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Investigation of Exhaust Emissions Combustion Characteristics in Single Spark Ignition-Engine Matic with Butanol-Gasoline Mixture

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Abstrak

Butanol sebagai bahan bakar yang mempunyai kadar oksigen tinggi sehingga proses pembakaran akan semakin ramah terhadap lingkungan. Pada penelitian ini butanol akan dicampurkan dengan bensin RON-90 dengan kapasitas 5%(B5); 7%(B7); 10%(B10); 12%(B12); 15%(B15) dan 18%(B18). mesin yang digunakan adalah transmisi matic kapasitas 109.5cc dengan rasio kompresi 9.5:1. Alat uji performa mesin dan emisi gas buang yang digunakan adalah 50L BRT Super-Dyno dan EPSG4 Gas Analyzer. Hasil penelitian menunjukkan bahwa penggunaan bahan bakar B18 untuk emisi gas buang CO mengalami penurunan 44% pada kecepatan mesin 6000rpm. Emisi gas buang CO_2 mengalami penurunan sebesar 47% pada kecepatan mesin 8000rpm. Emisi gas buang HC mengalami penurunan sebesar 28% pada putaran mesin 9000rpm. Berbeda dengan emisi gas buang NOx yang mengalami peningkatan sebesar 22% pada putaran mesin 9000rpm, hal tersebut disebabkan oleh temperatur diruang bakar semakin meningkat.

Keywords:
exhaust emissions;
combustion characteristics;
butanol-gasoline;
mixture.

Abstract

Butanol as a fuel has a high oxygen content, so the combustion process will be more friendly to the environment. In this study, butanol will be mixed with RON-90 gasoline with a capacity of 5% (B5); 7%(B7); 10%(B10); 12%(B12); 15%(B15) and 18%(B18). The engine used is an automatic transmission with a capacity of 109.5cc with a compression ratio of 9.5:1. The test equipment for engine performance and exhaust emissions is the 50L BRT Super-Dyno and EPSG4 Gas Analyzer. The results showed that using B18 fuel for CO exhaust emissions decreased by 44% at an engine speed of 6000rpm. CO_2 exhaust emissions have decreased by 47% at 8000rpm engine speed. HC exhaust emissions have decreased by 28% at 9000rpm engine speed. In contrast to NOx emissions, which increased by 22% at 9000rpm engine speed, this was due to the increasing temperature in the combustion chamber.

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1. Introduction

Utilized vehicles have increased problems in the surrounding environment with harmful pollutant exhaust emissions. An increase in the standard of living and a decrease in the desire to use public transportation so that people switch to using private cars as their daily transportation. It increased the use of gasoline motors. As a result, the environment is full of pollution and damage [1]. Regulations regarding exhaust emissions have been strictly enforced by the government, thus motivating researchers to seek and explore renewable energy sources to reduce global warming and its impact on human health [2]. Butanol is an additive to gasoline because it has a higheroctane rating than other fuel types used in the market. Butanol is also an oxygenated fuel, which can be made by fermenting agricultural resources such as starch or sugar, such as wheat, beet sugar, sugarcane, oil derivatives, dates, barley, and natural gas [3][4]. Oxygenate is a substance that has a high level of oxygen in its chemical composition, such as in biofuels and butanol [5][6]. Convincing technological innovation for the addition of butanol to standard market fuels to increase the octane rating rather than supplying lead-containing additives and causing damage to the surrounding environment [7][8].

The addition of butanol to standard fuel shows optimal performance and exhaust emissions. ABE-30% can increase thermal efficiency by 1.4% and reduce vehicle exhaust emissions, namely CO by 14%, HC by 9.7%, and NOx by 23%. The results of this research indicate that butanol perilously influences the quality of the combustion process. so butanol is very suitable to be used as a substitute for alternative fuels [9]. The use of conventional fuels that can harm the surrounding environment, both the used diesel and gasoline, motivates researchers to explore alternative fuels that can reduce and minimize the risk of emissions to the environment. The addition of various additives to the fuel will have an impact on engine performance and exhaust emissions. The level of butanol addition of 2% to 20% impacts specific fuel consumption by 8%, followed by a reduction in exhaust emissions of 13% CO and 25% HC. However, contrary to the resulting engine, power decreased by 11% [10].

