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Effect of Butanol on Performances and Exhaust Gas Emissions of Gasoline Engine with EGR System

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Abstract- Increased use of gasoline engines results in scarcity of fuel and air pollution. Butanol is a renewable alternative fuel that can improve engine performance and reduce exhaust emissions. Therefore, the current study focuses on the use of butanol as an alternative fuel for gasoline engines by investigating the impact of its use on engine performance and exhaust emissions with the exhaust gas recirculation (EGR) system. Butanol in this study varied in the range of 5% to 15% in conditions without EGR, hot EGR, and cold EGR. From these experimental results, it was found that torque and power increased by 15.8% in the addition of 15% butanol with cold EGR. The use of hot EGR with the addition of 15% butanol in fuel can reduce BSFC 18.9% and increase BTE 23.2% from without EGR system. EGT decreased by 5.7% by using cold EGR. The addition of 15% butanol in fuel reduces CO emissions by 74.2% and HC emissions by 46.3% from pure gasoline. Butanol 15% in fuel increases CO2 emissions by 19.04% and 10% butanol decreases O2 to 34.6% in cold EGR systems.
Keywords – Gasoline engines, Butanol, EGR, Engine performance, Exhaust gas emissions

I. INTRODUCTION

The increase in the number of gasoline engines has resulted in high consumption of gasoline and an increase in air pollution [1]. The high demand for gasoline has resulted in scarcity in its inventory which ultimately has an impact on rising fuel prices. In addition, substances from combustion from gasoline engines are very dangerous for health. To overcome this problem, butanol can be used as an alternative fuel for gasoline because of some physical properties of butanol which is better than gasoline. Butanol has a high octane value resulting in better fuel efficiency and engine power. Butanol has a high evaporation heat which causes the fuel to evaporate better in the combustion chamber. This causes better combustion and increases engine power [2]. Blending butanol on gasoline increases oxygen levels which are useful for the complete combustion process and this phenomenon is referred to as "leaning effect". The lean effect of increasing oxygen in fuel results in an increase in combustion efficiency in the cylinder [3]. High oxygen content in butanol can reduce CO and HC emissions [4].

The use of butanol as a gasoline engine fuel has been widely studied. Some researchers focus their research on engine performance, fuel economy, and exhaust emissions. M.S.M. Zaharin et al. (2018) studied the effect of adding butanol to the performance of gasoline engines fueled by ethanol-gasoline mixture [5]. Addition of butanol results in increased pressure inside the cylinder during the compression step. This is because butanol has a higher density than gasoline. In addition, the high oxygen content of butanol helps the combustion process and reduces CO and HC emissions. Yunqian Li et al. (2016) examined the performance of gasoline engines using a mixture of isopropanol-butanol-ethanol and gasoline fuel [6]. From this study, it was found that thermal efficiency increases with increasing alcohol concentration in fuel. This is because the alcohol mixture in the fuel has a high evaporation heat so the intake manifold temperature is lower. Gu, et al. (2012) also conducted experiments on gasoline engines with a mixture of gasoline and butanol with variations in ignition time in the EGR system. This study found that an increase in ignition time could increase emissions of HC and NOx, while CO emissions decreased. However, the use of EGR is able to reduce NOx emissions on a mixture of gasoline and butanol [7].

Based on the literature study that has been conducted, an investigation of the effects of butanol on performance and exhaust emissions on gasoline engines with the EGR system has never been done. Therefore, the final goal to be achieved from this study is to investigate the effect of butanol and gasoline fuel mixture on the performance and exhaust emissions of gasoline engines with hot and cold EGR. In this experiment, the gasoline engine was equipped with hot and cold EGR with a variation of the percentage of butanol in its mixed fuel.

