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Performance and Exhaust Emissions of Four-Stroke Gasoline Engines with Variations in Injection Duration Using E75 Ethanol Fuel

Muhamad Khoirul Anam[1*], Mohammad Lutfiyanto[2], Adi Mulyadi[3], Wisnu Kuncoro[1]

[1] Department of Mechanical Engineering, University of PGRI Banyuwangi, 68418, **Indonesia**

[2] Motorcycle Business Engineering, SMK Minhajut Thulab, 68472, **Indonesia**

[3] Department of Electrical Engineering, University of PGRI Banyuwangi, 68418, Indonesia

*anamkhoirulm@unibabwi.ac.id

Abstract

Ethanol is a biofuel in which its storage and physical condition are almost the same as gasoline (fuel oil). It is still possible to drive a gasoline engine with ethanol in low concentrations. However, applying high concentrations to gasoline engines will require modifications, such as changing injection duration and compression ratio. This is done to get better performance and emissions than the use of gasoline fuel. In this study, the gasoline engine used was a 177cc single-cylinder four-stroke engine with E75 (75% Ethanol and 25% Pertalite), where the test engine was modified on the injection duration section with the replacement of standard ECU components into a programmable ECU. The replacement aims to facilitate changes in engine parameters, such as injection duration. In injection duration mapping, basic mapping values are added by 2%, 4%, 6%, and 8%. Then, the compression ratio is changed from 11:1 to 13:1. In comparison, testing is performed under standard machine conditions using Pertalite (E0). To test engine performance, a Prony brake dynamometer is used, while to test exhaust emissions are used exhaust gas analyser. E75 fuel use in the study resulted in torque and power increased by 30% and 19% with additional injection duration (8%) and (6%). However, in E75 use the duration of injection (2%) and (4%) decreased. This is related to AFR values, where injection duration (2%) and (4%) run on lean AFR. Then the SFC result increases, which is affected by the low heat value of ethanol fuel. And the use of ethanol E75 can reduce CO and HC emissions by 69.5% and 17% respectively.

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1. Introduction

Energy has become a major human need in this modern era. Such as turning on the television, house lights, and other household appliances that require electricity and other energy. Another source of energy is fuel, which is generally used to drive motorized vehicles, which support human activities in terms of transportation [1]. Motor vehicle enthusiasts in Indonesia are very high, this can be seen from the number of vehicles that continues to increase every year [2]. According to the Central Statistics Agency, the number of vehicles in 2019 was 112,771,136 units and in 2020 there were 115,023,039 units. Thus, the use of petroleum fuel energy is also increasing, so its availability is reduced. According to the Indonesian Minister of Energy and Mineral Resources (ESDM), the availability of petroleum reserves will run out within 9.5 years [3]. In addition to the decreasing availability of petroleum fuels, the emissions produced are also very dangerous for the environment and human health. Compounds found in motor vehicle emissions include CO, HC, and NOx which are harmful pollutants for human survival and the earth's ecosystem [4]. Because of these problems, the search for alternative fuels must be implemented immediately, considering the dependence of humans on motorized vehicles for transportation.

One of the renewable fuels is ethanol derived from plants or collectively referred to as biomass [5]. When compared to gasoline, ethanol has advantages such as reducing emissions of HC and CO compounds [6]. Then ethanol also has better anti-knock characteristics, which allows the vehicle to have a higher engine compression ratio. In addition, ethanol is a liquid fuel whose storage and use are also the same as gasoline [7]. However, ethanol has different characteristics from gasoline, such as a higher-octane rating. Mixing ethanol in gasoline can increase the octane value, where ethanol contains 30% oxygen [8] On the other hand, the latent heat of vaporization of ethanol fuel is 3 to 5 times higher than that of gasoline, so the intake manifold temperature decreases [9]. Low concentration ethanol fuel can still be used in gasoline engines without changing vehicle parameters. However, the application of high concentrations still requires modifications, such as changes in injection duration, ignition timing, and compression ratio. To support this research, the writer cites several references to make the research more organized. For example, research conducted by A Setiyawan [10], where the engine used is a 110 cc 4 stroke gasoline engine with pertalite fuel, E10, E20, and E30. The results showed that the use of E30 fuel was more efficient when compared to pertalite. In addition, E30 fuel can reduce emissions of carbon monoxide (CO) and hydrocarbon (HC) compounds at 1500 rpm engine speed.