The effect of adding 10% to 50% butanol in the SI engine combustion process also shows optimal engine performance and emissions. The addition of butanol when the throttle is 70% will have an impact on the speed of flame propagation in the combustion chamber. Because the percentage of butanol is increasing, torque and power have increased in the butanol mixture below 30% at minimum throttle opening, followed by a decrease in specific fuel consumption. Exhaust emissions experienced a significant decrease in CO, CO_2, and HC, but the opposite occurred in NOx, which increased [11]. Increasing environmental pollution and depleting the amount of fossil fuels, alternative fuels such as ABE needs to be developed in vehicles. Another factor that affects the performance level and exhaust emissions of the SI engine is the optimal fuel injection process. Changes in injection construction in the combustion chamber have been shown to increase thermal efficiency by 0.2% to 0.6% and significantly reduce exhaust emissions of CO, HC, and NOx by 0.1% so the use of butanol fuel with gasoline has proven to be effective. Clearly, as an alternative fuel to replace fossil fuels [12].

Research on the SI engine with the PFI system using ABE and gasoline fuel. ABE capacity is 30% of the ratio of fuel components to be tested. The results showed that using ABE (6/3/1)30 resulted in the smallest CO and HC emissions, while the highest NOx value was produced using ABE (3/6/1)30. Exhaust emissions decreased when using ABE (3/6/1)30 compared to all other fuel mixtures. This research shows that butanol is very relevant to use as an alternative fuel because it positively impacts exhaust emissions and the surrounding environment [13].

Butanol has exclusive thermodynamic characteristics and a level of responsiveness to optimal combustion conditions used in the combustion chamber, so it is possible to use it as sustainable energy. The effect of butanol on vehicles shows very good performance as indicated by the specific fuel consumption level, which has decreased by an average of 3.8%. In addition, the increasing butanol in gasoline increased the engine's thermal efficiency. The other effects resulting from the addition of butanol to gasoline include increasing the penetration of the combustion process more optimally, the ignition process taking place earlier due to the effects of the advanced combustion process, and increasing the maximum pressure so that the combustion process is faster. The addition of butanol to gasoline also affects the level of vehicle exhaust emissions. CO, HC, and NOx have decreased significantly in the SI Engine because adding additives such as butanol can improve the complete combustion process, minimize exhaust gases and improve the cooling process in the combustion chamber walls [14].

Butanol is an alternative fuel that is very suitable for SI engines. Many previous researchers have proved its effect on the use of SI machines. However, many gaps remain to be explored regarding the combustion process. Adding 6% to 12% butanol to standard gasoline can increase engine performance and reduce exhaust emission ratios. The experiment shows that adding B12 to gasoline reduces HC and CO exhaust emissions, which are relevant so that the combustion process can occur perfectly in the SI engine [15]. The addition of butanol to gasoline can increase thermal efficiency by 4%. Exhaust emissions such as HC and NOx produced in the combustion process have decreased during the combustion process. It occurs due to the effect of butanol as an oxygen-rich additive that supports the complete combustion process [16].

Butanol is a sustainable energy source, very suitable for use in SI engines. Butanol has the characteristics of an oxygen-rich fuel, so it is very important in the combustion process. The oxygen level in butanol, which is quite large, causes the combustion process to be complete in the combustion chamber. This research has varied the use of butanol in gasoline with a capacity of 5% (B5) v/v, 7% (B7)v/v, 10% (B10)v/v, 12% (B12)v/v, 15% (B15)v/v, and 18% (B18)v/v. This research only examines the impact of butanol-gasoline use on the level of exhaust emissions, namely CO, CO_2, HC, and NOx. This study hopes that butanol as an alternative energy can show optimal results in the combustion process and positively contribute to the friendliness of the surrounding environment, especially in reducing air pollution levels.

2. Method

2.1. The Characteristics of fuel used.

Butanol is an alternative fuel that is easily available in the market. The characteristics of butanol are suitable for the combustion process to improve engine performance and optimize exhaust emission ratios. In this research, variations in butanol-gasoline use have been adjusted according to previous observations and literature studies. The dosage used to determine Butanol-gasoline is as follows: B5 contains 50 ml of butanol and 950 ml of RON 90 gasoline; B7 contains 70ml of butanol and 930ml of RON 90 gasoline; B10 contains 100ml of butanol and 900ml of RON 90 gasoline; B12 contains 120ml of butanol and 880ml of RON 90 gasoline; B15 contains 150ml of butanol and 850ml of RON 90 gasoline; B18 contains 180 ml of butanol and 820 ml of RON 90 gasoline, the ratio of the fuel mixture used can be shown in Table 2. The butanol-gasoline mixture has been tested for composition at the Energy and Environment Laboratory-ITS Surabaya. The composition results in Table 1 that have been tested are viscosity, density, octane value, oxygenate level, the heat of vaporization, and flame speed level.

