Experimental Study of Wet Ethanol Impact on Performance and Exhaust Gas Emissions of Gasoline Engine with EGR System

by Nazaruddin Sinaga

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I. INTRODUCTION

The increase in the number of gasoline engines causes an increase in gasoline fuel consumption, which has an impact on rising fuel prices because supplies are running low. Besides, an increase in the number of gasoline engine vehicles exacerbates air quality due to hazardous substances from vehicle exhaust gases. To overcome this problem, the use of alternative renewable fuels is a concern in the present. Ethanol with octane values and high oxygen levels is one alternative fuel that can replace gasoline fuel [12]. High octane value increases the performance of the gasoline engine [1]. The high octane value in ethanol results in better combustion causing the increase of engine power and torque [6,7]. On the other, the addition of ethanol causes a decrease in HC and CO emissions. This is because of the high oxygen content in ethanol results in better combustion efficiency [10]. Previous research was also conducted by Prakar Chansauria (2018) [26]. Addition of 10% ethanol into gasoline fuels results in a decrease in CO emissions of 60%. Other research in results shows that the use of exhaust gas recirculation (EGR) can improve engine performance [12]. However, the use of EGR increases the concentration of HC and CO [9]. The reason is that the low oxygen concentration in the combustion chamber rises HC and CO [13]. Cinzia Tornatore (2019) also states that EGR can increase HC and CO emissions [25].

Based on previous studies, research on the use of wet ethanol as a mixture of fuel in gasoline engine with the EGR system has never been performed. Therefore, this study tries to investigate the effect of wet ethanol as a mixture of gasoline engine with the EGR system. In this experimental study, hot EGR and cold EGR were applied to direct injection gasoline engine with variations in the percentage of wet ethanol. The wet ethanol effect with or without hot /cold EGR on the performance of the gasoline engine and exhaust emissions is analyzed.

II. EXPERIMENTAL SET-UP

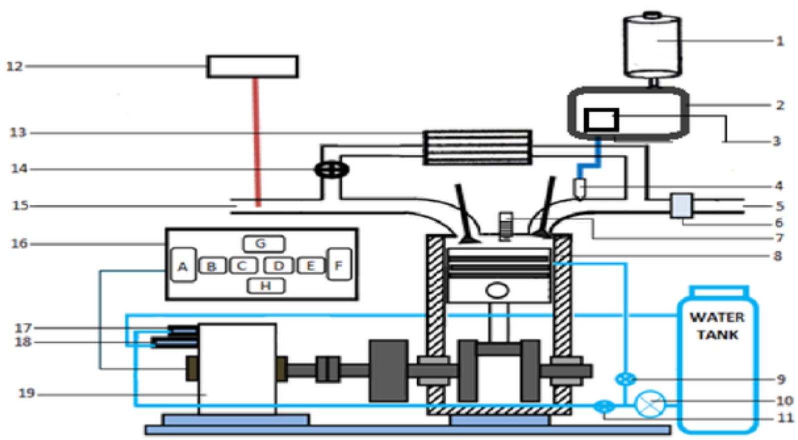
The fuel used in this study is gasoline and wet ethanol. Gasoline fuel was produced by PT. Pertamina, Tbk. Wet ethanol was obtained from the chemical store, Semarang, Indonesia. The percentage of the volume of wet ethanol blend into the fuel was 5% to 15% of the total volume of the mixture. Gasoline engine performance and emissions were analyzed in various fuel blend percentages. Some terms of fuel blends are given to facilitate analysis. P100 is pure gasoline, WE5 is a mixed fuel with a composition of 5% wet ethanol and the gasoline is a balance. The fuel blend was put into a mixer, then flows into the gasoline engine due to the work of the fuel pump. Fuel consumption was measured by monitoring the fuel flow rate at a constant level of a burret. In order to measure the torque of a gasoline engine, a dynamometer (DYNOmite Land & Sea type water brake dynamometer and accuracy of ± 0.3 Nm) was installed in-line with the engine shaft. A gas analyzer (stargass 898 with an accuracy of 0.926711) was used to monitor gas engine exhaust emissions.