However, along with the increase in engine speed, the decrease in the two components is not too significant. Then in testing the maximum power using the E30 obtained by 7.47 Hp, while the maximum torque is obtained at 5.56 Nm. Research Al - Muhshen. N.F.O [11], which investigated an engine with a DI (Direct Injection) engine using ethanol as fuel, showed that the initial DI time values = 240, 270, 300, and 330 BTDC (Before Top Dead Centre), resulting in thermal efficiencies in the range of 30 – 32% for light loads at 3500 rpm engine speed. Then at the reverse timing DI with values = 60, 80, 100, and 120 BTDC, resulting in thermal efficiency in the range of 21 – 27% for light loads at 3500 rpm engine speed. Thus, it can be interpreted that the initial DI timing is better than the reverse timer DI setting. This is because, in the reverse timing DI setting, the time required for mixing fuel with air is not met. This causes the engine performance to experience a decrease in the value of thermal efficiency [12].

Iodice. P, research [6], which examined the 998 cc 4 stroke engine fueled by ethanol G0 (petrol), G10, G20, and G30, with the cold start method and tested on a two-wheeled chassis dynamometer, the results showed that the CO content in G0 fuel was higher than the CO content of G10 and G20 fuels. This is due to the amount of oxygen contained in G10 and G20. More oxygen will further encourage the oxidation process of CO compounds in the combustion chamber so that CO compounds will decrease. The higher the concentration of ethanol in a mixture of ethanol and gasoline, the oxygen content in it also increases. However, G30 fuel produces higher CO compounds when compared to G10 and G20. This is because the higher the ethanol concentration, the lower the calorific value, and the latent heat of vaporization of the fuel increases. This causes the combustion temperature and combustion speed to decrease, which can lead to incomplete combustion and increase CO emissions. Then the content of HC compounds in G10 and G20 fuel also decreased compared to G0 fuel. This is because a higher percentage of ethanol increases fuel volatility, so fuel evaporation also increases during cold transient start and reduces the HC content. However, it is different from the G30 which has a higher HC content when compared to the G10 and G20. Where the volatility of the G30 fuel is lower, the calorific value decreases, and the latent heat of vaporization of the fuel increases simultaneously. This also causes a decrease in ignition temperature, resulting in high HC compounds. Then other causes such as the actual AFR (Air Fuel Ratio) condition above a certain lean limit, so that partial combustion can occur which causes combustion failure and increased HC emissions [13].

Xiangbo Duan [14], where the engine used is a 4 stroke 150 cc gasoline engine using E70 and E0 (Pertalite) by varying the ignition timing, injection duration, and compression ratio, showing the results that in mapping ignition timing with a compression ratio of 12.5 fuel E70 and compared to standard conditions E0, get an average torque increase of 0.67%. However, SFC increased by an average of 10.7%, this was due to the air-fuel ratio being richer than gasoline [13]. Therefore, if you want the same power as the use of gasoline, then the consumption of ethanol fuel must be higher [15],[16],[17]. The emission results for CO and HC compounds decreased by 52.74% and HC emissions decreased by 8.3%. For optimal fuel injection mapping and to obtain maximum torque at engine speeds of 2000 to 4000 rpm, the injection duration used was 175%. Then at engine speeds of 5000 to 6000 rpm, the best injection duration was at 150%, and at engine speeds of 7000 to 8000 rpm the best injection duration was at 125%. The research method used in this study was an experimental method, in which direct testing was carried out on a 177 cc 4-stroke gasoline engine with E75 fuel (75% Ethanol and 25% Pertalite). This study involved changing several engine parameters, namely increasing the injection duration and changing the compression ratio, to determine their effect on engine performance and emissions.