Table 1. Characteristics of the Fuel Used [8][17].

Properties of Fuel	RON-90	Butanol
Density (kg/m^3)	733	810
Octan Number of Research	90	97
Stoichiometric AFR (-)	11	15
Oxygen Level (%)	1	22
Vaporization Heat (kJ/kg)	410	716
AI Temperature (^{0}C)	294	343
LHV (MJ/kg)	41	33
Laminar flame velocity (cm/s)	1	22

Table 2. Fuel mixture ratio used

Fuel Blend	RON-90	Butanol
B5	950 ml	50 ml
B7	930 ml	70 ml
B10	900 ml	100 ml
B12	880 ml	120 ml
B15	850 ml	150 ml
B18	820 ml	180 ml

2.2. Test equipment and Engine

Small-capacity vehicles have been widely used in this country. The increasing use of small-capacity vehicles in urban areas has an impact on increasing the amount of fuel consumption and increasing air pollution in the environment [17][18]. Researchers use that basis to explore the effect of butanol-gasoline fuel on the performance and exhaust emissions it produces. In this study, a 109.5cc single-cylinder small-capacity vehicle was used, the compression ratio was 9.5:1, the maximum output power was 8.2kW at an engine speed of 8500rpm, and an automatic transmission system was used. Machine specifications can be shown in Table 3.

Table 3. Characteristics of the Engine-SI Used.

Detail	Specification
Machine Capacity (cm^3)	: 109.5 cc-4 strokes
CR	: 9.5 : 1
Max Power output (kW)	: 8500 rpm / 8.2 kW
Diameter x Stroke	: 47 x 63.1 mm
Cooling System	: Air system
Fuel Supply System	: PGM-FI
Transmission System	: Matic
Clutch Model	: ACCD Type
Max Torque output (Nm)	: 6.500 rpm / 9.3 Nm

Engine performance tests and exhaust emissions are crucial to determining an SI engine's ability level. Especially the level of exhaust emissions resulting from the combustion process, the increasing emissions of CO_2, HC, CO, and NOx will harm the surrounding environment. Figure 1 shows an engine performance test tool, namely the BRT Super-Dyno 50L, and an exhaust emission test tool using an EPSG4 Gas Analyzer. Furthermore, the test results are used as a reference for analyzing the research.

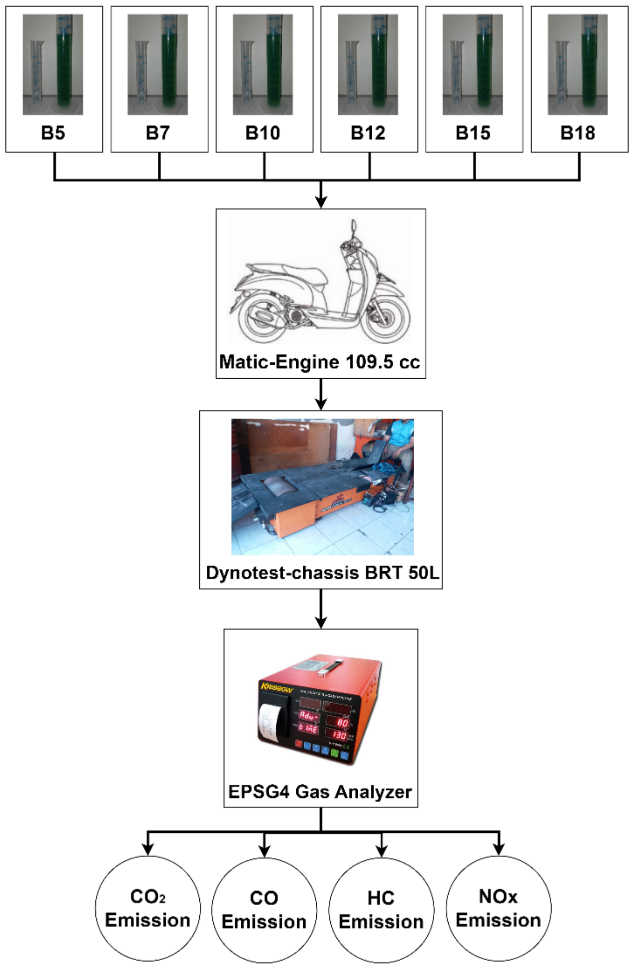

Figure 1. Test Equipment Engine-SI matic.

