A Strategy in Adjustment of Combustion Parameters of SI-PFI Engine with Pure Bioethanol Fuelled for a High Performance and Low Emission

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Abstract: - Many researchers reported that the gasoline-Bioethanol blend have a big advantage to reduced hydrocarbon emissions. But, there was an inconsistence in increases of NOx emission when the blend contained by Bioethanol less than 50%. Usage of pure Bioethanol fuels (E100) is one of solution to minimized NOx emission. This work investigated the effect of E100 on performances and emissions of spark ignition engine with varied compression ratio and engine speed. This study is a continuation research with applying two methodology. Mapping the injection duration is a method that used at the first study. In mapping the injection duration, the ignition timing was fixed at 7^{o}BTDC. But in this research, mapping the ignition timing strategy will complement of the first methodology. This paper evaluated advances of ignition timing from 10 to 22^{o}BTDC with an increment of 4^{o}BTDC. All the results will be compared with previous study, even when the engine runs with E0 fuels. Fortunately, there are a significance increase in performances was being achieved by this experiment as an improvement of previous process. The values describes about increases of the torque, power, BMEP and thermal efficiency as well as decreases of SFC and CO emission, meanwhile, HC emission tend to stable

Key-words: - injection duration, ignition timing, compression ratio, advance, pure bioethanol, mapping

1 Introduction

Indonesia as an agriculture country have an abundant natural resources, particularly in feedstock of biofuel. It is a big chance to develop usage of bioethanol fuel as a renewable energy for replace the fossil fuel. Changed gasoline as a main fuels for vehicles has been a major issue since in the last decade. It is caused by the availability of fuels has been limited, even, a high technology and costly infestation is needed to exploit the existing reserve [1]. Moreover, combustion product of gasoline fuels such as CO, HC, NO_x and CO_2 emissions are very harmful on human health and environment [2].

Application of bioethanol in automotive engine is a solution to reduce the greenhouse gas (GHG) that caused in global warming. As an oxygenate fuels, bioethanol had been reducing the hydrocarbon emission both as a blend fuels and pure fuels [3]. Bioethanol as a fuel in vehicle of Model T used by Henry Ford 1880, after that the fuel was popularized by Nicholas Otto as a transportation fuels since 1897 [4, 20]. The stockpiles of fossil fuel of Indonesia will run out for 12 – 15 years, so the alternative energy should be prepared early [5]. Moreover, the government of Indonesia have allocated about 20%-30% of bioethanol in all of energy consumption up to 2050 [6].

The aim of this study reported in this paper is to investigate the effect of E100 fuels on performances and emissions with varying the high compression ratio, and using a range of spark timing. As reviewed by Paloboran et al [7] that application of gasoline-bioethanol blend up to 20% (E0-E20) in spark ignition engine is not needed any adjustment on engine. Meanwhile, set of the compression ratio was required to accommodate the increases of octane rating in mixture when E25-E40 is used. The last one, adjusting the prime combustion parameters i.e. compression ratio, injection duration, ignition timing and air-fuel ratio should be done simultaneously when the gasoline is blended with ethanol more than 50%.

2 Literature Review

Bioethanol as a fuel has been mostly applicable in spark ignition engine than compression engine because the properties of bioethanol is close to gasoline rather than diesel. The advantageous properties of bioethanol in spark engine is a latent heat of vaporization that can increased the volumetric efficiency, reduced the over cylinder temperature and minimized NO_x emission [8]. Oxygen content of bioethanol led to speed of firing increased and complete combustion is obtained, then the variation of cycle is low. The oxygen content of bioethanol is also effective reducing the CO and HC emissions and improving the fuel efficiency [9]. The high laminar flame speed of bioethanol will be made the combustion process shortly, increased the stability of combustion and reduced the heat loss, in turn, increased the thermal efficiency [10]. Meanwhile, the high octane grade of bioethanol allow to improved the compression ratio, in turn, increased the power, torque, cylinder pressure and thermal efficiency [11].

In contrast, there are some drawback of bioethanol when applied in spark ignition engine. Reid vapour pressure of bioethanol caused the engine difficult started in the winter and being a trigger on increases of aldehyde emissions [12-14]. Aldehydes emission are also caused by presence of the hydroxyl (OH) compound in bioethanol that forming formaldehydes (HCHO) and acetaldehyde (CH_3CHO) emissions. The number of aldehydes emissions in the exhaust gas depending on the concentration of bioethanol in the fuels, load of engine and percentage of oxygen in the fuels [15-18]. Aldehydes emissions of pure bioethanol fuel is higher than gasoline-bioethanol blend, but NOx emission that is produced by the gasoline-bioethanol blend is higher than pure bioethanol [19].