With these parameters, the use of ethanol is expected to improve engine performance and reduce exhaust emissions. Therefore, the use of ethanol fuel has been considered as an alternative fuel solution in the future when petroleum fuels are exhausted, and then can reduce harmful pollutants produced by motor vehicles. The purpose of this work is to evaluate the effect of ethanol fuel use on engine performance and exhaust emissions, as well as to determine optimal fuel injection parameters. To achieve these objectives, the study was conducted using an experimental method using a 177 cc single-cylinder gasoline engine, with variations in fuel mixtures and injection durations as test variables. Performance and emission data were measured and analyzed to assess the effectiveness of ethanol use compared to pure gasoline.

2. Methods

Table 1. Engine Specification

Engine Type	LIQUID COOLED 4 STROKE, SOHC
Number of cylinders	Single Cylinder
Bore x Stroke	62 X 58,7 mm
Compression Ratio	11 : 1
Engine Volume	177,1 CC
Max of Power	12,2 kW / 8500 rpm
Max of Torque	14,5 Nm / 7500 rpm
Starter System	Electric Starter
Engine Oil Capacity	Change Filter Oil = 1 L
Engine System	Fuel Injection
Transmission Type	Constant mesh 5 – speed

This study uses a 177 cc 4 stroke 1 cylinder gasoline engine, which is then tested for engine performance and exhaust emissions using E75 fuel (75% ethanol and 25% pertalite). As reference data, before testing the use of E75 fuel and changes in engine parameters, first testing is carried out on standard engine conditions and the use of E0 fuel (100% pertalite). More detailed specifications of the test engine, it is presented in **Table 1**.

2.1 Materials

The fuel used is 99.7% ethanol, then mixed with gasoline (pertalite). The percentage of the mixture is 75% ethanol and 25% gasoline, or it can be called E75. In addition to E75 fuel, gasoline (pertalite) E0 was also tested as comparison data. For the initial stage of the research, the characteristics of the fuel were tested as shown in **Table 2**.

Table 2. Fuel Characteristics

No	Properties	Gasoline (E0 Pertalite 100%)	E75	Etanol
1	Research Octane Number	90	103,5	108
2	Density kg/m^3	0,76	0,79	0,8
3	Lower Heating Value kJ/kg	42690	34600	26805
4	Air Fuel Ratio	14,7	10	9
5	Viscosity at 20 ^{0}C/1 atm	0,42	1,1	1,20
6	Flash Point ^{0}C	- 43	8	13

During braking and stable engine speed, torque, emissions, and fuel consumption data can be collected and used for data calculation and analysis. The parameters for this study are presented in **Table 3**.

2.2 Research Design

To test the torque of the 177cc 4-stroke 1-cylinder petrol engine used a *prony brake dynamometer*, which is connected to *the engine crankshaft*. Then to test the fuel consumption of 10 ml use a stopwatch and measuring cup. To test HC and CO emissions, an *exhaust gas analyser was*. In terms of changing the injection duration mapping, the ECU (Engine Control Unit) used is a programmable ECU, making it easier to set engine parameters. For changing and measuring the compression ratio of the engine, a *burette* is used to measure the volume of the combustion chamber is changed. Before the test, the engine was started without the prony brake dynamometer brake load until it reached the engine working temperature of 80^0 C. The engine test used E0 and E75 fuel was started at an engine speed of 2000 to 6000 rpm and was carried out with the full open throttle method so that the engine power came out automatically full. When the throttle position is 100%, braking is applied to *the prony brake* until the engine speed drops and is stable at 2000 rpm to 6000 rpm alternately. The research image scheme can be seen in **Figure 1** below.

Table 3. Research Parameters

Input Parameters		**Output Parameters**	
Fixed Variable	Free Variable	Dependent Variable	Chart
1.The torque of a one cylinder 4-stroke 177cc gasoline engine 2.The compression ratio 13 : 1 3. Fuel E75 4.Gasoline Fuel (Pertalite) 5.Compression ratio (std)	1.Injection Duration fuel : a. 2% b. 4% c. 6% d. 9%	1. Power (kW) 2. Toque (Nm) 3.The fuel consumption time 10 ml or *sfc (specific fuel consumption)* 4.Exhaust gas emissions: a. HC b. CO	1. Torque to engine speed. 2. Power to engine speed. 3. *sfc* (*specific fuel consumption*) to engine speed. 4. HC exhaust emissions to engine speed. 5. CO exhaust emissions to engine speed.