II. EXPERIMENTAL SET-UP

This research used a direct-injection four-cylinder gasoline engine. Gasoline engine specifications used in this study can be seen in Table 1. In this study, the percentage of butanol mixed into gasoline was varied in the range of 5% to 15% of the total volume of the fuel mixture. To facilitate analysis, a certain percentage of butanol is expressed with a capital letter B followed by a number that shows the percentage in mixed fuels. For example, this B5 represents

5% of butanol in mixed fuels with the remaining 95% of gasoline. The physical properties of both fuels can be shown in Table 2. In this experiment, the engine speed was varied in the range of 2500 rpm to 4000 rpm in intervals of 500 rpm at constant engine loads. Experiments using mixed fuels were carried out on gasoline engines using hot/cold EGR and without EGR. The dynamometer (DYNOmite Land & Sea type water brake and accuracy ± 0.3 Nm) was installed in-line with the gasoline engine shaft to measure the torque produced by the engine with various mixed fuels. The gas analyzer (Stargas 898) was applied to monitor exhaust gases resulting from the combustion of gasoline engines with different mixed fuels. The experimental set up is shown in Figure 1.

Table -1 Engine Spesification

Toyota Kijang 7 K Engine	
Type Engine	Gasoline
Production	Toyota
Number of Cylinders	4
Capacity	1798 cc
Number of valves	(SOHC) 8 Valve
Maximum Power	94 Hp - 5000 rpm
Maximum Torque	155 Nm - 3200 rpm
Fuel system	EFI

Table -2 Fuel Properties

Properties	Gasoline	Butanol
Octan Number	88	98,3
Density 15oC (Kg/m3)	744	815
Calorific Value MJ/Kg	42,7	33,3
Water content (%V)	0,003	>5
Viscosity (mm2/s)	0,22	2,63
Oxygen content (%)	2,7	21,69

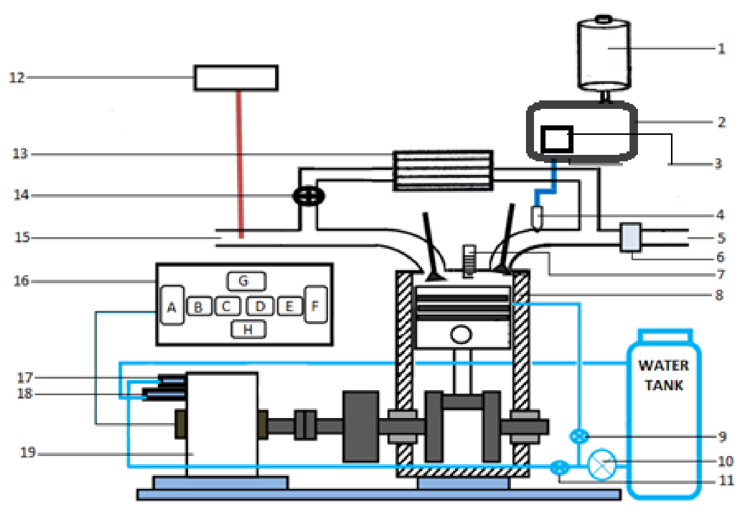

Figure 1 Experimental Set Up

Information:

1. Fuel Mixer
2. Burret
3. Fuel Pump
4. Injection Nozzle
5. Intake Manifold
6. Air Flow Sensor
7. Spark Plugs

11. Loading Water Valve
12. Gas analyzer
13. EGR cooler
14. EGR valve
15. Exhaust manifold
16. Main Display Panel
17. Inlet Water

A. Manometer of air intake manifold
B. T2 Temperature (EGR inlet)
C. T3 Temperature (EGR outlet)
D. Temperature T4 (mixed air)
E. Temperatut T5 (engine)
F. Air manometer includes EGR
G. Machine load display