Table -1 Fuel Properties

Properties	Wet-Ethanol	Bensin
Octane Number	109	88.8
Water Content (%v)	>5.0	0.003
Viscosity	1.623	0.22
Density Temperature15°C(kg/m3)	0.8974	744
Number Value (MJ/kg)	21.73	42.69
Flash Point (°C)	24	7.22
Laten Heat (KJ/Kg)	1139	328.91

Table -2 Engine Spesifications

Engine Toyota Kijang 7K	
Engine Type	Gasoline engine
Production	Toyota
Number of Cylinders	4 Straight
Engine Capacity	1781 cc
Valve	(SOHC) 8 valve
Maximum Power	94 hp - 5000 rpm
Maximum Torque	155 Nm – 3200 rpm
Fuel System	EFI



Experimental set-up

A. Manometer of air *intake manifold*	10. Cooling water valve	1. Fuel mixer
B. T_2 Temperature (EGR *inlet*)	11. Water pump	2. Burret
C. T_3 Temperature (EGR *outlet*)	12. Load valve	3. Fuel tank
D. T_4 Temperature (mixed air)	13. Dynamometer	4. Fuel pump
E. T_5 Temperature (engine)	14. Outlet water	5. Intake manifold
F. Air manometer includes EGR	15. Inlet water	6. Air flow sensor
G. *Display load engine*	16. Display panel	7. Spark plug
H. *Speedometer*	17. Exhaust	8. Gasoline engine
	18. Gas analyzer	9. Cylinder block

Mixer (1) was used to mix wet ethanol with gasoline to get homogeneous fuel blend. The mixer was placed higher than the engine so that the fuel blend flows into the engine based on the principle of gravity and is also assisted by a fuel pump (2). A burret was used to measure fuel consumption, in which the time of fuel consumption was determined for every 90 ml of fuel consumption (3). After that, the fuel was pumped into the injector (4). A dynamometer 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 load given to the engine was 25% of the load capacity that can be achieved by the engine. Pump (10) pushes 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 measurement using a thermocouple was 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 (18).

III. RESULTS AND DISCUSSION

3.1. Engine Performance Analysis

3.1.1 Brake Torque

Figure 2 demonstrates the value of the brake torque for various blend fuels with variations in engine speed. The addition of wet ethanol into gasoline fuels produces an increase in torque in each fuel blends. The highest increase in engine torque is observed in the WE15 blend. Engine torque using gasoline is found at 88.75 Nm at 4000 rpm. In the WE15 blend, the torque produced reaches 99.17 Nm at 4000 rpm. The highest torque increase of 11.74% is found at the engine speed of 4000 rpm with WE15 fuel in the cold EGR system. Increased oxygen levels in the combustion chamber are affected by oxygen levels in wet ethanol [11]. Oxygen content is higher in the molecular structure, causing more chemical energy to be released due to the combustion of fuel that is converted to thermal energy, so that torque and engine power increase [14]. The same research was also carried out by M.N.A.M. Yusoff (2018) [10]. The amount of oxygen content in the fuel mixture results in complete combustion causing an increase in engine torque.

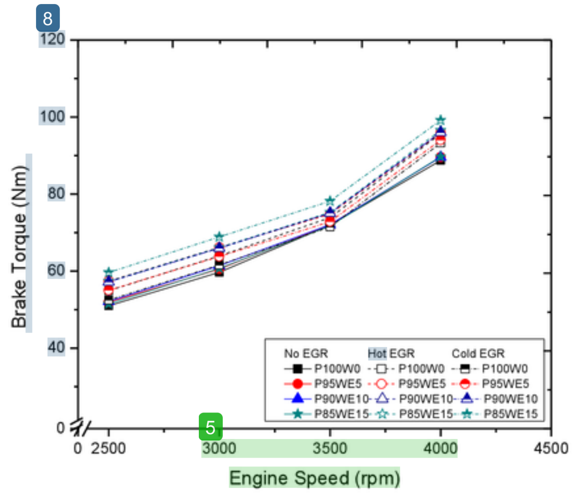


Figure 2. Brake torque for various fuel blends with or without EGR at variations in engine speed.