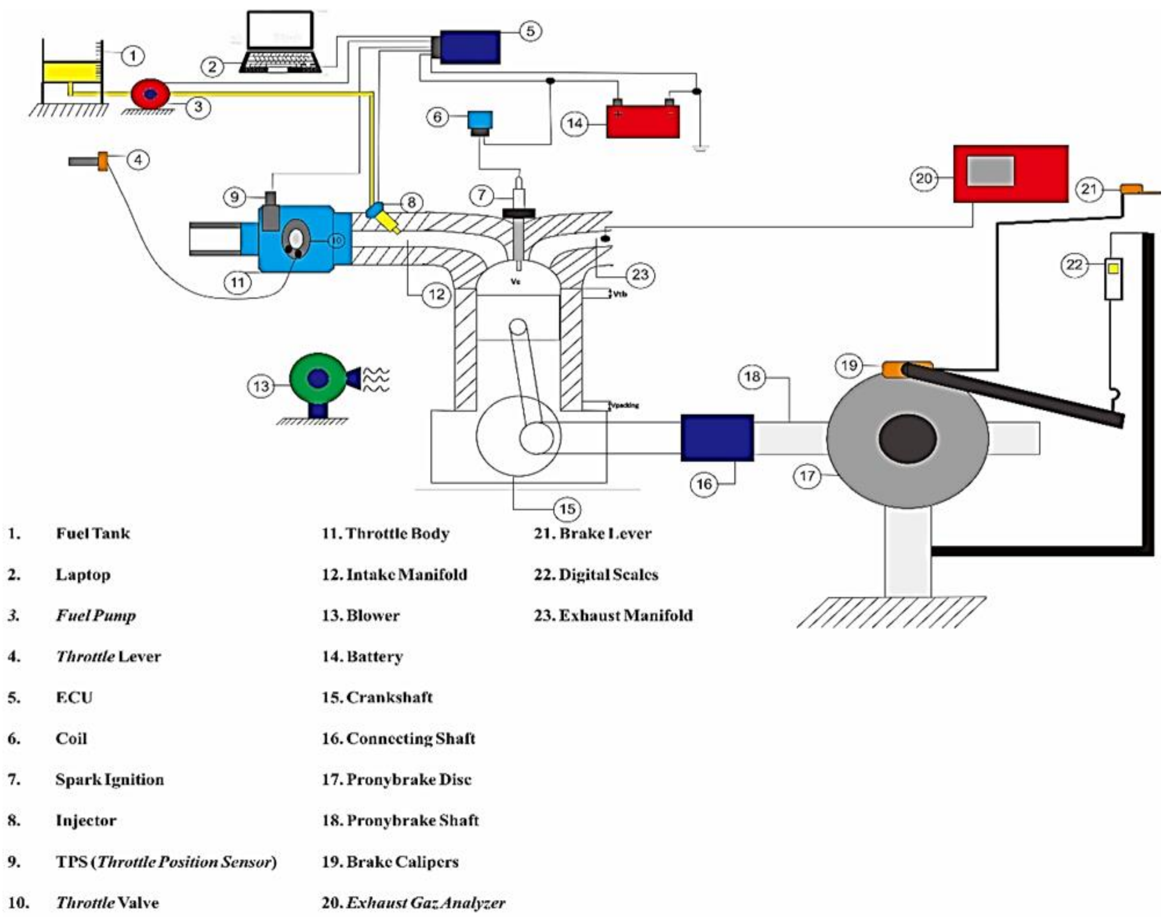


Figure 1. Research Scheme

3. Results and Discussion

The results of the research on the Performance and Exhaust Gas Emissions of a Four-Stroke Gasoline Engine Variation of Injection Duration Mapping with E75 Ethanol Fuel resulted in 5 sub-chapters of discussion which are discussed in sub-chapters 3.1 to 3.2 as follows.