8. Gasoline Engine
9. Colling Water Valve
10. Water Pump
18. Drains Out
19. Dynamometer
H. Speedometer

Mixer (1) was used to mix butanol with gasoline to get a homogeneous fuel mixture. The position of the mixer was placed higher than the engine so that the mixture of fuel flows into the engine based on the principle of gravity and was also assisted by a fuel pump (3) in a burret. Burret (2) was used to measure fuel consumption, where every 90 ml was calculated. Thereafter, the fuel was distributed to the injector (4). A tachometer was used to monitor engine speed with a proximity sensor. Dynamometer (19) was applied to measure the torque produced by a gasoline engine. Loading was carried out by flowing water into the dynamometer at a constant rate. The engine loads given to the engine were 25% of the load capacity that can be achieved by the engine. The water pump (10) pushed water from the water tank into the dynamometer for loading. The torque read by the sensor on the dynamometer was displayed on the load display (G). Temperature measurements using a thermocouple were mounted on the exhaust manifold, EGR inlet, EGR outlet and in the intake manifold and engine block. The temperature measurement results were displayed on the thermocouple display (B-C-D-E). Exhaust gas emissions were measured using a gas analyzer (12).

III. RESULTS AND DISCUSSION

3.1. Engine Performance Analysis

3.1.1 Brake Torque

Figure 2 shows the brake torque value for various fuels at different engine speeds with or without hot/cold EGR. From Figure 2, it can be observed that the brake torque increases with increasing engine speed. Addition of 10% butanol (B10 fuel) increases engine torque by 2.9% compared to gasoline. Increased torque is caused by high latent evaporation (HoV) of butanol so that the fuel evaporates better in the combustion chamber. Butanol also increases the percentage of oxygen in the fuel so that the thermal efficiency and engine torque are better [2, 19]. The use of EGR increases the ignition time and the duration of combustion resulting in the increase of pressure on the cylinder. The cold EGR system is capable of producing a longer burning duration and increases torque higher than hot EGR [9]. The highest torque increase of 15.8% is found at the 2500 rpm engine speed with B15 fuel in the cold EGR system.

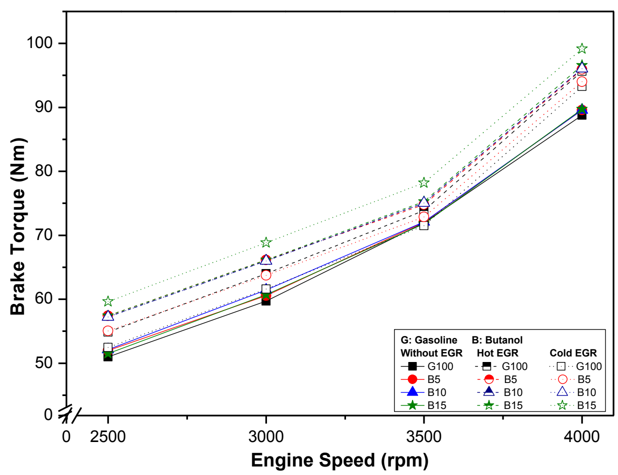

Figure 2. Brake Torque gasoline engine uses a mixture of gasoline and butanol fuel with and without the EGR system at variations in engine speed

3.1.2 Brake Power

Figure 3 shows the brake power value for various fuels at different engine speeds with or without hot/cold EGR. From Figure 3, it can be observed that the brake power increases with increasing engine speed. The highest power increase of 2.9% is found at the engine speed of 3000 rpm with B10 fuel. This increase in power is due to the high octane value of butanol so that the fuel is able to withstand high pressure on the cylinder [2, 5]. In addition, butanol has a high value of latent evaporation heat resulting in increased engine power. The use of EGR slightly increases engine power due to the presence of unburned fuel in the exhaust gas that is circulated into the combustion chamber [8]. The EGR contributes to the next combustion cycle which results in an increase in engine power. In addition, EGR increases flame propagation so that the duration of combustion increases which causes an increase in thermal efficiency and engine power [10]. The highest power increase of 15.8% by using cold EGR is found at 2500 rpm engine speed with B15 fuel.

