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Review article

Addition of Hydrogen in Spark Ignition Engine Combustion Process to Improve Engine Performance: A Review

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ABSTRACT

The increasing consumption of fossil energy causes fossil energy reserves to become depleted and pollutants in the environment increase. One approach to decreasing reliance on fossil fuels is through the use of renewable energy sources. Hydrogen can serve as a substitute fuel option. One of the uses of hydrogen as a renewable fuel is as an addition to gasoline combustion engines. This study includes a review of previous research on the addition of HHO to gasoline engines on the parameters of power, torque, specific fuel consumption, thermal efficiency, and exhaust emissions. The results of a review of previous studies show that the addition of HHO to gasoline engines can increase engine output power, torque, and thermal efficiency and can reduce combustion exhaust emissions and the addition of hydrogen can reduce specific fuel consumption.

ABSTRAK

Semakin tingginya konsumsi energi fosil menyebabkan cadangan energi fosil menipis dan peningkatan polutan pada lingkungan. Usaha untuk mengurangi penggunaan energi fosil salah satunya dengan energi terbarukan. Hidrogen menjadi salah satu alternatif yang dapat menjadi bahan bakar. Pemanfaatan

hidrogen sebagai bahan bakar terbarukan salah satunya sebagai tambahan pada mesin pembakaran bensin. Pada studi ini meliputi review penelitian-penelitian sebelumnya pada penambahan HHO pada mesin bensin terhadap parameter daya, torsi, konsumsi bahan bakar spesifik, efisiensi thermal, dan emisi gas buang. Hasil review dari studi-studi sebelumnya menunjukkan bahwa penambahan HHO pada mesin bensin dapat meningkatkan daya keluaran mesin, torsi, dan efisiensi thermal serta dapat mereduksi emisi gas buang pembakaran dan penambahan hidrogen dapat mengurangi konsumsi bahan bakar spesifik.

1. PENDAHULUAN

Continuous consumption of fossil energy can cause climate change because exhaust gas is produced and oil and gas reserves become depleted [1]. Emissions from exhaust gases from burning fossil fuels are an environmental problem that results in a greenhouse effect due to the phenomenon of increasing CO gas. The phenomenon of increasing CO gas will continue to increase due to exhaust gas emissions from fossil fuels as a result of environmental problems [2]. In some industrial countries, the use of transportation using fossil fuels is one of the contributors to exhaust emissions [3]. The role of renewable energy needs to be increased as part of reducing exhaust emissions pollution. Discussions regarding alternative energy need to be increased [4].

Alternative fuels can reduce pollutants when compared to fossil fuels [5]. Regulations on emissions and prevention of pollutants for environmental health are also the reasons why various fuel blending research is carried out [6]. There are many potential fuel sources that can be exploited available in nature [7]. Hydrogen is a viable alternative fuel that can be used in engines. [8]. Hydrogen is a renewable energy source that has a faster combustion speed than gasoline. The nature of hydrogen which has a high combustion speed can be a renewable fuel source for internal combustion engines to increase efficiency [9]. Hydrogen added to internal combustion engines has been carried out in various research and can increase the degrees of freedom in influencing combustion [10]. The mass of hydrogen is very light and only requires a small volume of air to reach the stoichiometric state. Meanwhile, air mass requires a high amount of air mass [11]. The special characteristics of combustion enable clean and efficient combustion operation in low load engines [12]. Directly injected (DI) hydrogen can enable engine output to increase power and efficiency and minimize NOx exhaust gases [13]. Introducing hydrogen into the combustion chamber can enhance the engine's ignition speed and lower the carbon content in gas emissions, resulting in cleaner exhaust gases. [14]. Hydrogen gas that will be introduced into the combustion chamber can be done by engineering the combustion chamber. The combustion chamber engineering process is needed so that hydrogen gas can be mixed in the combustion process [15]. Utilizing hydrogen as a fuel has the potential to decrease emissions from combustion exhaust. [16]. An additional benefit of hydrogen fuel is its ability to lower emission levels, which can positively impact health. [17]. Mixing fuel with hydrogen can be used as a material for analyzing the characteristics and performance of engines [18].

El-Kassaby et al. conducted a study on the impact of adding HHO gas to gasoline engines on their performance. In this research, Potassium Hydroxide (KOH) and Sodium Hydroxide (NaOH) were used as catalysts. HC, CO and NOx exhaust gases are also parameters reviewed

in this research. The results of research on adding HHO gas to gasoline engines show an increase in the thermal efficiency of gasoline engines by 10%. Fuel consumption can drop by up to 34%. Meanwhile, CO exhaust gas can be reduced by 18%, HC exhaust gas can be reduced by 14%, and NOx can be reduced by 15% [19].