3.1 Performance Analysis

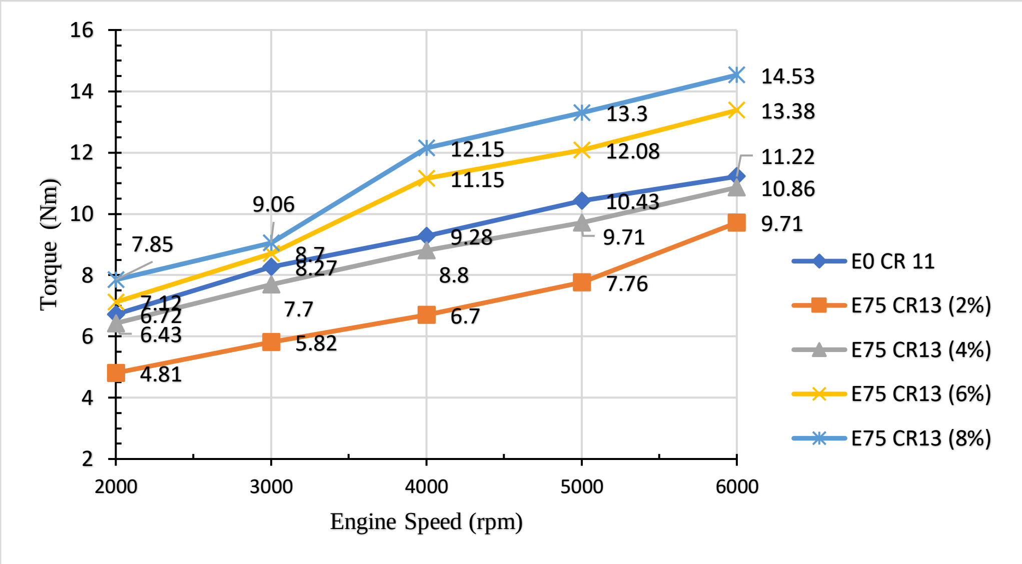
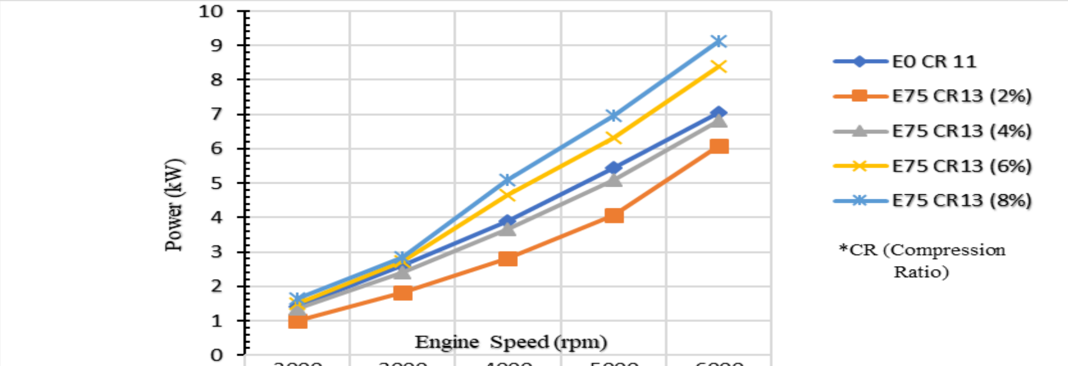


Figure 2. Torque Graph of Injection Duration Variation to Engine Speed

From Figure 2 above, it can be seen that the use of E75 fuel and E0 fuel shows the same trendline. Whereat engine speed of 2000 rpm to 6000 rpm, the torque value produced by all variations continues to increase. However, if we look further, the highest torque value of 14.53 Nm is found in the use of the E75 CR 13 with injection duration (8%). Then on the use of E75 CR with injection duration (6%), the highest torque was obtained at 13.38 Nm. The torque of the two variations is higher than the use of E0 CR 11, where the torque obtained by E0 is 11.22 Nm. Then the variation in the duration of the injection of E75 CR 13 (2%) and (4%) experienced a decrease in performance, where the resulting value was lower than the use of gasoline. This is because the AFR (air-fuel ratio) at 6% injection duration and 8% use of E75 is estimated towards AFR stoichiometry and at 2% and 4% duration to get a poor AFR (lean). Where the AFR stoichiometry value of gasoline fuel with ethanol is different. The AFR stoichiometry value for gasoline is 14.7: 1, and for ethanol fuel is 9: 1. If it is close to the AFR stoichiometry value for fuel, the combustion is more complete so that the engine performance is more optimal. So that it can be interpreted that to get a higher torque from the use of gasoline, the use of ethanol must increase the injection duration until it reaches AFR (rich). In addition, the increase in the compression ratio on the use of the E75 causes the temperature and pressure in the combustion chamber to increase, so that the piston thrust from TDC (Top Dead

Centre) to BDC (Bottom Dead Centre) is greater, causing engine performance to increase [18].