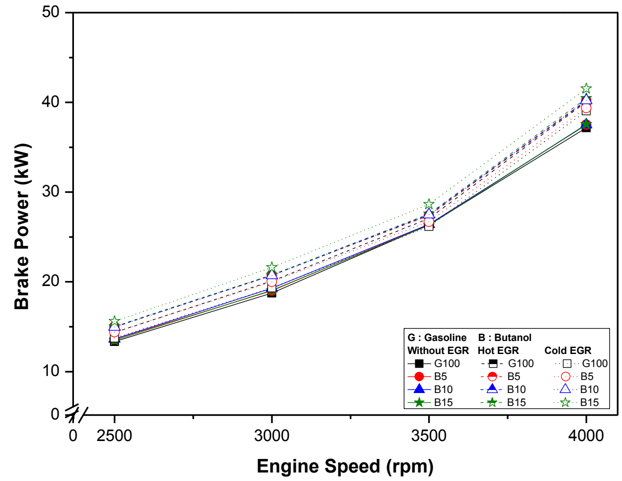

Figure 3. Brake Power gasoline engine uses a mixture of gasoline and butanol fuel with and without the EGR system at variations in engine speed

3.1.3 Brake Spesific Fuel Consumption(BSFC)

Figure 4 shows the BSFC value for various fuels at different engine speeds with or without hot/cold EGR. From Figure 4, it can be observed that BSFC increases with increasing engine speed. However, the addition of a percentage of butanol to fuel increases the BSFC value. The highest BFSC increase of 1.9% is found at 4000 rpm engine speed with B15 fuel. Increased BSFC is caused by a low heating value of butanol so that fuel consumption has increased [11, 18]. From the results of the study, it can be shown that the decrease in BSFC with the use of hot EGR is higher than that of cold EGR. Hot EGR causes the intake temperature to be higher increasing the duration of combustion which causes lower fuel consumption than cold EGR [9]. The highest BSFC reduction of 18.9% is found at engine speed 2500 with B15 fuel.

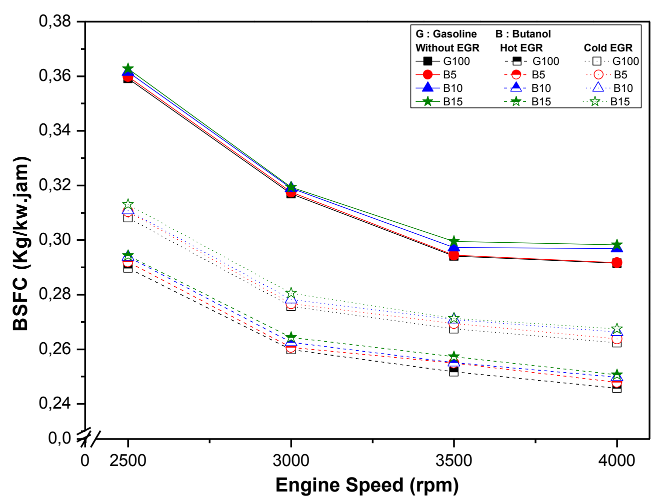

Figure 4. Brake Specific Fuel Consumption (BSFC) gasoline engine uses a mixture of gasoline and butanol fuel with or without an EGR system at variations in engine speed

3.1.4 Equivalence ratio

Figure 5 shows the equivalence ratio values for various fuels at different engine speeds with or without hot/cold EGR. From Figure 5, it can be observed that the equivalence ratio increases with increasing engine speed. Addition of butanol to gasoline reduces the equivalence ratio of 11.3% from that of pure gasoline with B15 fuel at an engine speed of 3500 rpm. The decrease in the equivalence ratio is caused by the high percentage of oxygen in butanol yielding the increases of flame during the combustion process. This oxygen can also reduce the air-fuel ratio and increases engine power [5]. The use of EGR slightly decreases the equivalence ratio due to the presence of unburned fuel in the exhaust gas that is circulated into the combustion chamber [8]. The use of hot EGR decreases the highest equivalence ratio of 9.5% from those without EGR with B10 fuel at 3000 rpm engine speed.

