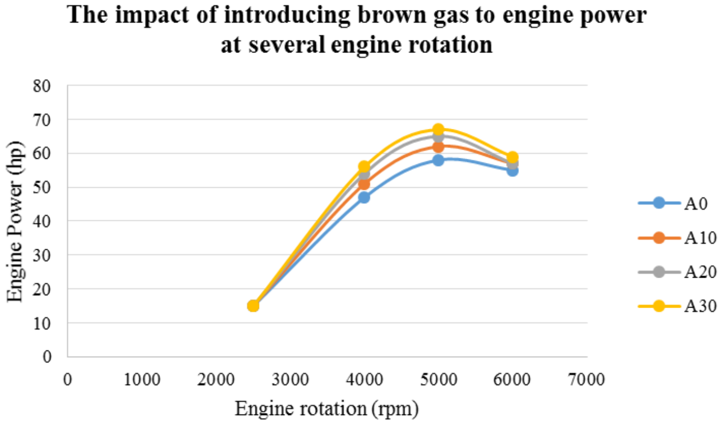

Fig. 6. Graph of power test results for a 1300 cc gasoline engine with various research scenarios.

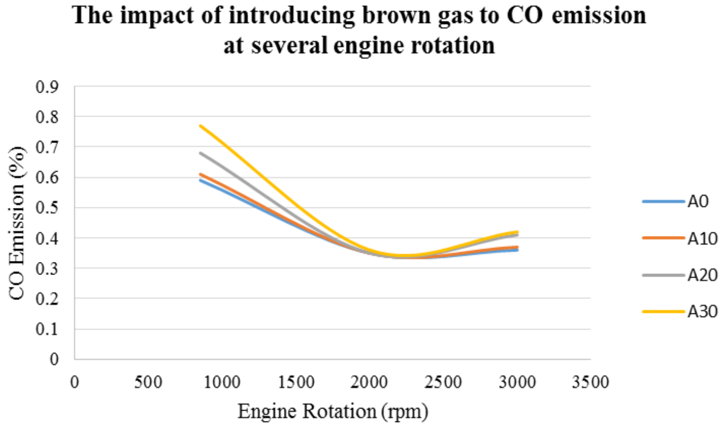

Fig. 7. Graph of CO emission test results for a 1300 cc gasoline engine with various research scenarios.

In the test without treatment, the maximum engine power is 58 hp. Meanwhile, with the addition of brown gas in both the A10, A20 and A30 tests, the maximum power was 62 hp, 65 hp and 67 hp respectively. The increasing of maximum power is 15.5% in the A30 treatment. The increasingof engine power is strongly suspected due to the addition of brown gas, becausehidrogen that contained in the brown gas is very flammable gas [22]. Logically, the air that enters the combustion chamber is not only oxygen but also hydrogen. So, the combustion results are better.

One of the characteristics of hydrogen gas at brown gas levels is is flammable at a low concentration of 4% in free air. Hydrogen can be burned by the chemical reaction (Eq. 1). Characteristics of hydrogen gas is shown in Table 3 [22].

$$2H_{2(g)} + O_{2(g)} \rightarrow 2\ H_2O_{\ (l)} + 572\ kJ\ (286\ kJ/mol) \quad (1)$$

Table 3. Characteristics of hydrogen gas

Variable	Value
Autoignition temperature (ºC)	858
Minimum ignition energy (mJ)	0.02
Flammability limits (volume % in air)	4-75
Stochiometris air fuel ratio on mass basis	34.3
Limits of flammability (equivalence ratio)	0.1-7.1
Net heating value (MJ/kg)	119.93
Flame velocity (cm/s)	265-325
Quenching gap in NTP air (cm)	0.064
Diffusity in air (cm^2/s)	0.63
Research octane number	130
Flash point	< -253ºC

Table 3 shows brown gas has the advantage that its octane number value reaches 130. This exceeds the octane number value of Pertalite (90) and Pertamax (92) which are traded in Indonesia.

Logically, this high octane number value can indirectly contribute to improving the quality of combustion procces.

3.2 Discussion about of the Impact of Introducing Brown Gas in to CO Emission

Exhaust gas emissions are a collection of toxic gases resulting from an incomplete combustion process. In a complete combustion reaction, hydrocarbon fuel with the chemical formula CnH_2n will react with free air (oxygen) and produce carbon dioxide gas (CO_2) and water vapor (H_2O). If combustion occurs incompletely, the chemical reaction will change as Eq. 2.

$$a\ C_nH_{2n+2} + b\ O_2 \rightarrow c\ CO_2 + d\ H_2O + e\ CO + f\ HC \qquad (2)$$

In an incomplete combustion reaction, the products of combustion are Carbon Monoxide (CO) and Hydrocarbons (HC). The gases will come out in the exhaust step. The process of expelling used gas from combustion from the cylinder occurs through the exhaust valve [24]. Fig. 7 is a graphical image of the emission test results for a 1300cc gasoline injection engine with the addition of brown gas flow.