3.1.2 Brake Power

Figure 3 demonstrates the value of brake power for various fuels with variations in engine speed. Brake power with WE15 fuel reaches 41.52 kW of which brake power with pure gasoline reaches 37.16 kW at 4000 rpm engine speed. This result informs that the addition of wet ethanol can increase brake power to 11.73%. The highest engine brake power increase is observed in the WE15 mixture. Brake power for WE15 blend without EGR is 37,558 kW. While brake power with hot EGR in the WE15 blend is 40.437 kW. Brake power with cold EGR WE15 blend is 41,520 kW at 4000 rpm engine speed. Increased oxygen levels and octane values in the combustion chamber cause complete combustion, increasing brake power [14]. Oxygen content is higher in the molecular structure, creating more chemical energy to be released due to the burning of fuel that is converted to thermal energy, so that torque and brake power increase [5]. The same research was also carried out by Ashraf Elfasakhany, (2018) and M.N.A.M. Yusoff, (2018) [5, 10]. The high octane value in ethanol results in better combustion, which results in increased engine power and power.

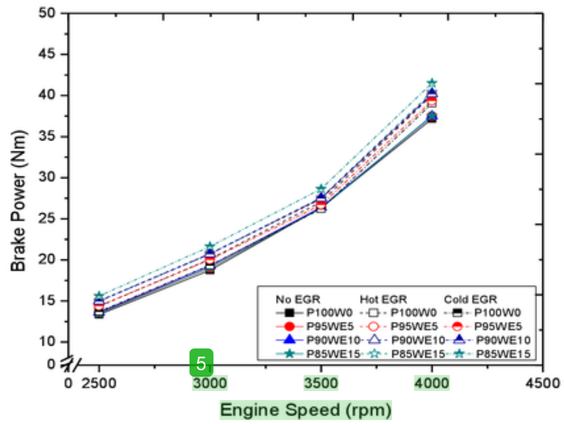


Figure 3. Brake power for various fuel blends with or without EGR at variations in engine speed.

3.1.3 BSFC (Specific Brake Fuel Consumption)

Figure 4 demonstrates the BSFC value for various fuels with variations in engine speed. The highest BSFC reduction of 3.80% is found in the blended of WE5 with [illegible]500 rpm engine speed. This is due to a lower heating value than that of gasoline. The low calorific value does not contribute to heat energy during combustion in the cylinder [6]. The low energy content of a blend of wet ethanol and gasoline causes an increase in BSFC [27]. The energy content and heat value of ethanol/methanol which is lower than gasoline cause an increase in fuel consumption compared to using gasoline [15]. Zhijin Zhang, et al. (2014) revealed that the use of EGR can reduce BSFC and emissions [16]. 18.9% decrease of BSFC in the use of hot EGR is found in the P85WE15 fuel with 2500 rpm engine speed. BSFC reduction using hot EGR is higher than that from cold EGR. This is because hot EGR increases the intake temperature causing the increase of the combustion duration resulting in lower fuel consumption than EGR cold, eventually [8].

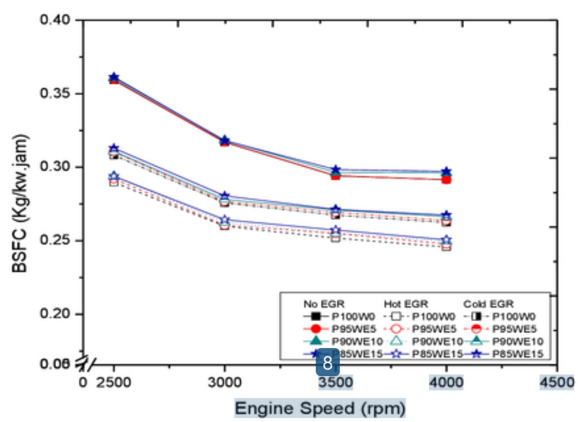


Figure 4. BSFC for various fuel blends with or without EGR at variations in engine speed.

3.1.4 Equivalence Ratio

Figure 5 shows the equivalence ratio value for various fuels with variations in engine speed. The addition of wet ethanol to gasoline fuel reduces the equivalence ratio of 11.47%. Decreasing the equivalence ratio caused by the high percentage of oxygen on wet ethanol results in a better combustion process in the combustion chamber [22]. This increase in oxygen percentage results in a decrease in the air-fuel ratio. The use of EGR on gasoline engines decreases the equivalence ratio due to the presence of unburned fuel in the circulating exhaust gas into the combustion chamber [12]. By installing EGR, the equivalence ratio decreases to 9.5% from those without EGR with WE15 fuel at 4000 rpm engine speed.