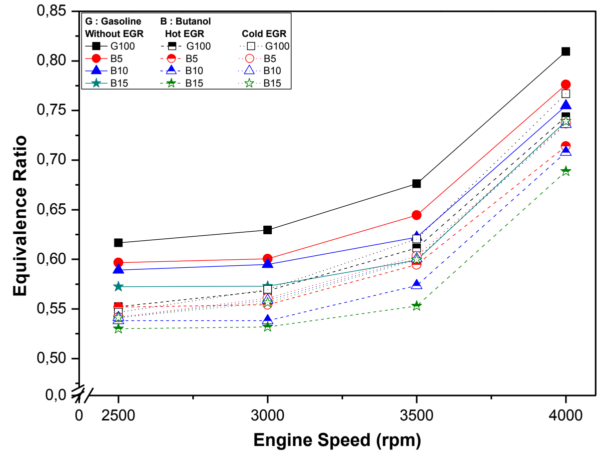

Figure 5. Equivalence ratio of gasoline engines uses a mixture of gasoline and butanol fuel with or without the EGR system at variations in engine speed

3.1.5 Brake Thermal Efficiency(BTE)

Figure 6 shows the value of brake thermal efficiency (BTE) for various fuels at different engine speeds with or without hot/cold EGR. From Figure 6, it can be observed that BTE increases with increasing engine speed. Addition of butanol 15% (B15 fuel) increases BTE 2.2% at 3000 engine speed. BTE increase is due to the high percentage of oxygen in butanol [2, 8]. In addition, the addition of butanol increases the latent heat of evaporation so that the fuel evaporates better in the combustion chamber resulting in an increase in thermal efficiency [6]. From the results of the study, it can be shown that the use of EGR increases BTE due to the presence of excess oxygen in the exhaust gas which replaces the fresh air entering the cylinder so that the oxygen percentage increases [12]. This results in more complete combustion and increases thermal efficiency. The use of hot EGR increases BTE 23.2% at 2500 rpm engine speed with B5 fuel.

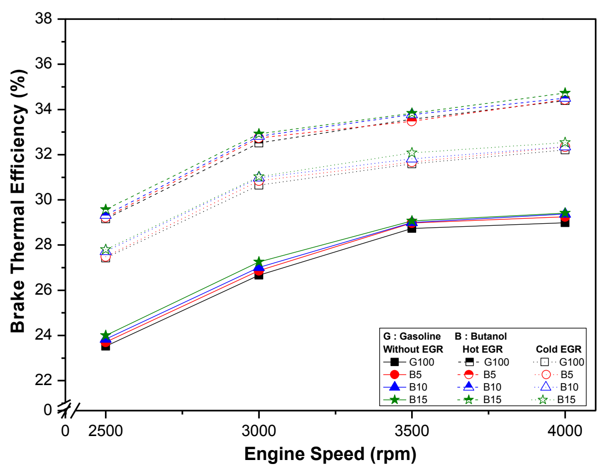

Figure 6. Gasoline brake thermal efficiency (BTE) for various mixed fuels with or without EGR systems at variations in engine speed

3.1.6 Volumetric Efficiency

Figure 7 shows the volumetric efficiency value for various fuels at different engine speeds with or without hot/cold EGR. From Figure 7, it can be demonstrated that volumetric efficiency has increased with increasing engine speed. Addition of 15% butanol increases 9.7% volumetric efficiency at 3500 rpm engine speed. Volumetric efficiency increase is caused by high latent evaporation heat in butanol [3, 6]. The use of EGR decreases volumetric efficiency because EGR reduces the amount of fresh air entering the combustion chamber. This is because a certain percentage of the air entering the combustion chamber are replaced by exhaust gas [14]. In addition, the exhaust gas temperature from the EGR circulation increases the intake temperature causing a decrease of volumetric efficiency [10]. The use of cold EGR reduces volumetric efficiency by 3.03% on B5 fuel with 2500 rpm engine speed.

