A design and performance analysis of a hydrogen reactor as a co-combustion in the motor engine for reducing emission gas production by using halanaerobium hydrogeniformans water

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Abstract. A hydrogen reactor (HR) as co-combustion in a motor engine for reducing emission gas (EG) production has been successfully developed. The use of a motor engine in transportation does not only consume a lot of gasoline but also creates depletion in fossil fuel resources which subsequently increases the EG production. The increase of EG caused the highly hazardous to the environment such as global warming that affected climate change. To overcome this problem, we investigated the effect of HR on reducing EG production and consumption of gasoline for the motor engine. We manufactured the volume 34.5mL, 40.8mL, and 56.5mL of HR, then we used Halanaerobium hydrogeniformans water as hydrogen sources. For combustion, 1L Pertalite gasoline was applied in the engine motor. The experiment was conducted in variation temperature of HR (100 ℃, 110 ℃, 120 ℃, 130 ℃, 140 ℃), and velocity of the motor engine (2000rpm, 3000rpm, 4000rpm). We examined that the EG production namely hydrocarbon, carbon dioxide, and carbon monoxide were decreasing with the use of HR compared without the HR for all experimental conditions. The result tests also show that the use of HR reduced the consumption of gasoline along with the combustion process. This study demonstrated that HR as co-combustion combined with Halanaerobium hydrogeniformans water has the potential for environmental protection such as climate change due to global EG production.

1. Introduction
Currently, increasing concern for the environment caused by climate change, such as problems in agriculture, has become a global concern [1]. Climate change is the result of global warming. One of the most significant factors causing global warming is the increase in EG. Meanwhile, the increase in EG is influenced by industrial activity and the combustion reaction in motorized vehicles that use fossil fuels such as gasoline [2].

On the other hand, the use of fossil fuels is still the primary energy source for the community, especially in the transportation sector [3]. After the combustion process with a specific ratio of air/fuel, the chemical energy of fossil fuels can be used. However, if the combustion product is incomplete, monoxide (CO) and unburned hydrocarbon (HC) emissions cannot be avoided. Besides, nitrogen oxide (NOx) and CO2 emissions must also be considered. Then the damage caused by the exhaust gas to the environment can be estimated.

Based on the consideration of the hazardous aspects of fossil fuels to the environment, as well as the depletion of these fossil fuel reserves, the search for environmentally friendly alternative energies has been carried out in the last few decades [4]. Also, massive research on electric vehicle technology, solar
cells, etc. has been carried out. However, this research still faces several obstacles if it is applied in a short time for a large area. These obstacles are because there are still vehicles that use internal combustion for a very long time [5].

Therefore, this study aims to use clean fuel in the internal combustion engine. This clean fuel is obtained by entering hydrogen gas into the combustion chamber. Various methods have been developed to obtain hydrogen gas such as water electrolysis and steam reforming [6]. In this research, the hydrogen reactor is designed to be built as a co-combustion in the motor engine using Halanaerobium hydrogeninformans as a hydrogen source [7], and it is possible to reduce exhaust emissions.

2. Material and experimental method

Source of hydrogen in the form of water Halanaerobium hydrogeninformans as much as 1 liter was obtained from P.T. Permata Agro Nusantara, Indonesia. The hydrogen reactor is made of iron and is shaped like a tube containing a steel ball. Three types of hydrogen reactor designs have been made based on the volumes, namely 34.5mL, 40.8mL, and 56.5mL, as shown in Figure 1.

Figure 1. Hydrogen reactor.

The experimental method was explained in detail in Figure 2, 1 liter of Pertalite gasoline as fossil fuel is put into the combustion chamber on the combustion engine. The fuel motor used is the Kiger Kil60 engine. The motor is started with/without using a hydrogen reactor. When using a hydrogen reactor, hydrogen gas is obtained from the evaporation of Halanaerobium hydrogeninformans. The wet steam containing hydrogen and oxygen is then dried in a hydrogen reactor. Next, the dry hydrogen and oxygen steam will be injected into the combustion chamber through the combustion engine air valve.

Figure 2. The detailed experimental method of the combustion engine by using hydrogen reactor as co-combustion

Several experimental conditions have been carried out. The first condition is the variation in temperature changes in the hydrogen reactor. The temperature variations are 100 °C, 110 °C, 120 °C, 130 °C, and 140 °C. Next is the variety of speed of the combustion motor. The various speeds are 2000rpm, 3000rpm, and 4000rpm. Several test parameters were carried out. The exhaust of EG was
determined by using the Gas Analyzer NHA-402EN, Nanhua, in Dinas Perhubungan Kabupaten Bandung. The results of the exhaust of EG were shown in volume percentages, namely CO$_2$, CO, O$_2$, and HC in ppm. Finally, the volume of consumption of Peralite from the combustion engine was obtained by using the measuring cup in which the initial Peralite was 1 liter.