Fig. 7 shows there is a reduction in CO emission levels with the addition of a brown gas mixture to the incoming air flow. The CO value with treatment in conditions A0, A10, A20 and A30 at each engine rotation is always below the CO value without treatment (A0 code). For example, at stationary rotation, the CO emission value is 0.77%, while each test result at A10, A20 and A30 is 0.68%; 0.61% and 0.59%. Thus, the maximum reduction in CO gas emissions reached 23.37% in treatment A30 and it can be stated that there was a reduction in CO gas emissions with the addition of brown gas to the incoming air flow. The results of this research are in line with the results of other studies which state that the addition of brown gas can produce better CO exhaust emissions (lower value) like the conclussion research from [25][26][27].

The CO value at rotation below 1000 rpm is the highest value. This is in line with the theory which states CO gas is produced because the system lacks oxygen [28]. During this rotation, not much air or oxygen enters, because the throttle valve is closed and the engine tends to have a richer mixture. This can be confirmed from research data which shows thespeeds below 1000 rpm, the value of λ is 1.025. While at 2000 rpm, the value of λ is 1.082 and at 3000 rpm, the value of λ is 1.034. This λ value also confirms the value of CO gas is greater at 3000 rpm rotation than at 2000 rpm rotation. In brief, the lowest CO gas emissions can be obtained at 2000 rpm rotation (medium rotation).

Based on the results and discussion that has been described, this study has limitations including:

a. Engine performance is only limited to the power value and CO gas emissions only.
b. The PWM setting value on the brown gas generator is set to remain at 20% so that the current and voltage values are constant at 5A and 9V respectively.
c. The sum of electrodes on the brown gas generator is only 6 pcs.

4 Conclusion

Based on the results and discussion, it can be concluded as follows.The highest wet cell type brown gas production rate is produced by adding 30 grams of NaOH, namely 0.15 L/min. The Procces of mixing brown gas in the inlet air flow is able to increase power and reduce CO gas emission levels in a 1300 cc gasoline injection engine. Mixing wet cell type brown gas with a PWM setting of 20% and the number of electrodes is 6, is able to increase maximum engine power by 15.5% and reduces the maximum CO exhaust emissions by 23.37%.

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References

[1] J. R. Serrano, R. Novella, and P. Piqueras, "Why the development of internal combustion engines is still necessary to fight against global climate change from the perspective of transportation," *Appl. Sci.*, vol. 9, no. 21, 2019, doi: 10.3390/app9214597.

[2] M. Sabeghi, M. Moghiman, and D. Gandomzadeh, "Experimental study of the effect of HHO gas injection on pollutants produced by a diesel engine at idle speed," *Int. J. Hydrogen Energy*, vol. 48, no. 24, pp. 9117–9126, 2023, doi: https://doi.org/10.1016/j.ijhydene.2022.12.010.

[3] X. Gu, M. Cheng, X. Zhang, and Y. Zeng, "The pollutant discharge improvement by introducing HHO gas into biomass boiler," *Int. J. Hydrogen Energy*, vol. 46, no. 45, pp. 23292–23300, 2021, doi: https://doi.org/10.1016/j.ijhydene.2021.04.133.

[4] S. Bhardwaj, A. Singh Verma, and S. K. Sharma, "Effect Of Brown Gas On The Performance Of A Four Stroke Gasoline Engine," *Int. J. Emerg. Technol. Adv. Eng.*, vol. 4, no. 1, pp. 300–308, 2014, [Online]. Available: www.ijetae.com

[5] N. Alam and K. M. Pandey, "Experimental Study of Hydroxy Gas (HHO) Production with Variation in Current, Voltage and Electrolyte Concentration," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 225, no. 1, 2017, doi: 10.1088/1757-899X/225/1/012197.

[6] A. B. Vethamony and V. Thangavel, "Experiments on the effect of temperature on HHO production by Alkaline water electrolysis," *Mater. Today Proc.*, 2023, doi: https://doi.org/10.1016/j.matpr.2023.03.771.

[7] B. Subramanian and V. Thangavel, "Analysis of onsite HHO gas generation system," *Int. J. Hydrogen Energy*, vol. 45, no. 28, pp. 14218–14231, 2020, doi: https://doi.org/10.1016/j.ijhydene.2020.03.159.

[8] D. V. N. Lakshmi, T. R. Mishra, and R. D. S. S. Mohapatra, "Effects of Brown Gas Performance and Emission in a SI Engine," *Int. J. Sci. Eng. Res.*, vol. 4, no. 12, pp. 170–173, 2013.

[9] H. Harman and A. Ahyar, *Design of HHO Generator to Reduce Exhaust Gas Emissions and Fuel Consumption of Non-Injection Gasoline Engine*, vol. 4, no. 1. 2019. doi: 10.21831/dinamika.v4i1.24276.

[10] F. Salek, M. Zamen, S. V. Hosseini, and M. Babaie, "Novel hybrid system of pulsed HHO generator/TEG waste heat recovery for CO reduction of a gasoline engine," *Int. J. Hydrogen Energy*, vol. 45, no. 43, pp. 23576–23586, 2020, doi: 10.1016/j.ijhydene.2020.06.075.