Brayek et al. investigated the hydrogen-oxygen mixture in gasoline engines, focusing on how this mixture affects exhaust emissions and engine performance. The results of this research show a reduction in hydrocarbon emissions of 18%, a reduction in carbon monoxide exhaust gas of 31.8% and a reduction in carbon dioxide of up to 30% [20]. Research on the addition of HHO gas to engine fuel was carried out by Yilmaz et. al. The research aims to observe the benefits of hydrogen for engine performance, exhaust emissions and specific engine fuel consumption. The research results show that brake power increases when the engine is equipped with HHO. Specific fuel consumption decreases in engines with HHO. Exhaust gas emissions in the form of hydrocarbons (HC) are reduced in the final result [21].

Research on engine performance using hydrogen from dry cells was carried out by Ismail et. al. The use of dry cells has the advantage of being compact in size so it is easy to apply to machines. This research explains the increase in thermal efficiency and brake efficiency in gasoline engines that add hydrogen. A comparison of fuel consumption reveals that gasoline engines with added hydrogen consume less fuel compared to those running on gasoline alone. Meanwhile, the power that a petrol engine can produce is higher with hydrogen than a petrol engine alone. Temperature measurements show higher temperatures in gasoline engines compared to gasoline engines with hydrogen [22].

Shuai et. al. conducting research on hydrogen and oxygen fuels derived from water electrolysis. The results of this research show an increase in cylinder pressure relative to the crank angle when using more and more hydrogen mixed [23].

Polverino et. al. researching the use of energy to produce hydrogen in vehicles according to needs. This research explains fuel savings by injecting or adding HHO to internal combustion engines. A small amount of HHO can save fuel at a certain power range [24].

Malik et al. have performed research on generating hydrogen through spark discharges in diesel, kerosene, gasoline, and methane. This study details the efficiency of producing hydrogen and hydrocarbon gases. This research shows that gasoline obtains the energy efficiency required to produce hydrogen of 3.8 mol gases/kWh and 2.5 mol H2/kWh [25].

This review examines the impact of hydrogen gas addition on gasoline engine performance and its effects on exhaust emissions. Performance parameters such as torque, power, efficiency, and specific fuel consumption are analyzed. The study also evaluates exhaust emissions, focusing on carbon monoxide and hydrocarbons, aiming to elucidate the effects of HHO gas addition on the combustion process in gasoline engines.

1. Electrolysis Process

Hydrogen fuel comes from hydrogen which is given heat through electrical energy through an electrochemical reaction process. This process is called reverse electrolysis. [26]. Hydrogen fuel is typically produced through a reformation process involving methane steam and water vapor, aided by a catalyst to generate hydrogen and carbon dioxide gas. This sustainable process enables the production of hydrogen from renewable sources. [27]. Figure 1 explains the schematic of the hydrogen electrolysis process. The following is a reaction from electrosis.

$$2H_{2\,(gas)} + O_{2\,(gas)} \rightarrow 2H_2O + \text{energy} \quad (1)$$

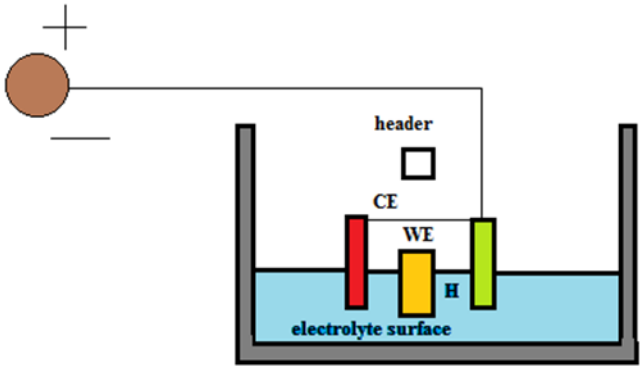


Figure 1 schematic electrolysis [28]

Basically, the conventional electrolyte process treats water as an electrolyte to produce hydrogen [29]. Oxygen can be produced from the anode and then released, while the cathode can produce hydrogen. [30]. The production of oxy-hydrogen gas follows Faraday's Law, which involves two electrode plates. Hydrogen is generated at the negative electrode, while oxygen is produced at the positive electrode [31]. The following is the reaction equation for water (H2O) in the electrolysis process.