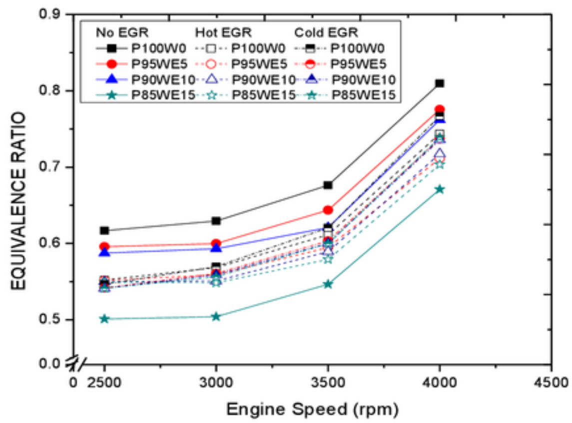


Figure 5. Equivalence ratio for various fuel blends with or without EGR at variations in engine speed.

3.1.5 Brake Thermal Efficiency(BTE)

Figure 6 shows the value of thermal efficiency for various fuels with variations in engine speed. The addition of wet ethanol to gasoline fuels increases thermal efficiency. The highest thermal efficiency increase of 2.85% is found at 4000 rpm engine speed with WE15 fuel in the cold EGR system. The high percentage of oxygen on wet ethanol increases thermal efficiency [23]. Increased thermal efficiency is caused by hot gas in the intake manifold due to EGR [19].

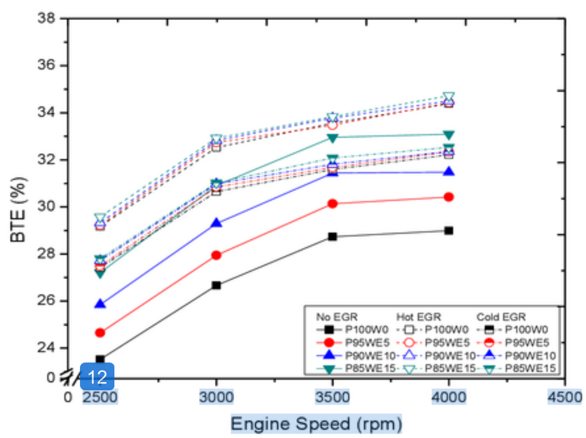


Figure 6. Brake thermal efficiency (BTE) for various fuel blends with or without EGR at variations in engine speed.

3.1.6 Volumetric Efficiency

Figure 7 shows the value of volumetric efficiency for various fuels with variations in engine speed. The highest increase in volumetric efficiency of 6.13% is found in the WE15 blend with an engine speed of 4000 rpm. Volumetric efficiency increases are caused by high latent evaporation heat on ethanol [24, 25]. The use of EGR decreases volumetric efficiency because EGR reduces the amount of fresh air entering the combustion chamber. This is because some of the air entering the combustion chamber is replaced by exhaust gas [28]. In addition, the use of the EGR system recirculates exhaust gases with high temperatures into the intake, so that volumetric efficiency decreases [2]. The use of cold EGR reduces volumetric efficiency by 4.07% with WE5 fuel at 2500 rpm engine speed.

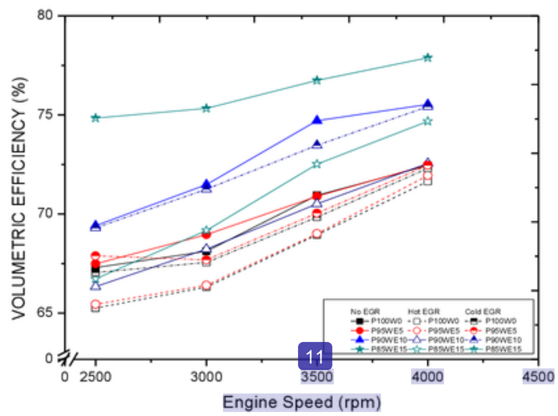


Figure 7. Volumetric efficiency for various fuel blends with or without EGR at variations in engine speed.