There were two strategies to overcome the cold start problems when bioethanol is used. Firstly, the temperature of air or fuels is increased before it flowing into the combustion chamber. The second is using two fuel tanks which the gasoline fuel is used early. When the temperature of engine was hot, then supply of the fuel could be switched to the bioethanol [20]. Solubility of bioethanol in the water or otherwise are a hundred percent so the engine material is damage easily, particularly that made from metal and rubber [20]. In the certain pressure and temperature, gasoline-bioethanol blend could be separated each of other. This problem can attacked by using isopropanol as a co-solvent in the blend [21]. In the same volume, power and torque that is produced by bioethanol is lower than gasoline. It is contributed by heating value of bioethanol is lower than that gasoline. Therefore, increase of torque and engine power could be done by increasing the bioethanol injection. Adding of injection volume can be conducted with enlarging the hole of injector or extended the injection duration.

The study about usage of bioethanol as a blue energy had been being investigated by several researchers with many aspect. Therefore, this study will be revealing the effect of pure bioethanol on Indonesia's motorcycle at various high compression ratio. As a mentioned earlier, high octane number of bioethanol allowed to improving the high compression ratio for generate high thermal efficiency, as stated by the formula [22]:

$$\eta_{th} = 1 - \frac{1}{\gamma^{k-1}} \quad ....(1)$$

Where, γ is compression ratio and k is heat of capacity. Balki et al. [23] studied the combustion effect of methanol (M100), bioethanol (E100) and gasoline (E0) on characteristic of performance and emissions at various compression ratio, wide open throttle and constant engine speed. The maximum of combustion efficiency was reached at compression ratio of 8.5:1 by E0, E100 and M100 with 97.57%, 99.26% and 99.45% respectively. Therefore, the BMEP and BTE of M100 and E100 increased when the compression ratio increased. The BMEP and BTE of gasoline cannot to follow in the trend BMEP and BTE of M100 and E100. It is caused by the octane grade of gasoline lower than alcohol fuels. Meanwhile, the CO and HC emissions increased when the compression ratio increased up to 9.5:1. There is an increase of combustion chamber surface ratio to cylinder volume when the compression ratio increased. As a result, there is a misfiring in cylinder, so the CO and HC emissions formed.

Chelik MB [22] showed that the power and torque of E50 fuels is higher than those E25, E75 and E100 at compression ratio of 6:1 and 2000 RPM. The average of power of E50 increased by 23% if compared with E0 when the compression ratio was seated at 10:1. The power of E50 increased by 29% higher than gasoline when the engine runs at 1500-4000 RPM. The CO emissions of E50 decreased significantly if the compression ratio increased at 1500-4000 RPM. On the other hand, the CO_2, HC and NO_x emissions increased slightly when the compression ratio increased too. It is influenced by the ignition timing of engine is too advance for E50 so the fire is easy to extinct when the compression ratio was increased [24]. This study was supported by the experiments of Farha et al [25-26] and Sudarmanta et al [27]. They have presented the CO and HC emissions decreased when the percentage of bioethanol and compression ratio increased. On their study, the ignition timing was adjusted by minimum advance for maximum brake torque method.

The caloric value of bioethanol is only two-thirds than caloric value of gasoline. It is impacted to the specific fuel consumption (SFC), where the SFC of bioethanol is higher than gasoline. Turkoz et al [28] have been proving that the power and torque is higher when the injection duration was extended with widening the hole of injector in two times from the standard. Celik have stated that the heating value of bioethanol is lower than that of gasoline. Therefore, it necessitates 1.5–1.8 times more bioethanol fuel to achieve the same energy output. Paloboran et al [29] have been explaining that is required 150% -200% of the injection duration to obtain the maximum torque when the E100 fuel is used. Furthermore, the average of power was in 12.62kW, 12.97kW and 13.28kW at the compression ratio of 12, 12.5 and 13 respectively, while the gasoline was in 11.44kW. Then, the CO and HC emission was decreased in ranging 38–65% and 12 – 18% when the compression ratio was increased from 12 to 13 if compared to gasoline.

Ignition timing have a dominant impact on the performance and emissions of internal combustion engines, so it is should be re-adjusted when the compression ratio will be changed [12]. Yucesu at al [30] studied effect of various ignition timing on the torque and BSFC at constant engine speed. In this study, E10, E20, E40 and E60 fuel were burnt at compression ratio of 8:1 and 10:1. The result showed that the maximum torque and BSFC was in 26^o BTDC at 8:1 of compression ratio, and in 22^o BTDC at compression ratio of 10:1. It was proving that the ignition timing is retarded when the compression ratio increased at the constant speed.

Meanwhile, Phuangwongtrakul et al [31] investigated the effect of variations in ignition timing on the torque and BSFC. The engine was run at compression ratio of 10.5 and constant engine speed of 5000 rpm. The result shows the ignition timing was advanced when the percentage of bioethanol increased. The maximum brake torque (MBT) is a method to determine the suitable of the ignition timing on each of engine speed. This strategy has been conducted successfully by several researchers, those are; Sudarmanta, Costa R, Alexandru et al [32] and Yoon SH et al [33]. Their conclusion stated that the ignition timing should be advanced when the compression ratio and engine speed increased. The studies that is conducted by Binjuwair S [34] and Sayin C [35] shows the thermal efficiency and power increased when the ignition timing was advanced, since the engine speed increased. As an additional result, the BSFC, HC and CO emissions decreased at the same treatment.