$H_2O \rightarrow H_2$ (Katoda) +1/2 O_2 (Anoda) (2)

Table 1 properties of hydrogen dan gasoline

Properties	Hydrogen	Gasoline	Reference
Density (kg/m3)	0.085	719.7	[32]
Temperature penyalaan (°C)	536	501 - 744	[32]
Air fuel ratio kondisi stoichiometics	34.4	14.6	[5]
Molecular Weight	2.015	106.22	[5]
Diffusion coefficient in air at NTP conditions (cm2/s)	0.61	0.05	[11]
Net Heating Value (MJ/kg)	119.7	44.79	[11]

The process of electrolysis has been around for a long time by dividing water into pure hydrogen and oxygen by applying an electric current. In electrolysis technology, there are two types of electrolysis, namely proton exchange membrane (PEM) and base electrolysis which works at low temperatures around 50-80°C. The mechanism for high temperature electrolysis is to separate solid oxides [33]. Catalysts are needed to reduce olefins in crude hydrocarbons [34].

Electrolysis of water containing high concentrations of KOH compounds is able to replace H^+ and OH^- so that an equilibrium can be formed to increase the OH^- content and increase the thermal conductivity of the liquid. Reactions through kinetic performance can carry out absorption, transfer of electrons and release of electrons. This process occurs in a non-neutral layer on the electrode surface [35].

In the total volume of distilled water there is the same amount n of H_2 converted from H_2O depending on the environmental conditions when the H_2 is converted. The application of the

ideal gas law used in this condition can be explained [36]:

$$V_{H_2O} = \frac{RT}{P} n_{H_2} \quad (3)$$

Figure 2 explains the cycle of hydrogen and water. Hydrogen and oxygen are produced from the breakdown of water and can be recombined to release energy. Water that is given energy in the form of photons, electrons or heat can produce hydrogen. When hydrogen releases energy, water is produced [37].

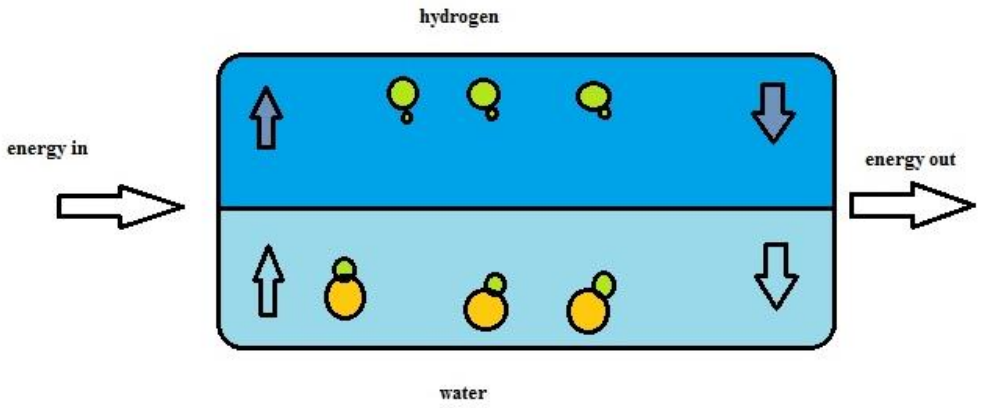


Figure 2 hidrogen-water cycle [37]

2. HHO Generator

The HHO generator is a system that works to convert water into hydrogen and oxygen through an electrolysis process with an alternating current (DC) energy source [38]. The HHO generator acts as an electrolyzer consisting of an electrolyte solution and metal electrodes [39]. The results of the reaction in the HHO generator produce gas bubbles around the electrode [40]. The product of the HHO generator process is a mixture of hydrogen and oxygen called oxyhydrogen [41]. The nature of hydrogen gas is very flammable [42].

The addition of hydrogen to gasoline fuel can change it into mixed gasoline with an active chemical reaction when the combustion process reacts [43]. As a result of adding HHO gas to the combustion engine, the amount of energy produced is different [44]. The use of hydrogen in engine fuel makes it possible to increase efficiency and reduce emissions. Hydrogen has a higher ignition speed than gasoline. The addition of hydrogen to the combustion of a gasoline engine is carried out by flowing hydrogen and oxygen resulting from the electrolysis process through the intake manifold. The volume of HHO gas collected in the cylinder per unit time is the HHO flow rate so that the HHO productivity rate can be shown in the following equation [19].

$$\text{HHO Productivity} = \frac{\text{volume}}{\text{time}} \quad (3)$$

3. Effect Of HHO on Gasoline Engine Performance

4.1 Influence of HHO on engine power parameters

The addition of HHO gas to the combustion of gasoline engines shows an influence on the power characteristics of gasoline engines. Table 2 shows the effect of increasing the HHO flow rate on gasoline engine combustion. Pure gasoline and gasoline with HHO added show differences in power where gasoline with HHO added shows an increase in power [45].