3. Results and discussions

3.1. Temperature of HR

The effect of temperature from HR on exhaust EG is shown in Figure 3. Figure 3a shows the change in the fluctuating value of HC gas emission for 2000 rpm conditions. HR volume of 34.5mL is the most efficient reactor in reducing HC gas emission levels. This result shows that evaporation at the 34.5mL reactor provides a more consistent supply of hydrogen gas to the combustion chamber. However, the reduction in HC gas emission content at an HR volume of 34.5mL is relatively the same as the HC gas emission produced without the hydrogen reactor. So that at 2000 rpm engine speed, the reactor temperature of HR does not have a significant effect because the resulting emission data are fluctuating.

Figure 3a. Comparison of HC emission for different HR volume under different temperature at 2000 rpm

Figure 3b. Comparison of HC emission for different HR volume under different temperature at 3000 rpm

Figure 3c. Comparison of HC emission for different HR volume under different temperature at 4000 rpm

Figure 3b shows the change in the fluctuating value of HC gas emission for 3000 rpm conditions. HR volume of 40.8mL is the most efficient reactor in reducing HC gas emission levels. This result shows that evaporation at the 40.8mL reactor provides a more consistent supply of hydrogen gas to the combustion chamber. However, the reduction in HC gas emission content at HR volume of 40.8mL at
3000 rpm engine speed, the reactor temperature of HR does not have a significant effect because the resulting emission data are still fluctuating.

Figure 3c shows the change in the fluctuating value of HC gas emission for 4000 rpm conditions. HR volume of 56.5mL is the most efficient reactor in reducing HC gas emission levels. This result shows that evaporation at the 56.5 mL reactor provides a more consistent supply of hydrogen gas to the combustion chamber. However, the reduction in HC gas emission content at HR volume of 56.5mL at 3000 rpm engine speed, the reactor temperature of HR does not have a significant effect because the resulting emission data are fluctuating continuously.

3.2. Velocity of motor engine
The effect of the velocity of the motor engine on exhaust EG is shown in Table 1. The most considerable reduction in HC gas emissions occurred in the 40.8mL reactor at a temperature of 130 °C at an engine speed of 3000 rpm, which was 177ppm. The most considerable reduction in CO emissions occurred in the 56.5mL reactor at a temperature of 100 °C at an engine speed of 4000 rpm, which was 57%. The most massive increase in CO₂ emissions occurred in the 34.5mL reactor at a temperature of 130 °C at an engine speed of 3000 rpm, which was 24%.

The higher the engine rotation speed, the resulting emissions will have a lower emission value because more fuel combustion occurs. The hydrogen reactor has succeeded in reducing the emission of HC and CO gases as well as helping to improve fuel combustion by increasing the content of CO₂ gas emissions and reducing the content of O₂ gas produced.

Table 1. Comparison of HC emission for different HR volume under different temperature at the different velocity of the motor engine.

| Temperature (°C) | Velocity of motor engine (rpm) | Without HR | HR volume of 34.5mL | HR volume of 40.8mL | HR volume of 56.5mL |
|-----------------|-------------------------------|------------|---------------------|---------------------|---------------------|
| 100             | 2000                          | 264        | 263                 | 243                 | 230                 |
|                 | 3000                          | 240        | 207                 | 205                 | 243                 |
|                 | 4000                          | 151        | 141                 | 148                 | 148                 |
| 110             | 2000                          | 264        | 262                 | 279                 | 253                 |
|                 | 3000                          | 240        | 210                 | 247                 | 230                 |
|                 | 4000                          | 151        | 146                 | 145                 | 147                 |
| 120             | 2000                          | 264        | 260                 | 269                 | 266                 |
|                 | 3000                          | 240        | 245                 | 241                 | 218                 |
|                 | 4000                          | 151        | 140                 | 153                 | 134                 |
| 130             | 2000                          | 264        | 255                 | 263                 | 267                 |
|                 | 3000                          | 240        | 197                 | 177                 | 246                 |
|                 | 4000                          | 151        | 138                 | 145                 | 155                 |
| 140             | 2000                          | 264        | 257                 | 269                 | 270                 |
|                 | 3000                          | 240        | 209                 | 192                 | 236                 |
|                 | 4000                          | 151        | 140                 | 135                 | 142                 |

3.3. Fuel consumption
The fuel consumption of the motor engine for 10 minutes testing is shown in Table 3. The smallest fuel consumption occurs at the HR volume of 56.5mL at 140 °C when the engine speed is 2000rpm. However, overall the existence of HR as a co-combustion on the motor engine can reduce fuel consumption. In terms of the temperature factor in the reactor, the temperature significantly affects the
resulting fuel consumption efficiency. The reason is that the higher the temperature, the wet hydrogen steam drying process will be faster.