3 Experimental Section

The engine test that used in this experiment are 4 stroke engine, 1 cylinder and types of CB150R by Honda manufacturers. The compression ratio standard of engine is 11: 1, but it has been developed to 13: 1 to accommodate the use of bioethanol.

Table 1: Engine test

Parameters	Standard
Engine type	4 Stroke, 4 Valve, 1 cylinder
Bore	63,5 mm
Stroke	47,2 mm
Displacement volume	149,5 mm
Compression ratio	11,0 : 1
Ignition system	Full transistorized
Maximum power	12,5kW(17 PS)/10000RPM
Maximum torque	13,1Nm(1,34kgf.m)/8000RPM
Intake valve open	5^o BTDC, lifting 1 mm
Intake valve close	35^o ABDC, lifting 1 mm
Exhaust valve open	35^o BBDC, lifting 1 mm
Exhaust valve close	5^o ATDC, lifting 1 mm
Valve Train	Chain, DOHC

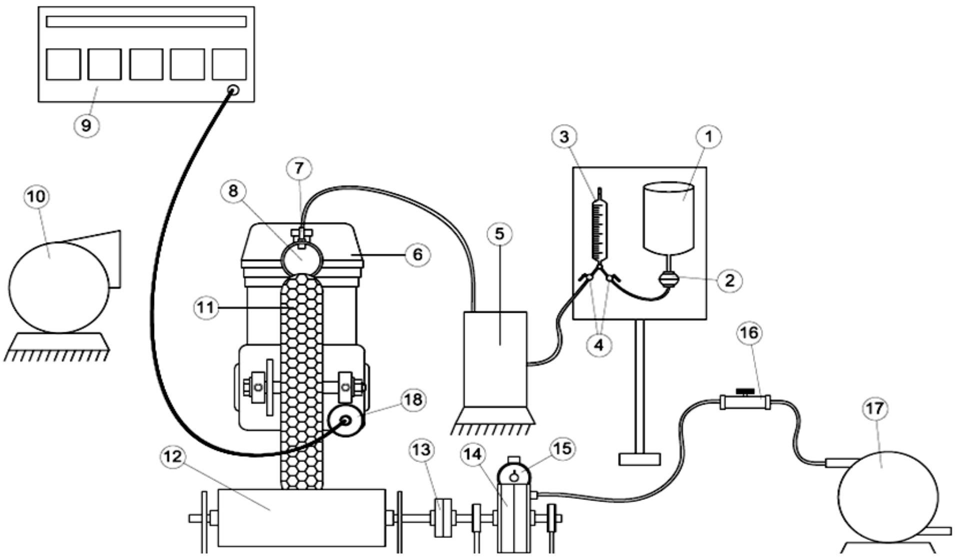
Compression ratio standard of engine is 11:1 which was develop up to 13:1 with applying a dome on cylinder head. While at the compression ratio of 12:1 and 12.5:1, a suitable gasket is applied on the engine. The detailed of engine specifications are shown in table 1.

The main condition in this test is a fully open throttle and speed engine varied from 2000 to 8000 rpm. While, the lambda (relative air fuel ratio) was calculated within formula [36]:

$$\lambda = \frac{AFR_{actusl}}{AFR_{stoic}} \quad (2)$$

Set of the engine speed is controlled by a water brake dynamometer type of DYNOmite, and the torque is recorded after the engine reaches at the specified speed. Some of thermocouples are mounted at any engine equipment to record the coolant oil temperature, cylinder block and cylinder head. A STARGAS 898IND is placed on exhaust manifold to detected the CO and HC emissions. As additional information that CO_2 and NOx emissions sensor is may not worked properly.

Type of gasoline is used have a RON 92, in Indonesia it is called PERTAMAX. While, the bioethanol that is used in this test have a RON of 110. The bioethanol fuel in this test is produced by Energy Agro Nusantara (ENERO) Co. Ltd. Time of fuel consumption is noted when the engine has spent in each of 25 mL of fuel. In this test, the best mapping the injection duration that obtained from previous study was applied. While, mapping the ignition timing is performed at all compression ratio and engine speed. The ignition timing of 10-22^{o}BTDC with an increment of 4^{o} were investigated in this experiment. The best of ignition timing based on the maximum brake torque. The entire of testing process is controlled by an electronic control management of ECU SUM-IT.