	2000	3000	4000	5000	6000
E0 CR 11	1,4	2,6	3,88	5,45	7,04
E75 CR13 (2%)	1	1,82	2,8	4,06	6,09
E75 CR13 (4%)	1,34	2,41	3,67	5,08	6,82
E75 CR13 (6%)	1,5	2,73	4,66	6,32	8,4
E75 CR13 (8%)	1,64	2,84	5,08	6,96	9,12

Figure 3. Power Graph of Injection Duration Variation on Engine Speed

Figure 3 above shows the trendline of engine power results using E75 with several variations in injection duration and using E0 without changing the engine. It can be seen that the engine torque results are almost the same as the engine power results, in other words, the engine power results are influenced by the torque produced. Then when the engine speed increases from 2000 rpm to 6000 rpm, the engine power results show an increase. This is influenced by the turbulence of the airflow entering the combustion chamber which is getting higher as the engine speed increases. This results in a more optimal air and fuel mixture so that the torque and engine power produced will increase. The highest engine power is found in the use of the E75 CR 13 for injection duration (8%) and injection duration (6%). Where the increase in power by 29% and 19% of the results of the use of power E0 CR 11 without modification. However, when using E75 CR 13 for the duration of injection (4%) and (2%), there was a decrease in the value of engine power by 3.3% and 15% compared to the use of E0 CR 11. The power value of using E75 was influenced by the heating value of ethanol fuel. lower than gasoline. So that the use of ethanol requires a longer injection duration to produce higher power than the use of gasoline [19].

Figure 4 above shows the trendline of BSFC (Brake Specific Fuel Consumption) results using E75 with several variations in injection duration and using E0 without changing the engine. From the graph, it can be seen that the SFC value decreased from 2000 rpm to 6000 rpm. This is because, at low engine speed, the load received by the engine is greater. While the power generated at low engine speed is relatively small, the resulting SFC is large. Taken for example at 5000 rpm engine speed, the highest SFC is found in the variation of E75 CR 13 injection duration (2%). The result of this variation increased by 30% from the result of SFC E0. Then in the variation of E75 CR 13 the duration of injection (4%), (6%), and (8%) also increased by 27%, 18%, and 12%, respectively. This is because the LHV (Lower Heating Value) of ethanol is lower than gasoline. So, ethanol requires more fuel consumption than gasoline to get the same power output [20].