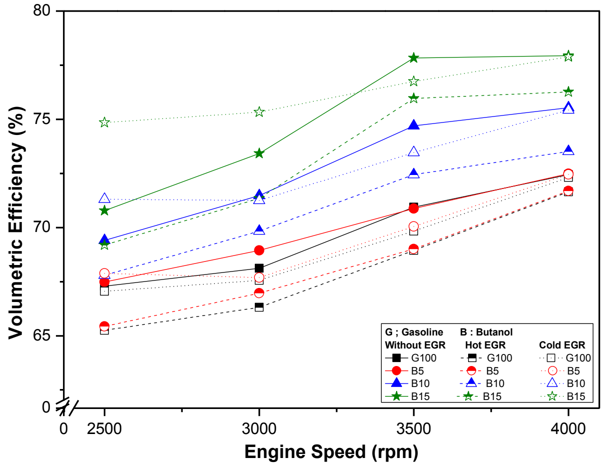

Figure 7. Volumetric efficiency of gasoline engines with variations in fuel mixtures with or without EGR systems at variations in engine speed

3.1.7 Exhaust Gas Temperature (EGT)

Figure 8 illustrates the EGT value for various fuels with different engine speeds with or without hot/cold EGR. From Figure 8, it can be found that EGT increases with increasing engine speed. The highest EGT increase of 6.4% is found in the addition of 15% butanol with 2500 rpm engine speed. Addition of butanol causes more complete combustion resulting in the increase of cylinder temperature. This condition is affected by a higher flash speed in butanol [5, 13]. The use of EGR decreases EGT because the amount of oxygen circulated into the combustion chamber is less [9]. The use of cold EGR is able to reduce EGR more effectively than that of hot EGR. The highest decrease of EGT 3.2% by using cold EGR is found in addition of 15% butanol with 2500 rpm engine speed.

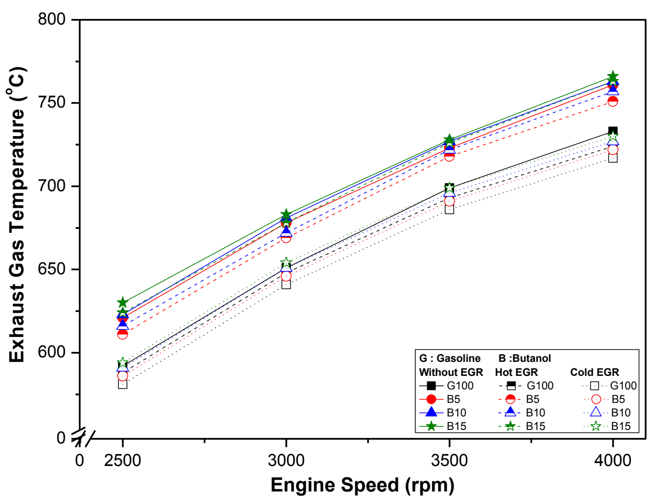

Figure 8. Exhaust Gas Temperature (EGT) on various types of fuel with or without an EGR system at variations in engine speed

3.2. Exhaust Gas Emission Analysis

3.2.1 Emissions of Carbon monoxide (CO) and Hydrocarbons (HC)

Figures 9 (a) and (b) show CO and HC emission values for various fuels with different engine speeds with or without hot/cold EGR. From Figures 9 (a) and (b), it can be observed that CO and HC emissions decrease with increasing engine speed. The highest reduction in CO emission is 74.2% in addition of 15% butanol with 2500 rpm engine speed while HC emission decreases the highest 46.3% in addition of 15% butanol with an engine speed of 3500 rpm. Decreasing CO and HC emissions are caused by a high percentage of oxygen in butanol yielding in the decrease of CO and HC emissions [4]. In addition, the high flame speed of butanol causes combustion in the