Table 2 the effect of adding HHO on engine output power [45]

Gasoline		Gasoline + HHO 0,25 L/min		Gasoline + HHO 0,5 L/min	
RPM	power (kW)	RPM	power (kW)	RPM	power (kW)
3268,519	46,616	3393,519	55,406	3000	46,4272
3500	55,217	3657,407	59,849	3259,259	55,7845
3671,296	58,809	4000	68,355	3504,630	60,4159
4000	64,386	4250	72,987	3731,481	64,0076
4231,481	70,151	4500	74,877	4000	73,2703
4500	73,932	4703,704	76,389	4245,370	77,9017
4712,963	72,987	5000	77,618	4500	80,7372
5000	72,420	5222,222	78,091	4750	82,2495
5259,259	71,758	5500	79,036	5000	82,3440
5500	73,932	5773,148	78,091	5250	83,6673
5787,037	76,957	6000	76,673	5500	85,0851
6000	76,578	6148,148	80,548	6009,259	84,2344

The phenomenon of increasing engine power was also described by Falatah et al. where mixing hydrogen and gasoline fuel in a spark ignition (SI) engine can increase the power produced by the engine. Increasing the amount of hydrogen in the fuel mixture also increases the power produced by the engine [46].

4.2 Effect of HHO on Engine Torque Parameters

Table 3 shows the effect of increasing HHO gas in gasoline engines on torque parameters. An increase in torque parameters occurs when HHO gas is added to the combustion compared to just burning gasoline alone. Additional oxygen content in HHO and HHO - in the fuel mixture for a better combustion process so that engine power increases [47]. The phenomenon of increasing torque also occurred in Madyira and Harding's research by adding HHO to the fuel to increase torque in order to maintain rotational speed when there was an increase in engine load [48].

Table 3 effect of adding HHO on torque parameters [47]

Gasoline		Gasoline + HHO	
RPM	Torque (Nm)	RPM	Torque (Nm)
1307,692	0,3969	1303,3	0,4251
1707,692	0,5268	1707,69	0,5890
1993,407	0,6031	2002,2	0,6709
2305,495	0,6229	2305,49	0,7189
2630,769	0,6398	2626,37	0,7331
3004,396	0,6144	3013,19	0,7189
3492,308	0,5268	3531,87	0,6314
3751,649	0,4534	3760,44	0,5720
4015,385	0,3743	4010,99	0,4958
4287,912	0,2754	4292,31	0,4025
4490,110	0,2076	4494,51	0,3206
4837,363	0,0636	4846,15	0,1850

4.3 Effect of HHO on Thermal Efficiency Parameters

HHO gas added to internal combustion engines with gasoline can increase the maximum pressure [49]. Engine operation that adds a fuel mixture provides an increase in maximum piston pressure which has an effect on increasing energy efficiency [50]. Figure 3 shows the effect of adding HHO gas on the measurement of thermal efficiency parameters. Research on the addition of HHO gas to gasoline engines carried out by Babariya et al on the thermal efficiency parameters of vehicle gasoline engines experienced an increase when using the addition of HHO [51]. A comparison of the thermal efficiency of a 4-stroke petrol engine using the addition of HHO and without the addition of HHO carried out by Vandana Gajjar showed that thermal efficiency increased when a 4-stroke petrol engine added HHO gas [52]. A trend of increasing thermal efficiency occurs when adding the HHO ratio compared to when there is a rich mixture because there is a lack of oxygen so the fuel combustion becomes incomplete causing thermal efficiency to decrease [53]. The phenomenon of increasing efficiency by adding hydrogen to internal combustion engines in research conducted by Al-Rousan explains that adding hydrogen to gasoline engines can increase thermal efficiency by 3% and 8% [54].