2.3. Flowchart Of Research Distribution

The initial stage of this research is to determine and sort out previous references as a theoretical basis, namely by collecting several previous publications or papers that have something to do with the research to be carried out. After that, in the second stage, the researcher can determine the gaps in the research to be carried out by sorting out several variations of the fuel used, including B5, B7, B8, B10, B12, B15, and B18, which have been shown in Figure 2.

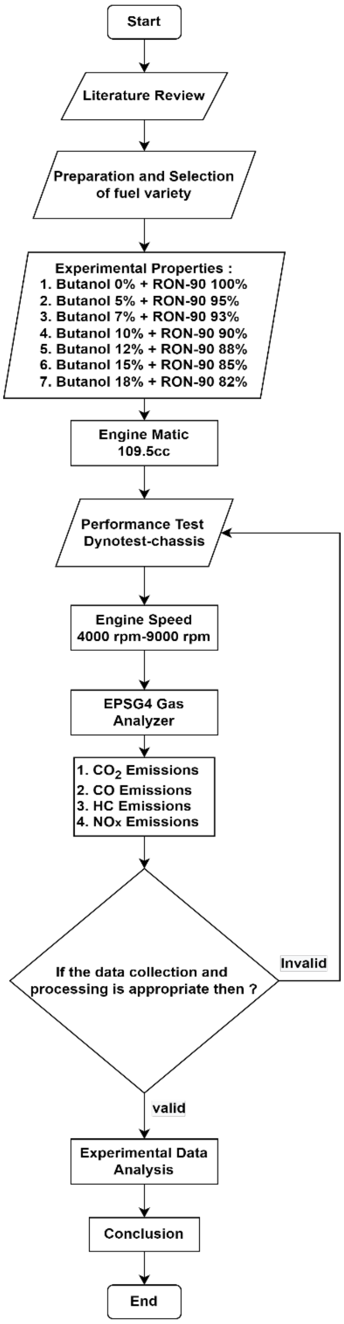

Figure 2. Research Steps.

In the third stage, the researcher determines the capacity and specifications of the vehicle to be used are vehicles with 109.5cc automatic engines. In the fourth stage, the selected vehicle will be tested on a 50L BRT Super-Dyno with a variation of engine speed of 4000-9000rpm, with the result being the engine performance shown on the CPU monitor display. At the same time, the vehicle is simultaneously connected to the EPSG4 Gas Analyzer exhaust emission tester, which shows CO_2, CO, HC, and NOx emission results. In the fifth stage, all test results are compiled for analysis to produce a conclusion that can explain in detail the impact of butanol-gasoline use on the exhaust emissions produced.

3. Result And Discussion

Unburned hydrocarbons directly result from imperfections in the combustion process, which is closely related to various engine design and operation variables. The two most important variables in design are the design of the induction system and the design of the combustion chamber, while the main operating variables are air-fuel ratio, speed, and load [4]. The engine's induction and maintenance systems greatly affect the engine's air-fuel ratio, which means it also directly impacts the resulting hydrocarbon and carbon monoxide emissions. With the right induction system design, we can improve the air-fuel ratio operation and optimum mix quality (for each level of speed and different loads). In contrast, engine maintenance such as piston ring wear levels, engine lubrication, and deposits often affect the air-fuel ratio of the mixture that enters the combustion chamber or also burns in the combustion chamber [10]. This analysis is intended to determine the effect of butanol variations on the resulting exhaust emissions compared to testing RON-90 fuel on the SI-Matic engine. The exhaust emissions reviewed include CO_2, CO, HC, and NOx.

Carbon monoxide from motor vehicle exhaust occurs due to incomplete combustion, caused by a lack of air in the mixture entering the combustion chamber, or it could also be due to the lack of time available to complete combustion. Carbon monoxide emissions are high when idling and reach a minimum when accelerating and at a constant speed (steady speed). Closing the throttle, which will reduce the oxygen supply to the combustion chamber, is the main cause of carbon monoxide, so deceleration from high speed will produce the highest CO in the exhaust gas of motorized vehicles. Carbon monoxide is also very much determined by the quality of the mixture, homogeneity, and A/F ratio. The better quality of the mixture and homogeneity will make it easier for oxygen to react with carbon. The amount of oxygen in the mixture (A/F ratio) also determines the amount of CO produced, considering that the lack of oxygen in the mixture will cause carbon to react imperfectly with oxygen (so CO is formed). Carbon monoxide also tends to occur at high combustion temperatures. Even in a poor mixture (having enough oxygen), if the combustion temperature is too high, the oxygen formed in carbon dioxide can dissociate (break away) to form carbon monoxide+oxygen. A high CO content indicates an incomplete combustion process, while HC indicates residual fuel without time to burn.