1. Fuel Tank
2. Filter fuel
3. Glass gauge
4. Valve
5. Fuel pump
6. Engine test
7. Injector
8. Throttle body
9. Gas analysers
10. Blower
11. Back train
12. Roller of back train
13. Clutch
14. Dynamometer
15. Torque gauge
16. Valve
17. Water pump
18. Exhaust manifold

Figure 1: The engine test

4 Result and Discussion

4.1 Mapping the duration injection

Mapping the duration injection strategy have been applied in the previous study. One the important thing of the method, the injection volume of bioethanol depend on the engine speed. The injection volume of 150-175% was required to obtain in the maximum torque at 5000-8000 rpm. But, the injection volume of 200% is needed at 2000-4000 rpm at all of the compression ratio. At the low engine speed, the injection volume of bioethanol is bigger caused by the caloric value of bioethanol is low. But, in the high engine speed, the cylinder temperature will increased, so the bioethanol fuel is easy evaporated to produces the maximum torque. Overall, the best performance of engine was obtained in the injection duration of 150% - 200% at all of the compression ratio.

As a review, if compared with E0 at the compression ratio 11:1, the engine performance of E100 fuels increased by 5.24% at the compression ratio of 12:1. Moreover, the performance increased by 7.74% and 9.39% when the E100 is used at the compression ratio 12.5:1 and 13:1 respectively. Meanwhile, the CO emission decreased significantly by 38.8%, 50.3% and 63.7% at the compression ratio 12, 12.5 and 13 respectively. Then, the HC emission decreased slightly by 11.8%, 14.1% and 17.8% when the compression ratio was increased gradually.

In contrast, there is an increase of SFC about 71.1% when the bioethanol is applied at the compression ratio of 12:1. The SFC decreased slightly to 66.2% and 61.2% when the engine runs at the compression ratio of 12.5:1 and 13:1. Similarly, the thermal efficiency of bioethanol is inferior to gasoline. The thermal efficiency of gasoline is about 34% at compression ratio of 11, while the bioethanol efficiency are approximately

20%, 21% and 22% at compression ratio of 12, 12.5 and 13 respectively. One of the objective of the study is to overcoming the losses of the SFC and thermal efficiency of bioethanol.

4.2 Brake Torque

Figure 2 presented the effect of E100 and E0 on the torque at variations in engine speed. The torque of gasoline was obtained by the engine standard, but the bioethanol was obtained by mapping the ignition timing at all the compression ratio and engine speed. The study have been identifying the ignition timing were affected by the compression ratio and engine speed. The ignition timing would increase when the compression ratio and engine speed increases. The ignition timing that have been obtained at the compression ratio of 12 are 10^{o} BTDC on 2000-3000 rpm, 14^{o} BTDC on 4000 rpm and 18^{o} BTDC on 5000-8000 rpm. But, the spark timing of 14^{o} was in range 4000-5000 and 4000-6000 rpm when the compression ratio is increased of 12.5 and 13.

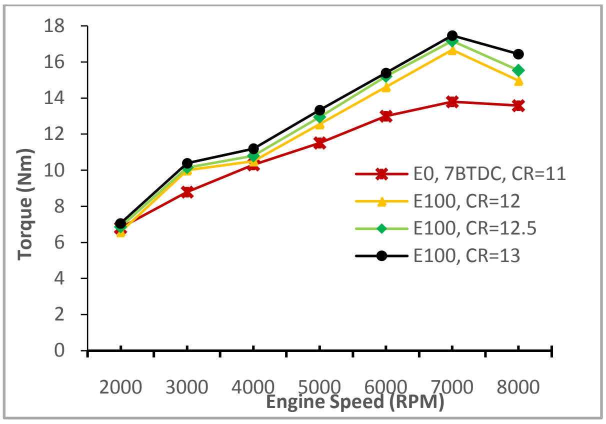


Fig 2. The effect of E100 and E0 on the torque at variations in engine speed.

In this test, the 22^{o} and 26^{o}BTDC is too advanced in all the compression ratio and engine speed, even their values is lower than gasoline. It was found also that there is a decrease of torque when the engine runs on top speed. It was caused by the lack of air in the blend, while the mass flow rate of fuel increased at the high speed. The increase in the average of torque at the maximum compression ratio is about 16% when compared to gasoline. Mapping the ignition timing have been successful increasing the torque by 7% when compared to the previous study.

4.3 Brake Power

Figure 3a-b and 4a-b showed the effect of E100 and E0 on the brake power at variations in speed and compression ratio that produced from mapping the ignition timing. In theoretically, the power had been being written in equation [37]:

$$\text{BHP} = 2\pi NT\left[\frac{Nm}{s}\right] \quad \ldots.. \ (3)$$

Where N is engine speed (revolution per second) and T is torque (Nm), so the torque have a direct correlation with the brake power. In the figure 3a-b and 4a was described that the ignition timing have not a significant impact on the brake power at rpm of 2000-4000. The power of bioethanol is start to increasing when the engine speed had been running at 5000-8000 rpm, particularly in the ignition timing of 18^{o}. The power of 18^{o} is seems dominant than others in figure 3, 4 and 5, although it could be offset by the gasoline in figure 3.