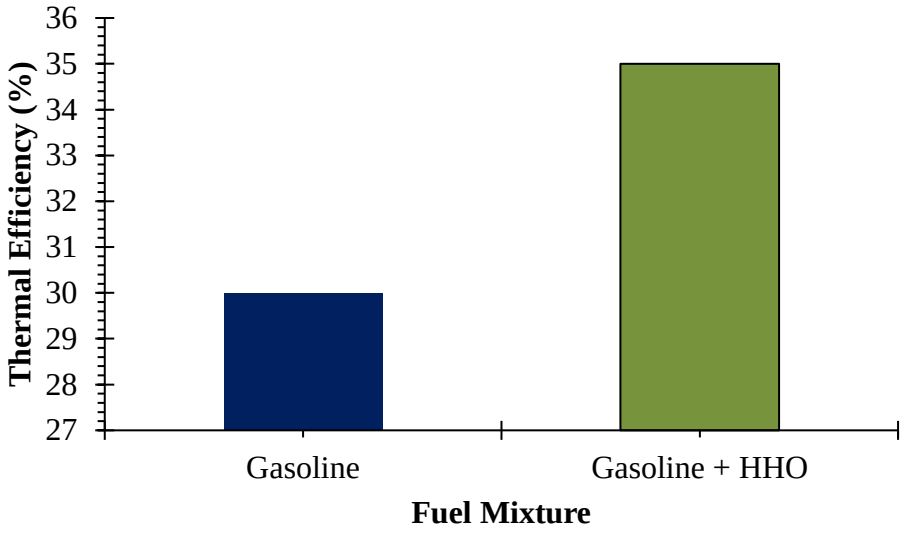


Figure 3 effect of adding HHO gas on engine thermal efficiency [51]

4.4 Effect of HHO on Engine Specific Fuel Consumption Parameters

Figure 4 shows the effect of adding HHO gas to gasoline engine combustion on specific fuel consumption parameters. The addition of HHO gas to combustion can reduce specific fuel consumption because the combustion reaction is more efficient due to hydrogen and oxygen reacting directly without ignition delay [55]. Research on the addition of HHO to internal combustion engines was also carried out by Sharma et al. explained that specific fuel consumption parameters decreased when HHO was added to the fuel mixture [56].

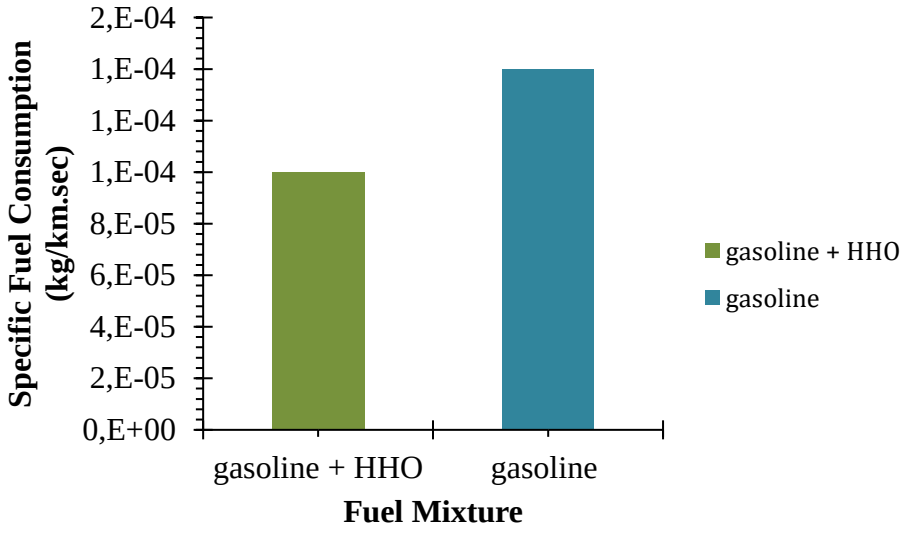
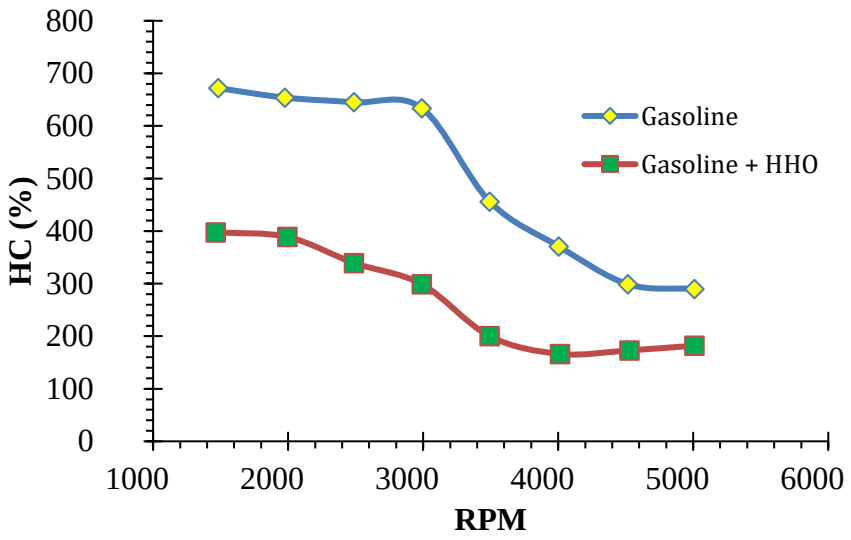