Figure 3 shows that in butanol-gasoline fuel, at low-high engine speed (4000 – 9000 rpm), the exhaust emission levels of both CO produced by B0 are higher than those produced by B18. The use of B0 experienced a significant increase at 6000 rpm with a value of 3.2%, and B18 experienced a significant decrease of 1.8% at 6000 rpm. As with the power analysis for low-medium engine speed, this is caused by incomplete combustion in the combustion chamber so that the fraction of the burned fuel and air mixture becomes small power, and the losses are large. One form of this loss is exhaust gas which is formed from the results of combustion.

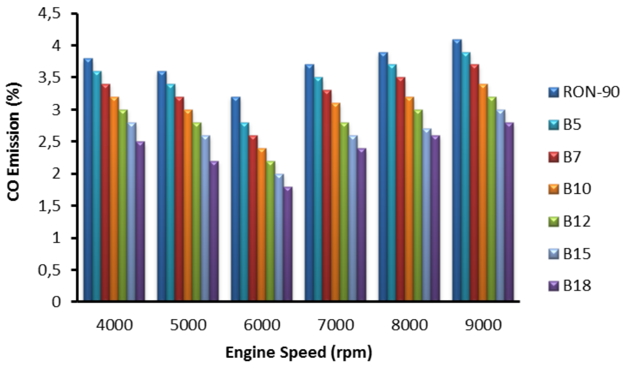

Figure 3. Comparison of CO emission to engine speed

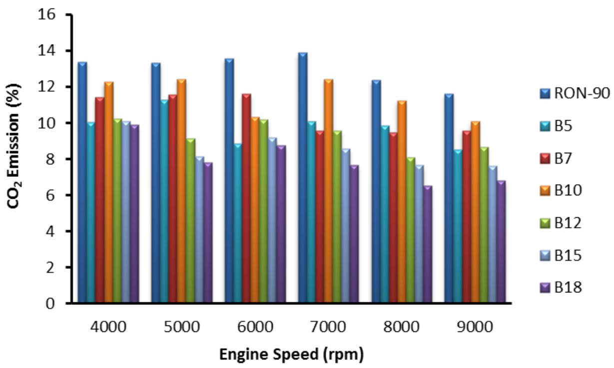

Figure 4. Comparison of CO_2 emission to engine speed

Figure 4 shows that in butanol-gasoline fuel, at low-high engine speed (4000 – 9000 rpm), the level of CO_2 exhaust emissions produced by B0 is higher than that produced by B18. The use of B0 experienced a significant increase at 7000 rpm with a value of 12.4%, and B18 experienced a significant decrease of 6.5% at 7000 rpm. As with the torque analysis for low-high engine speed, this is caused by incomplete combustion in the combustion chamber so that the fraction of the fuel and air mixture burned becomes small power, and the losses are large. One form of this loss is exhaust gas which is formed from the results of combustion.

During the compression and combustion processes, the increase in pressure in the combustion chamber will force a certain amount of gas to enter the small gaps in the combustion chamber (for example, the gap between the piston and liner). These gases will come out during the expansion and exhaust strokes and become a source of hydrocarbons in vehicle exhaust. Another source is a layer of lubricating oil that sticks to the liner walls, pistons, and cylinder head (cylinder head). This oil layer can absorb (absorb) and then release (desorb) the hydrocarbon components in the mixture (before and after combustion) to allow some fuel to escape during combustion. The HC source, as mentioned above, will also come out through the exhaust gas into the free air, increasing the HC levels produced by motorized vehicles. The explanation above shows that the HC sources are more complex and are not only caused by a lack of oxygen for combustion.