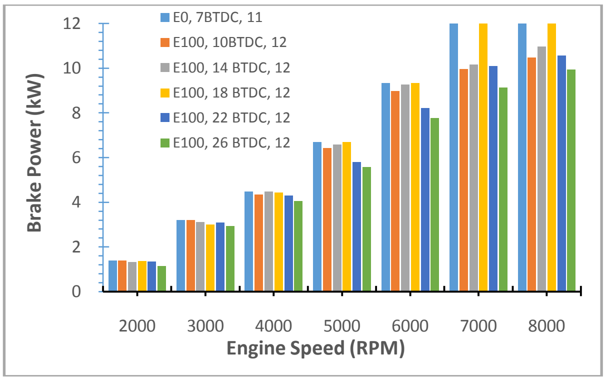


Fig 3. Brake power versus rpm at CR of 11&12

By these experiment, known that the 18 BTDC is the suitable ignition timing for E100 fuels at all the compression ratio and engine speed. The high of gasoline heating value has been being a contributor in a power of gasoline is equal to bioethanol in compression ratio of 12. But, the low of gasoline octane number has a caused these trend cannot be continued when the compression ratio was increased at 12.5 and 13 respectively.

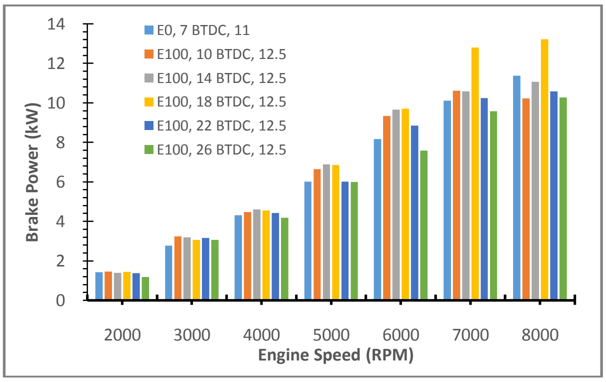


Fig 4. Brake power versus rpm at CR of 11&12.5

There is an increase of power by about 3% and 2% if the compression ratio was increased from 12 to 12.5 and 13 at each of the ignition timing. Moreover, the power increased by about 12%, 15% and 18% at the compression ratio 12, 12.5 and 13 respectively if compared with the gasoline (figure 6). The top power of the engine only about 11.4kW when E0 is applied, while in the ignition timing of 18^{o} BTDC is about 12.8kW, 13.2kW and 14.0kW at the compression ratio 12, 12.5 and 13 respectively.

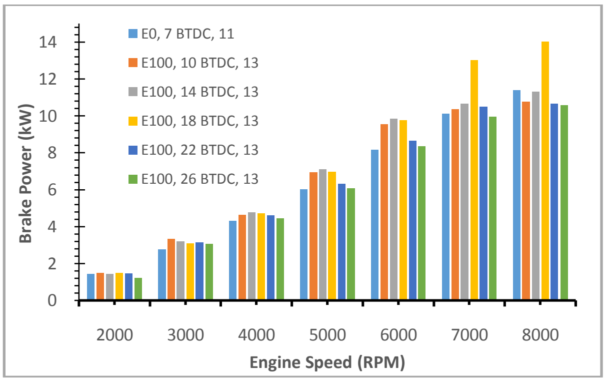


Fig 5. Brake power versus rpm at CR of 11&13

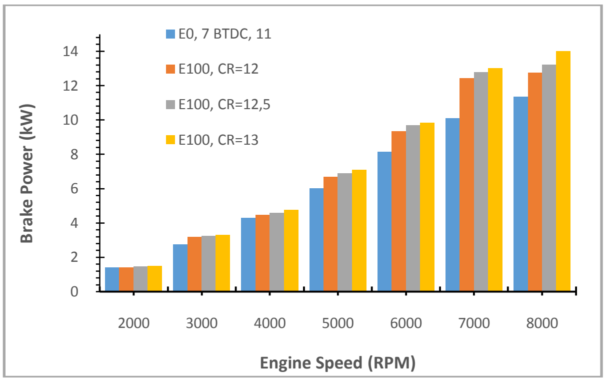


Fig 6. Brake power versus rpm at CR of 11-13

4.4 Brake Mean Effective Pressure

Figure 7-9 provided the effect of various ignition timing and speed of engine on brake mean effective pressure at 12, 12.5 and 13 of compression ratio. In general, the BMEP have a similar trend with the power and torque, because one each other cannot be separated. But, there is a differentiation on the BMEP between gasoline and bioethanol, particularly at the compression ratio of 12. The BMEP of gasoline is more powerful than bioethanol in figure 3, but it is not seems at figure 7. The stroke volume of piston increased when the compression ratio decreased, while the torque of gasoline lower than those bioethanol at these situation, so the BMEP of gasoline lower than those bioethanol, especially in the high speed. The phenomenon can be described by the formula as follow [38]:

$$\text{BMEP} = \frac{\text{BHP x z}}{\text{A x L x N x i}} \left[\frac{N}{m^2}\right] \qquad \text{... (4)}$$