Figure 4 pengaruh penambahan gas HHO terhadap konsumsi bahan bakar spesifik mesin bensin [55]

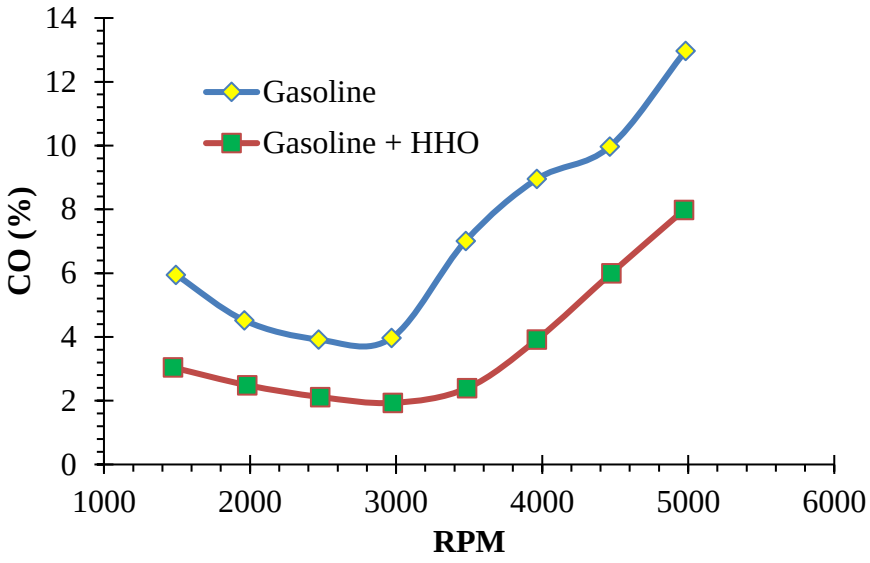
4.5 Effect of HHO on Exhaust Gas Emission Parameters

The process of burning fuel with hydrogen (Hydrogen-ICE) can make it possible to become a carbon-free fuel [57]. Measuring emission parameters shows that HC levels decrease when

gasoline engines are given a hydrogen mixture. Figure 5 shows the effect of adding HHO on HC and CO emissions in gasoline engines. The flammable nature of hydrogen helps the combustion of the fuel mixture so that the cylinder temperature results in the oxidation of CO to CO2 [58]. The phenomenon of decreasing CO emissions was also demonstrated in the research of Bortnikov et al. which explains that the CO content decreases in the hydrogen-gasoline mixture compared to using the gasoline-air mixture alone [59]. Shivaprasad et al. conducting research on the addition of hydrogen to gasoline engines showed that the measurement parameters of hydrocarbon (HC) emissions decreased in line with the increase in the hydrogen fraction [60]. The decreasing trend in CO emissions was also explained in research conducted by Aghahasani et al. where the addition of HHO gas can reduce CO emission levels by up to 91% [61].



(a)



(b)

Figure 5 Exhaust gas emission output (a) HC, (b), CO [58]

4. Conclussion

The addition of hydrogen gas to the gasoline engine combustion process can affect the performance of the gasoline engine. Hydrogen gas added to the combustion of a gasoline engine can increase the output power compared to the combustion process of a gasoline engine without additional hydrogen gas. The increase in petrol engine performance with the addition of hydrogen gas is also shown in the increase in torque produced by the petrol engine. Increased thermal efficiency also occurs when hydrogen gas is added to the gasoline engine combustion process. The addition of hydrogen gas can reduce exhaust gas emissions from the combustion of gasoline engines. The reduction in exhaust emissions when burning a gasoline engine with hydrogen gas added can be proven by decreasing levels of hydrocarbon (HC) emissions and carbon monoxide (CO) emissions.

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