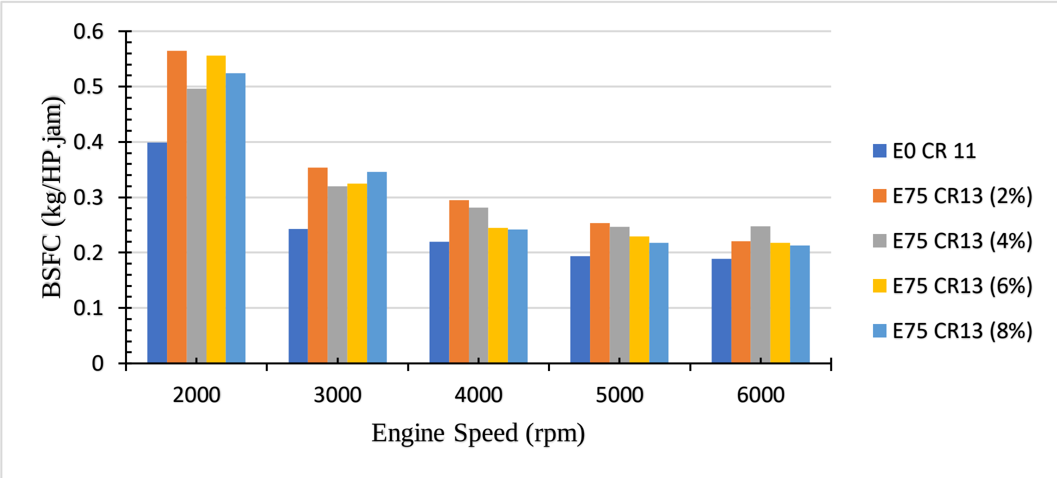


Figure 4. BSFC Graph of Injection Duration Variation on Engine Speed

3.2 Exhaust Gas Emission Analysis

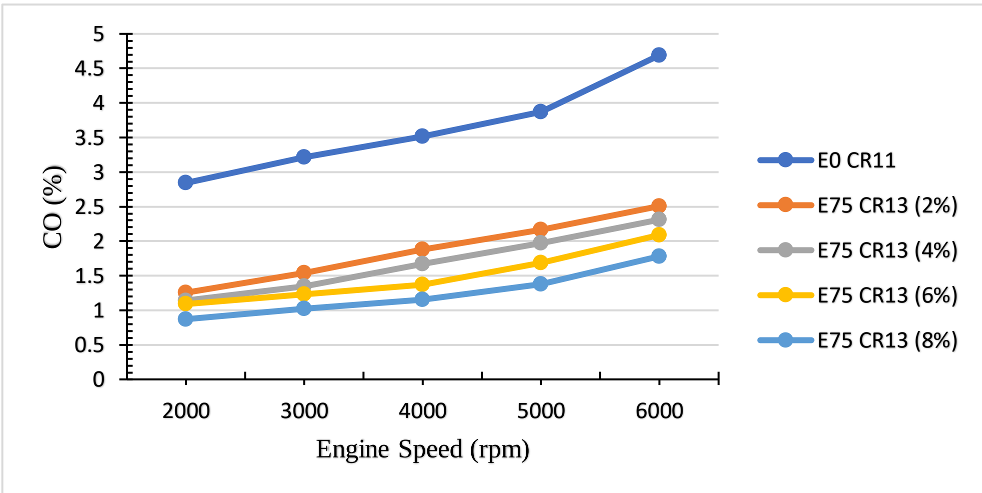


Figure 5. Graph of CO Emissions for Variations in Injection Duration with Engine Speed

Figure 5 shows the results of CO (carbon monoxide) emissions from the use of E75 fuel and gasoline at engine speed. The graph above shows the trendline of increasing CO emission values with increasing engine speed in all variations. This is because, at a higher engine speed, the combustion speed remains, while the mechanical speed increases. So that combustion is not complete, resulting in a lot of unburned fuel and increased CO emissions. For comparison between the results of E75 and E0 CO emissions, it is found that the trendline of CO emission results decreases with the use of all variations of E75. Seen at 2000 rpm engine speed, the highest reduction in CO emissions was 69.5% and was obtained from the use of E75 CR 13 with injection duration (8%). Then the use of E75 CR 13 with injection duration (2%), (4%), and (6%), reduced CO emissions by 55.8%, 60%, and 62%. This is by Hasan, H. research, where a mixture of gasoline and ethanol can reduce CO emissions. Because ethanol fuel has an oxygen element, where the oxygen element in ethanol is a reactant that can bind CO to CO2 (carbon dioxide) [13]. In addition, the addition of the engine compression ratio also results in a decrease in CO emissions. Where the addition of the compression ratio to the use of E75, produces a higher temperature and pressure in the combustion chamber so that combustion is more optimal and CO emissions are reduced [21].