[11] K. Ragupathy, "Modeling and analysis of diesel engine with addition of hydrogen-hydrogen-oxygen gas," *Therm. Sci.*, vol. 21, pp. 465–471, 2017, doi: 10.2298/TSCI17S2465R.

[12] S. Liu, L. Zhang, Z. Wang, L. Hua, and Q. Zhang, "Investigating the combustion stability of shale gas engines under HHO," *Fuel*, vol. 291, no. December 2020, 2021, doi: 10.1016/j.fuel.2020.120098.

[13] G. Abbas Gohar and H. Raza, "Comparative Analysis of Performance Characteristics of CI Engine with and without HHO Gas (Brown Gas)," *Adv. Automob. Eng.*, vol. 06, no. 04, 2017, doi: 10.4172/2167-7670.1000172.

[14] T. B. Arjun, K. P. Atul, A. P. Muraleedharan, P. A. Walton, P. B. Bijinraj, and A. A. Raj, "A review on analysis of HHO gas in IC engines," *Mater. Today Proc.*, vol. 11, pp. 1117–1129, 2019, doi: 10.1016/j.matpr.2018.12.046.

[15] S. Thangaraj and N. Govindan, "Investigating the pros and cons of browns gas and varying EGR on combustion, performance, and emission characteristics of diesel engine," *Environ. Sci. Pollut. Res.*, vol. 25, no. 1, pp. 422–435, 2018, doi: 10.1007/s11356-017-0369-4.

[16] T. M. Ismail, K. Ramzy, M. N. Abelwhab, B. E. Elnaghi, M. Abd El-Salam, and M. I. Ismail, "Performance of hybrid compression ignition engine using hydroxy (HHO) from dry cell," *Energy Convers. Manag.*, vol. 155, no. September 2017, pp. 287–300, 2018, doi: 10.1016/j.enconman.2017.10.076.

[17] M. A. El Kady, A. El Fatih Farrag, M. S. Gad, A. K. El Soly, and H. M. Abu Hashish, "Parametric study and experimental investigation of hydroxy (HHO) production using dry cell," *Fuel*, vol. 282, no. July, 2020, doi: 10.1016/j.fuel.2020.118825.

[18] A. K. El Soly, M. A. El Kady, A. E. F. Farrag, and M. S. Gad, "Comparative experimental investigation of oxyhydrogen (HHO) production rate using dry and wet cells," *Int. J. Hydrogen Energy*, vol. 46, no. 24, pp. 12639–12653, 2021, doi: 10.1016/j.ijhydene.2021.01.110.

[19] M. S. Gad and S. M. Abdel Razek, "Impact of HHO produced from dry and wet cell electrolyzers on diesel engine performance, emissions and combustion characteristics," *Int. J. Hydrogen Energy*, vol. 46, no. 43, pp. 22277–22291, 2021, doi: 10.1016/j.ijhydene.2021.04.077.

[20] R. Novriyandi, "Aplikasi Gas HHO pada Sepeda Motor 150 cc," 2016.

[21] Y. Wahyono, H. Sutanto, and E. Hidayanto, "Produksi gas hydrogen menggunakan metode elektrolisis dari elektrolit air dan air laut dengan penambahan katalis NaOH," *Youngster Phys. J.*, vol. 6, no. 4, pp. 353–359, 2017.

[22] A. C. Yilmaz, E. Uludamar, and K. Aydin, "Effect of hydroxy (HHO) gas addition on performance and exhaust emissions in compression ignition engines," *Int. J. Hydrogen Energy*, vol. 35, no. 20, pp. 11366–11372, 2010, doi: 10.1016/j.ijhydene.2010.07.040.

[23] B. Subramanian and S. Ismail, "Production and use of HHO gas in IC engines," *Int. J. Hydrogen Energy*, vol. 43, no. 14, pp. 7140–7154, 2018, doi: 10.1016/j.ijhydene.2018.02.120.

[24] T. Dentom, *Advance Automotive Fault Diagnosis 4th*. Oxford: Elsevier Butterworth-Heinemann, 2017.

[25] P. Jakliński and J. Czarnigowski, "An experimental investigation of the impact of added HHO gas on automotive emissions under idle conditions," *Int. J. Hydrogen Energy*, vol. 45, no. 23, pp. 13119–13128, 2020, doi: 10.1016/j.ijhydene.2020.02.225.

[26] J. Paparao and S. Murugan, "Dual-fuel diesel engine run with injected pilot biodiesel-diesel fuel blend with inducted oxy-hydrogen (HHO) gas," *Int. J. Hydrogen Energy*, vol. 47, no. 40, 2022, doi: https://doi.org/10.1016/j.ijhydene.2022.03.235.

[27] Z. Zhao, Y. Huang, X. Yu, and Guo, "Effect of brown gas (HHO) addition on combustion and emission in gasoline engine with exhaust gas recirculation (EGR) and gasoline direct injection," *J. Clean. Prod.*, vol. 360, 2022, doi: https://doi.org/10.1016/j.jclepro.2022.132078.

[28] Z. Arifin and Sukoco, *Pengendalian Polusi Kendaraan*. Bandung: Alfabeta, 2009.