Where z is a coefficient of motor, A x L is volume of stroke and i is amount of cylinder. In contrast to the power, the BMEP of bioethanol increased sequentially in ignition timing when the engine speed increased up to 6000 rpm in all the compression ratio. But, in engine speed of 7000-8000 the increase of BMEP was only dominated by the ignition timing of 18^{o}BTDC, while the others tend to decreased. The BMEP of bioethanol decreased when the engine achieved top speed. It is caused by the increase of friction loss and decrease of volumetric efficiency in high engine speed, so the BMEP of engine decreased. However, by mapping the ignition timing strategy, the BMEP of bioethanol can be maintained for increased gradually up to the 7000 rpm. Overall, the BMEP of bioethanol higher than those gasoline, because the laten heat of vaporization of bioethanol higher than those gasoline.

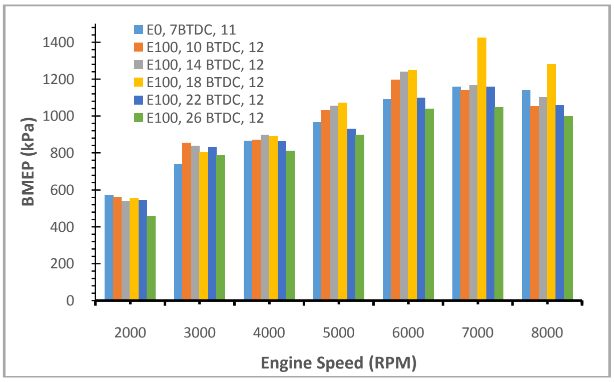


Fig 7. BMEP versus rpm at CR of 11&12

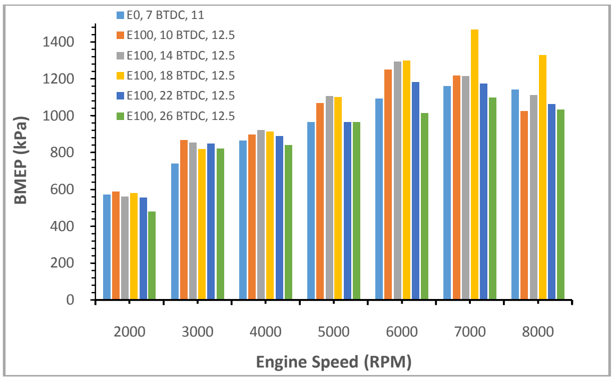


Fig 8. BMEP versus rpm at CR of 11&12.5

4.5 SFC and Thermal Efficiency

One of the drawback of bioethanol compared to gasoline is the caloric value where the heating value of bioethanol lower than gasoline, in turn, injection volume of bioethanol higher than those gasoline to obtaining the same power. Moreover, the low of vapour pressure of bioethanol has caused increase of fuel consumption, particularly in a low engine speed. The fuel consumption is more decreased when the engine speed increased. The cylinder temperature would increase when the engine speed increased, so the bioethanol will be evaporates easily. Figure 11 showed the effect of E100 and E0 on the SFC at variations in the compression ratio and engine speed.

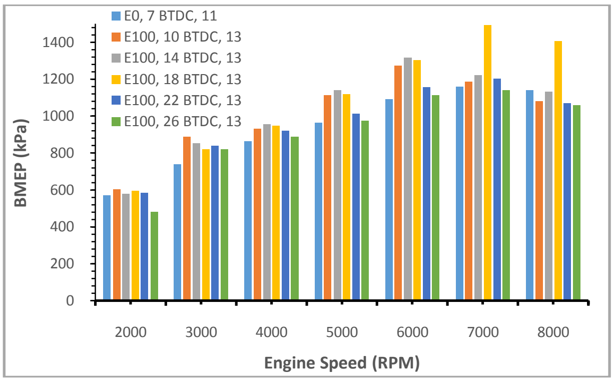


Fig 9. BMEP versus rpm at CR of 11&13

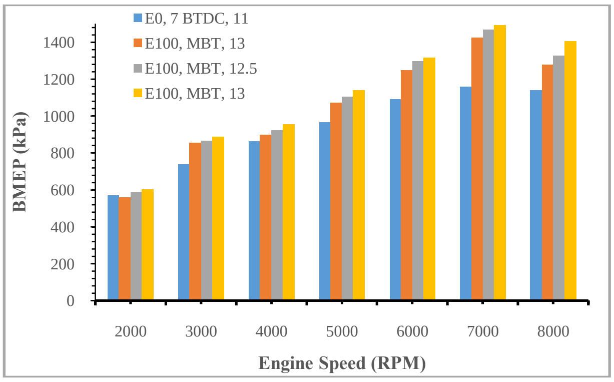


Fig 10. BMEP versus rpm at CR of 11-13

All of the SFC of bioethanol illustrated the same trend line at the all compression ratio, even the SFC of compression ratio of 12 and 12.5 has a very slight differences. By increasing the compression ratio, the fuel consumption of bioethanol decreased by about 0.5% and 11% at the compression ratio of 12.5 and 13. However, compared with the gasoline, there is an increases of the SFC by about 72.7% when bioethanol is applied at the compression ratio of 13. Nevertheless, the SFC of bioethanol gradually decreased when the engine speed increased. In the high of compression ratio and engine speed, combustion of bioethanol is better, because the bioethanol fuels is easy to evaporate and then the complete combustion would be obtained [39].