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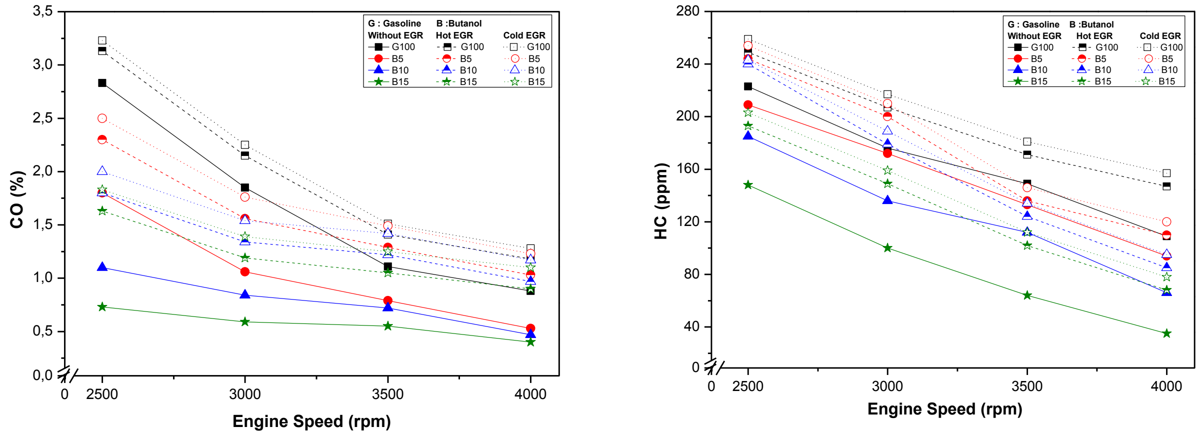
cylinder to be more perfect so that the addition of butanol can reduce CO and HC emissions. The use of EGR slightly increases CO and HC emissions due to the presence of some of the exhaust gas that is circulated back into the combustion chamber. The EGR makes the fuel mixture heterogeneous so that the fuel does not burn completely which results in increasing CO and HC emissions [15]. The highest CO emission increase is 87.9% in B10 fuel with an engine speed of 4000 rpm while the highest increase in HC emissions is 91.4% with B15 fuel at 4000 rpm engine speed by using cold EGR.



(a) (b)

Figure 9. (a) CO emissions (b) HC emissions for various types of fuel with or without an EGR system at variations in engine speed

3.2.2 Carbon Dioxide (CO2) Emissions

Figure 10 illustrates the value of CO2 emissions for various fuels at different engine speeds with or without hot/cold EGR. From Figure 10, it can be illustrated that CO2 emissions generally increase with increasing engine speed. The highest CO2 emission increase is 58.6% with the addition of 10% butanol at 4000 rpm engine speed. The increase in CO2 emissions is due to the high percentage of oxygen in butanol which reacts with carbon atoms that do not burn during the combustion process causing the increase in the formation of CO2 [5]. The high value of CO2 in the exhaust gas indicates that the combustion process in the combustion chamber is better. The use of EGR slightly increases CO2 emissions because some of the air entering the combustion chamber is replaced by exhaust gas in the form of CO2 and H2O from the combustion residue [16]. This causes an increase in CO2 emissions. The use of cold EGR increases CO2 emissions by 19.02% with B15 fuel at 4000 rpm engine speed.

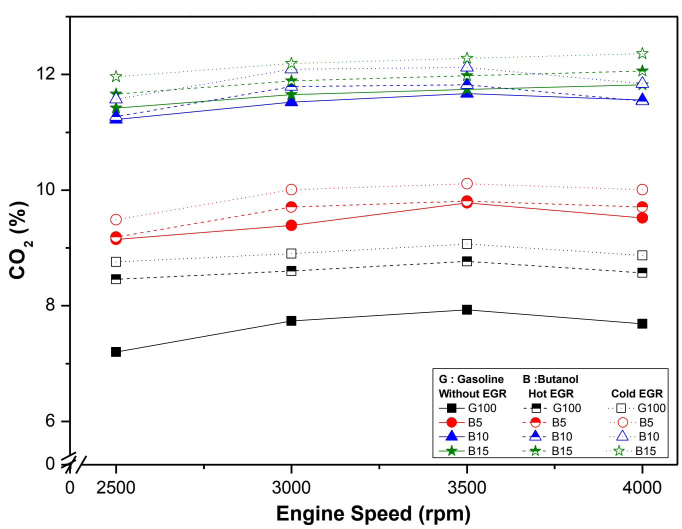


Figure 10. CO2 emissions for various types of fuel with or without an EGR system at variations in engine speed