Apart from temperature, the engine rotational speed of the motor also affects. The higher the engine's rotation speed, the greater the fuel consumption and the lower the efficiency of the savings, because the more significant the workforce required, the greater the consumption. Another critical factor is the HR volume dimension. The larger the reactor size, the higher the savings. When the volume of the reactor is greater, the greater the capacity of the wet hydrogen vapor storage capacity will be dried. Thus, the hydrogen steam drying process will be accelerated.

| Table 2 The fuel consumption of the motor engine for 10 minutes testing |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Temperature in Celcius | Velocity of motor engine (rpm) | Without HR | HR volume of 34.5mL | HR volume of 40.8mL | HR volume of 56.5mL |
| 100 | 2000 | 53.333 | 5.00 | 4.00 | 2.00 |
| 100 | 3000 | 103.333 | 9.00 | 5.67 | 5.83 |
| 100 | 4000 | 141.667 | 11.67 | 12.00 | 10.00 |
| 110 | 2000 | 53.333 | 4.67 | 4.00 | 1.67 |
| 110 | 3000 | 103.333 | 8.17 | 5.33 | 4.17 |
| 110 | 4000 | 141.667 | 11.67 | 11.00 | 8.17 |
| 120 | 2000 | 53.333 | 4.33 | 3.17 | 1.00 |
| 120 | 3000 | 103.333 | 7.67 | 4.00 | 4.00 |
| 120 | 4000 | 141.667 | 10.67 | 10.17 | 6.33 |
| 130 | 2000 | 53.333 | 3.83 | 3.00 | 1.00 |
| 130 | 3000 | 103.333 | 7.00 | 3.67 | 2.00 |
| 130 | 4000 | 141.667 | 9.83 | 8.67 | 5.00 |
| 140 | 2000 | 53.333 | 2.83 | 2.17 | 0.75 |
| 140 | 3000 | 103.333 | 6.17 | 3.00 | 1.83 |
| 140 | 4000 | 141.667 | 9.00 | 7.17 | 4.33 |

These research results do not contradict other research results, namely, by using hydrogen injection into the combustion engine, it can reduce emissions of HC and CO gases produced by combustion [8]. Therefore, the hydrogen enrichment by using Halanaerobium hydrogen information water in this research can reduce emission gas, but further research is needed to obtain a deeper analysis.

4. Conclusions
The following conclusions have been drawn from the above study. The hydrogen reactor has succeeded in reducing the emission of HC and CO gases. Engine speed affects improving fuel combustion by increasing the content of CO₂ gas emissions and reducing the content of O₂ gas produced. The higher the engine rotation speed, the resulting emission will have a lower emission value. Although in this study, the temperature at the hydrogen reactor did not significantly affect the resulting exhaust gas emission content. In terms of fuel consumption, the hydrogen reactor can reduce fuel consumption at various engine speeds and temperature variations. Furthermore, using a hydrogen reactor with Halanaerobium hydrogeninformans water, emissions such as HC, CO, and smoke can be considerably reduced. That means this study could contribute to protecting the environment, such as climate change, by reducing the EG production that affected global warming.

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References

[1] Pan Z and Atungulu G G 2010 Infrared heating for food and agricultural processing (US: CRC Press) p 300

[2] Hosseini S M and Ahmadi R 2017 Performance and emissions characteristics in the combustion of co-fuel diesel-hydrogen in a heavy duty engine Appl. Energy 205 911–25

[3] IEA 2020 CO2 emissions from fuel combustion: Overview [online] available https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview

[4] Zheng Z Q, Wang X F, Zhong X F, Hu B, Liu H F and Yao M F 2016 Experimental study on the combustion and emissions fueling biodiesel/n-butanol, biodiesel/ethanol and biodiesel/2,5-dimethylfuran on a diesel engine Energy 115 539–49

Huang H Z, Liu Q S, Wang Q X, Zhou C Z, Mo C L and Wang X Q 2016 Experimental investigation of particle emissions under different EGR ratios on a diesel engine fueled by blends of diesel/gasoline/n-butanol Energy Convers. Manage. 121 212–23

[5] Han D, Ickes A M, Bohac S V, Huang Z and Assanis D N 2011 Premixed low-temperature combustion of blends of diesel and gasoline in a high speed compression ignition engine Proc Combust Inst 33 3039–46

[6] Rosler H, Van der Zwaan B, Keppo I and Bruggink J 2014 Electricity versus hydrogen for passenger cars under stringent climate change control Sustain. Energy Technol. Asses. 5 106–18

Castro N, Toledo M and Amador G 2019 An experimental investigation of the performance and emissions of a hydrogen-diesel dual fuel compression ignition internal combustion engine Appl. Therm. Eng. 156 660–7

[7] Begemann M B, Mormile M R, Sitton O C, Wall J D and Elias D A 2012 A streamlined strategy for biohydrogen production with Halanaerobium hydrogeniformans, an alkaliphilic bacterium Front Microbiol. 3 93

[8] Aldhaidhawi M, Chiriac R, Badescu V, Descombes G and Podevin P 2017 Investigation on the mixture formation, combustion characteristics and performance of a Diesel engine fueled with Diesel, Biodiesel B20 and hydrogen addition Int. J. Hydrog. Energy 42 16793–807

Akal D, Oztuna S and Büyükakın M K 2020 A review of hydrogen usage in internal combustion engines (gasoline-Lpg-diesel) from combustion performance aspect Int. J. Hydrog. Energy. 45 35257–68

Schmitt S, Wick M, Wouters C, et al. 2020 Effects of water addition on the combustion of iso-octane investigated in laminar flames, low-temperature reactors, and an HCCI engine Combust. Flame 212 433–47