Brake thermal efficiency expressed the ability of combustion system to optimize the potential energy of fuel, then converting to become mechanic output. Commonly, the BTE is stated in an equation [40]:

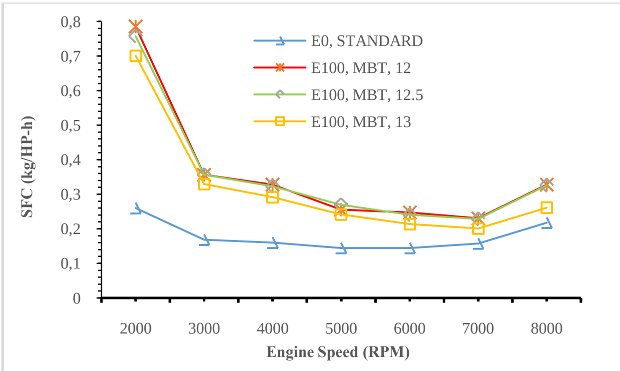


Fig 11. SFC versus rpm at MBT

$$BTE = \frac{3600 \text{ x } BHP}{\text{Fuel Consumption x } LHV} \quad \ldots (5)$$

Where LHV is low heating value of fuel and BHP is brake horse power of engine. Figure 12 display the effect E100 and E0 on the BTE at variations in compression ratio and engine speed. In the previous study, the BTE of gasoline is superior to those bioethanol at all of the engine speed and compression ratio. But by mapping the ignition timing strategy, the BTE of bioethanol can be close to the gasoline, even the BTE of bioethanol higher than gasoline at a high engine speed.

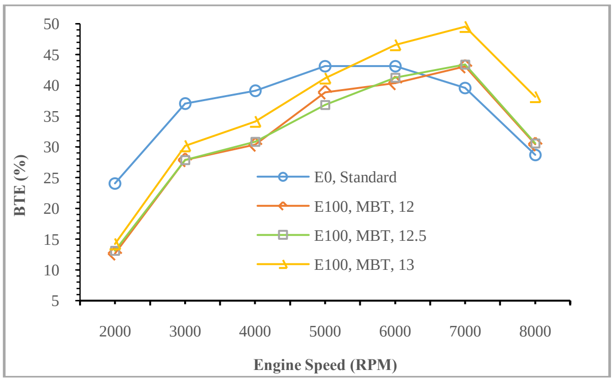


Fig 12. BTE versus rpm at MBT

Similar with the SFC, the BTE of bioethanol at the compression ratio of 12 and 12.5 tend to steady. However, the BTE of bioethanol at the compression ratio of 13 increase by about 13.5% if compared with compression ratio of 12. Presence of oxygen in bioethanol allowing a better combustion process, thus resulting in high temperature and pressure as well as higher power output. Increasing bioethanol percentage in gasoline will increases oxygen-carbon ratio, so the complete combustion will be obtained. On the other hand, latent heat of vaporization of bioethanol is high help to reducing the heat transfer to the cylinder walls, therefore increases of cylinder pressure and power which result in high brake thermal efficiency. These condition have been proven by Farha [25] which is the BTE of bioethanol decreased when the percentage of bioethanol decreased. Otherwise, the BTE of bioethanol increased when the engine speed, compression ratio and percentage of bioethanol increased too.

4.6 The CO and HC Emission

Figure 13 showed the effect of E100 and E0 on the CO emissions at variations in engine speed. Usage of bioethanol as a vehicle fuels would reducing the CO emission significantly. It is caused by the presence of oxygen in the bioethanol fuels that will making the combustion process close to the stoichiometric condition, then complete combustion could be obtained. That is why, the CO emission decreased when the percentage of bioethanol in a blend increased. By the high oxygen content, the combustion process will be faster, than reduced product of carbon concentration and increases of combustion efficiency. In this test, if compared with gasoline, the CO emissions decreased by about 50%, 61% and 74% when the engine runs at the compression ratio of 12, 12.5 and 13 respectively.