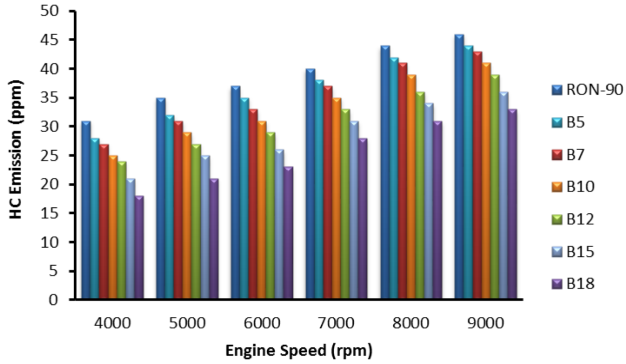

Figure 5. Comparison of HC emission to engine speed

From Figure 5 with butanol-gasoline fuel, it can be seen that at low- medium engine speed (4000 – 6000 rpm), the levels of HC exhaust gas produced by B0 are higher than those produced by B18. B0 fuel has increased HC emissions by 46ppm at an engine speed of 9000rpm. Meanwhile, B18 fuel has decreased by 33ppm at an engine speed of 9000rpm. As with the power and torque analysis, this low-medium engine speed is due to incomplete combustion in the combustion chamber so that the fraction of the burned fuel and air mixture becomes small power, and the losses are large. One form of this loss is exhaust gas which is formed from the results of combustion. At medium-high engine speed (6000-9000 rpm), the level of HC exhaust gas produced by B0 is lower than that produced by B18. It is due to the perfect combustion in the combustion chamber so that the fraction of the burned fuel and air mixture becomes a large power, and the losses are small. One form of this loss is exhaust gas which is formed from the results of combustion.

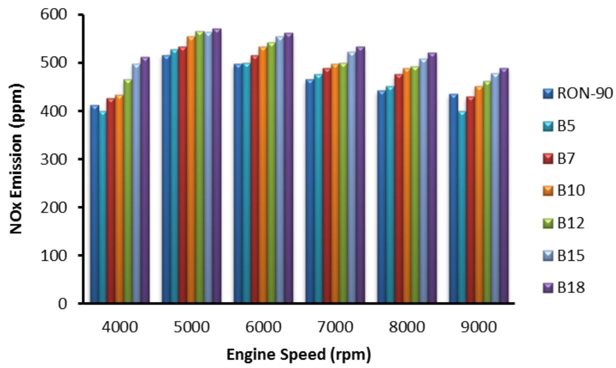

Figure 6. Comparison of NO_x emission to engine speed

The NOx is formed when nitrogen molecules in fuels, such as coal and oil, are released and react with excess oxygen in the combustion air. Fuel NOx emissions are a significant environmental concern with the potential to contribute up to 50% of total emissions when burning oil and up to 80% of total emissions when burning coal [2]. Most industries rely on combustion systems, such as boilers and engines, to provide heat or power to power their processes. Importantly, every manufactured fuel combustion system produces NOx emissions at various levels. The sectors contributing the largest share of NOx emissions are transportation, power generation, industrial processing, and commercial and industrial heating. Sources of NOx emissions are separated into two main categories: Cellular Sources and Stationary Sources [1].

From Figure 6 with butanol-gasoline fuel, it can be seen that at low-medium engine speed (4000–6000 rpm), the exhaust emission levels of NOx produced by B18 are higher than those produced by B0. B18 fuel has increased NOx emissions by 578ppm at an engine speed of 9000rpm. Meanwhile, B18 fuel experienced a fairly good decrease of 412ppm at an engine speed of 4000rpm. As is the case with the power and torque analysis carried out, this low-medium engine speed is due to incomplete combustion in the combustion chamber so that the fraction of the fuel and air mixture burned becomes small power, and the losses are large. One form of this loss is exhaust gas which is formed from the results of combustion. At medium-high engine speed (6000-9000 rpm), the level of NOx emissions produced by B0 is lower than that produced by B18. It is due to the perfect combustion in the combustion chamber so that the fraction of the burned fuel and air mixture becomes a large power, and the losses are small. One form of this loss is exhaust gas which is formed from the results of combustion.

4. Conclusion

Innovation of butanol-gasoline fuel must be improved, especially in using small-medium capacity vehicles for daily activities. This research has shown the important role of alternative energy in the form of butanol-gasoline fuel mixtures. From the research analysis reviewed above, it is concluded that butane-gasoline with a capacity of variants B0 to B18 has reduced CO levels by 44%, which occurs at an engine speed of 6000rpm for all fuel variations. CO_2 decreased by 47% at 8000rpm engine speed for all fuel variants. HC decreased by 28% at 9000rpm engine speed for all fuel variants. In contrast to the NOx emissions, which have increased for all fuel variants, namely 22% at 9000rpm, this is due to the use of butanol which has a high octane value so that the combustion process increases and the temperature of the combustion chamber increases from time to time.

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