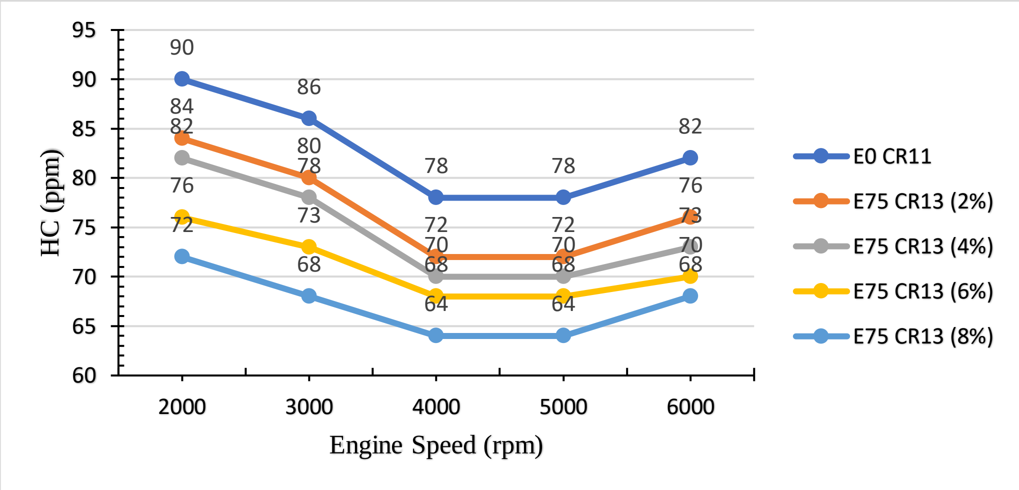


Figure 6. Graph of HC Emission Variations in Injection Duration with Engine Speed

Figure 6 presents the trendline of HC emission variations on the duration of injection using E75 and gasoline at engine speed. The graph above shows that when the engine speed starts to increase, the HC emission value decreases. However, when the engine speed is high, HC emissions start to increase again. This is due to the increased homogeneity of the air and fuel mixture when the engine speed begins to increase. However, HC emissions increase again when reaching higher engine speeds. This is due to the combustion speed which tends to remain constant, while the mechanical speed increases. So that the combustion in the combustion chamber is not normal, and causes HC emissions to rise. In all variations, the use of the E75 experienced a reduction in HC emissions compared to the use of gasoline. The highest reduction in HC emissions is 17% at 6000 rpm engine speed with the use of the E75 CR 13 injection duration (8%). The advantage of ethanol in reducing HC emissions is the presence of oxygen. Where the element of oxygen in ethanol functions as a binder of HC compounds and reduces HC emissions from the engine.

4. Conclusion

The results of testing the torque and power of the engine using the E75 increased by 30% and 19% at 8000 rpm engine speed, and were obtained with the injection duration (6%) and (8%). Where the variation is estimated towards the ethanol stoichiometric AFR of 9:1 so that the performance increases. While the use of E75 injection duration (2%) and (6%) decreased, it can be estimated that this variation runs on AFR (lean). In addition, the increase in the compression ratio on the use of the E75 causes the temperature and pressure in the combustion chamber to increase, so that the piston thrust from TDC (Top Dead Centre) to BDC (Bottom Dead Centre) is greater, causing engine performance to increase.

The results of the SFC value at 5000 rpm engine speed, the highest SFC value results in the use of E75 CR 13 with injection duration (2%). The percentage increase is 30% compared to the use of the E0 CR 11 without modification. Then the use of E75 CR 13 with injection duration (4%), (6%), and (8%) also increased by 27%, 18%, and 12%. The increase in SFC value using ethanol is due to the lower LHV (Lower Heating Value) value of ethanol fuel compared to gasoline. This causes ethanol to require more fuel consumption.

The results of CO emission using E75 decreased by 69.5% and were obtained from the use of E75 CR 13 with injection duration (8%). Then the use of E75 CR 13 with injection duration (2%), (4%), and (6%), reduced CO emissions by 55.8%, 60%, and 62%. The decrease in CO emissions is caused by the presence of oxygen in ethanol which acts as a CO binder to CO2 so that CO emissions decrease.

The results of HC emissions using E75 decreased by 17% at 6000 rpm engine speed with the use of E75 CR 13 injection duration (8%). The advantage of ethanol in reducing HC emissions is the presence of oxygen. Where the element of oxygen in ethanol functions as a binder of HC compounds and reduces HC emissions from the engine. In addition, a high compression ratio causes the temperature and pressure to increase so that combustion in the combustion chamber is more optimal.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials - All data is available from the authors.

Competing interests - The authors declare no competing interest.

Additional information - No additional information from the authors.

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