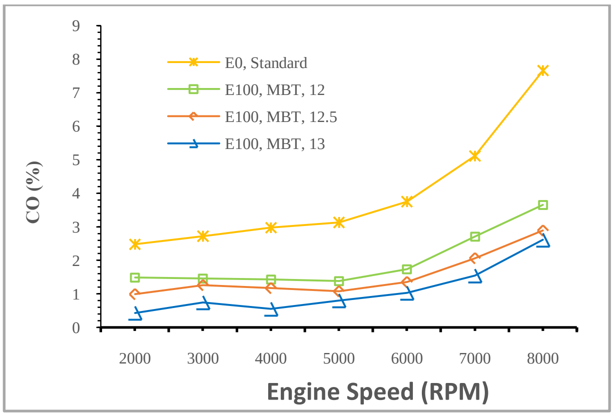


Fig 13. The CO emission versus rpm at MBT

Meanwhile figure 14 showed the effect of E100 and E0 on the HC emissions at variations in engine speed. As known, product of unburnt hydrocarbon (ubHC) is generated by the incomplete combustion. Incomplete combustion that be experienced by the fuel in the cylinder is influenced by the unbalance of air-fuel ratio. Besides that, the low of cylinder temperature and inhomogeneous of charge by the lean of mixing process has become another cause on incomplete combustion. Therefore, the use of bioethanol could be a solution in reducing the HC emissions. The reason, bioethanol fuels has an oxygen compound significantly for improving combustion process, even in the low of engine speed. Moreover, presence of oxygen in bioethanol and high laminar flame speed of bioethanol would making the combustion process is being faster, then the cylinder temperature is higher.

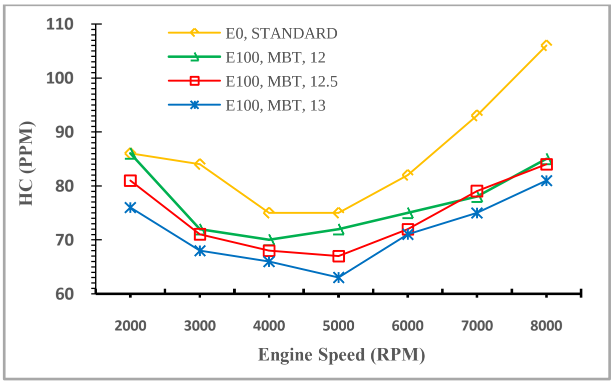


Fig 14. The HC emission versus rpm at MBT

Increasing the compression ratio will effect on improving in the mixing process, in turn, the HC emissions decreased. As addition, the ignition timing taking an important role in reducing the CO and HC emissions, where it is should be advanced when the engine runs with bioethanol. Increasing the compression ratio and re-adjust on ignition timing has been conducted in this study. The result, HC gases decreased by about 10%, 12.8% and 16.4% at the compression ratio of 12, 12.5 and 13 respectively, if compared with gasoline.

5 Conclusion

The conclusion of this study is showing the changes in increase of performance and decrease of emission from mapping the injection duration until mapping the ignition timing strategies.

The torque increased by about 2, 3 and 4% at compression ratio of 12, 12.5 and 13 respectively, after the ignition timing is applied in previous study. Meanwhile, the power and BMEP have a same value in increase i.e. 4, 5 and 6% at each of increase of the compression ratio.

Furthermore, the specific fuel consumption increased around 5-7% at the compression ratio of 12-12.5, but decreased slightly by 2% at the compression ratio of 13. Nevertheless, there is a significant increase of the brake thermal efficiency at all of the compression ratio. Noted that the BTE increased by about 52%, 48.2% and 62.6% at the compression ratio of 12, 12.5 and 13 respectively. These phenomenom is an indication that heat loss along the combustion process could be reduced for decreasing the SFC and increasing the power. On these section, the oxygen content of bioethanol, laminar flame speed and latent heat of vaporization has been a key in improving the BTE.

In case of the CO and HC emission, mapping the ignition timing methodology has been successful decreased these emissions lower than previous study. The CO emissions decreased by about 16.7%, 19.4% and 24.2% at each of the compression ratio increase. While, the HC gases decreased around 1.5-2% when the engine runs at the speed of 6000-8000 rpm, but increased around 3% at the speed of 2000-5000 rpm.

Overall, mapping the ignition timing has been succesfully complemented the injection duration strategy of the previous study to increases the performance of engine and decreases the emissions. However, there is a number of correction both in mapping of the injection duration and ignition timing. The increment of injection volume and ignition angle should be narrower than those previous study. For example, the injection volume is raised by 10% and the ignition timing around 2 degree of the ignition standard of engine when the bioethanol is applied.

From the result above, suggessted that mapping the injection duration and ignition timing should be conducted gradually in a suitable methodology. Firstly, mapping the injection volume is based on the maximum brake torque. This method aims to obtaining the high performance on the each of engine speed. The second, mapping the ignition timing is based on minimum fuel consumption, that aims to reducing the use of fuel, but engine works remain on the high torque. But, for minimum emission or on the others purpose, the second methodology can be used. These methodology will be applied in the advanced study with varying in percentage of bioethanol.

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