Oxygen (O2)

Figure 11 shows the O2 concentration in the exhaust gas for various fuels at different engine speeds with or without hot/cold EGR. From Figure 11, it can be described that O2 generally decreases slightly with increasing engine speed. However, the addition of butanol to gasoline increases the concentration of O2. Addition of 10% butanol (B10 fuel) increases the concentration of O2 94.2% from that of pure gasoline at 2500 rpm engine speed. Addition of butanol to fuel increases the percentage of oxygen in the combustion chamber so that the combustion in the cylinder increases. Excess oxygen from the combustion products will be released as exhaust gas yielding the increase in O2 concentration [20]. The use of EGR causes the combustion temperature and oxygen percentage to decrease [9]. The decrease in oxygen is caused by exhaust gas which replaces some of the fresh air entering the cylinder [10]. In addition, the use of EGR causes the temperature inside the cylinder to go down and the percentage of O2 in the exhaust gas to decrease [17]. The use of cold EGR reduces the highest O2 concentration by 34.6% with B15 fuel at 4000 rpm engine speed.

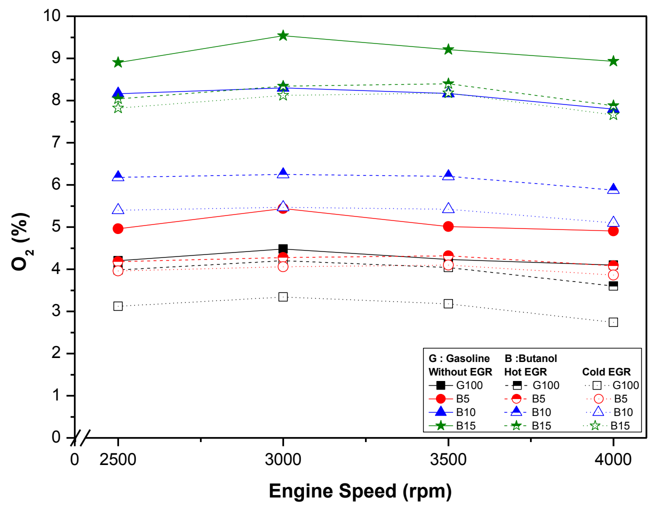


Figure 11. O2 for various types of fuel with or without an EGR system at variations in engine speed

IV. CONCLUSION

Butanol was a renewable alternative fuel that can improve engine performance and reduce exhaust emissions. From the results of this study, it was found that the use of butanol as an alternative fuel for gasoline engines had an impact on engine performance and exhaust emissions with the EGR system. From the results of this experiment, it was found that the highest torque was increased by 15.8% with the addition of 10% butanol at the 2500 rpm engine speed by using cold EGR. Engine power was also experienced the highest increase of 15.8% with B15 fuel at 2500 rpm engine speed by using cold EGR. BSFC was increased by 1.9% at 4000 rpm engine speed with B15 fuel while the use of hot EGR reduced BSFC to 18.9% from those without EGR. Addition of butanol to fuel and the use of hot EGR reduced the equivalent equivalence ratio to 9.5% from those without EGR with B10 fuel at an engine speed of 3000 rpm while the BTE increased 23.2% at 2500 rpm engine speed with B5 fuel. In this work, the volumetric efficiency value decreased to 3.03% and reduced EGT to 3.2% by using cold EGR. From the results of this test, it was also found that cold EGR increased CO emissions by 87.9% and 91.4% HC emissions from those without EGR. CO2 emission was increased by 19.02% while the O2 concentration was reduced to 34.6% due to the use of cold EGR. Based on the experiments that have been carried out, the addition of butanol to fuel with the use of EGR on the gasoline engine had a positive impact on performance and exhaust emissions.

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