3.1.7 Exhaust gas temperature.

Figure 8 illustrates the EGT value for various fuels with variations in engine speed. The highest EGT increase of 4.1% is observed in the addition of 10% wet ethanol with 4000 rpm engine speed. The increase oxygen percentage in ethanol causes more complete combustion so that the cylinder temperature increases [5]. The use of EGR decreases the combus temperature because of the presence of exhaust gas which is recirculated into the engine [3]. The use of EGR causes the combustion temperature to decrease because the amount of oxygen circulated into the combustion chamber decreases [28]. The use of cold EGR is effective in reducing EGT rather than hot EGR. The highest decrease in EGT of 4.5% by using cold EGR is obtained by adding 10% wet ethanol with 4000 rpm engine speed.

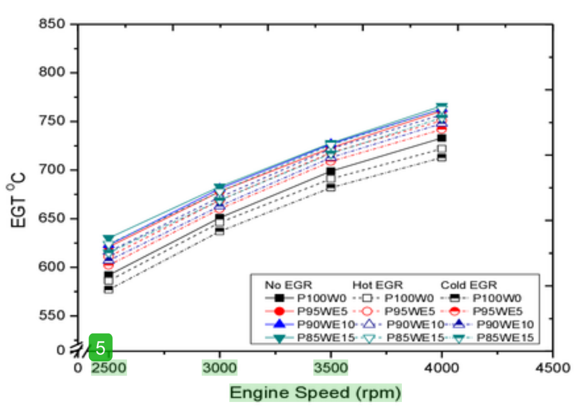


Figure 8. Exhaust gas temperature for various fuel blends with or without EGR at variations in engine speed.

3.2. Exhaust Gas Emission Analysis

3.2.1 Emissions of carbon monoxide (CO)

Figure 9 shows CO concentrations for various fuels with variations in engine speed. CO emissions experienced the highest decline of 41.1% with 15% ethanol at 4000 rpm engine speed. CO emission reduction is caused by a high percentage of oxygen in ethanol yielding a decrease of CO emissions [23]. Besides, high ethanol flame speed makes combustion in the cylinder more perfect so that the addition of ethanol can reduce CO emiss s [10]. The use of EGR slightly increases CO emissions due to the presence of exhaust gas, which replaces the fresh air entering the combustion chamber, making the mixture of heterogeneous fuels. The heterogeneous mixture causes imperfect combustion process, which increases CO values [16]. The use of cold EGR increases CO 75.4% emissions with WE15 fuel at the engine speed of 4000 rpm.

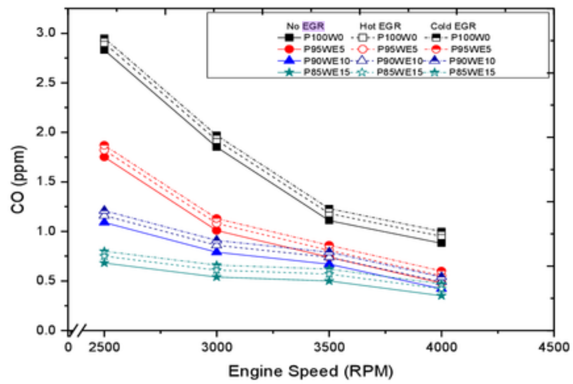


Figure 9. CO concentration for various fuel blends with or without EGR at variations in engine speed.

3.2.2 Emissions of Hydrocarbons (HC)

Figure 10 illustrates the concentration of HC for various fuels with variations in engine speed. HC emission has the highest decrease of 35.44% with 15% ethanol at a 4000 rpm engine speed. Decreasing HC emissions is caused by high oxygen concentrations in ethanol, which results in complete combustion yielding the decrease of HC emission [10, 23]. However, the use of EGR increases HC and CO emissions due to the reduction in oxygen concentration in the combustion chamber [9, 26]. The use of cold EGR increases 44.30% HC emission with WE15 fuel at 4000 rpm.

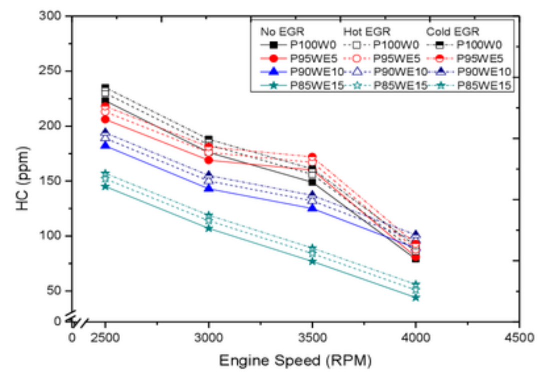


Figure 10. CO concentration for various fuel blends with or without EGR at variations in engine speed.

3.2.3 Emissions of Carbon Dioxide (CO2)

Figure 11 shows the value of CO2 levels for various fuels with variations in engine speed. CO2 emissions experienced the highest increase of 11.82% with 5% ethanol at an engine speed of 3500 rpm. The high percentage of oxygen in ethanol reacts with carbon atoms during the combustion process causing the increase of the formation of CO2 [22]. The high value of CO2 in the exhaust gas indicates that the combustion process in the combustion chamber is better. The use of EGR 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 results [19]. This condition causes an increase in CO2 emissions. The use of cold EGR increases CO2 emissions by 28.1% with WE5 fuel at an engine speed of 3500 rpm.

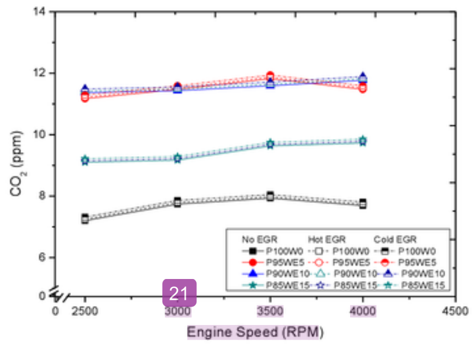


Figure 11. CO2 concentration for various fuel blends with or without EGR at variations in engine speed.

3.2.4 Emissions of Oxygen (O2)

Figure 12 describes the value of O2 levels for various fuels with variations in engine speed with or without EGR. The O2 concentration has the highest increase of 74.04% with 5% ethanol at 2500 rpm engine speed. Increased O2 level is caused by the presence of oxygen in ethanol which results in complete combustion [10]. The use of EGR on the gasoline engine causes some O2 in the cylinder to be replaced by exhaust gas [2]. The exhaust gas circulation in the EGR decreases the O2 concentration in the cylinder so that it causes the combustion temperature to decrease [8]. The use of cold EGR reduces the highest O2 concentration by 44.8% with WE15 fuel at 4000 rpm engine speed.

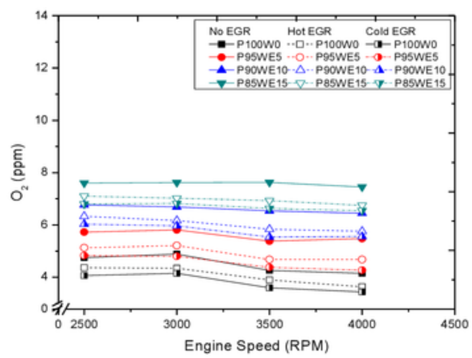


Figure 12. O2 concentration for various fuel blends with or without EGR at variations in engine speed.

IV. CONCLUSION

Experiment to determine the performance and exhaust emissions of gasoline engines with gasoline and wet ethanol blends have been carried out. Some of the results of experimental study can be summarized as follows:

1. From the experimental results, it was found that torque and power were increased by 11.74% with 15% wet ethanol at 4000 rpm engine speed by using cold EGR.
2. The increase of BSFC of 3.80% was found at 2500 rpm engine speed with 15% wet ethanol fuel while the use of hot EGR reduced BSFC to 18.9% from those without EGR.
3. The addition of wet ethanol to fuel and the use of hot EGR can reduce the highest equivalence ratio of 11.47% from those without EGR with WE15 fuel at 4000 rpm engine speed.
4. BTE increased 22.85% at 4000 rpm engine speed with WE15 fuel.
5. Volumetric efficiency has decreased to 4.07% and reduced EGT to 4.5% by using cold EGR.
6. From the results of this experiment, it was also found that the use of cold EGR increased CO emissions by 75.4% and emissions of HC 44.30% from those without EGR. CO2 emissions increased to 28.1% while the O2 concentration was reduced to 44.8% due to the use of cold EGR.

V. ACKNOWLEDGMENT

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