Performance and Emissions Investigation of Methanol-Butanol-Ethanol Accumulation as an Alternative Gasoline Mixture in Spark Ignition Engines

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Abstract

Alternative fuels such as Methanol-Butanol-Etanol (MBE) are worthy of development because of their optimal characteristics in spark ignition (S.I.) engines. Selective government regulations on vehicle emissions require a shift to environmentally friendly innovative Energy. Fuel-containing alcohol has been proven to reduce pollution levels in vehicles optimally. This research has explored MBE fuel mixtures with three variants through experimental methods. Variations MBE1, MBE2 and MBE3 were mixed with gasoline (RON-90) with capacities (5:2:1, 8:4:1, and 10:6:1)v/v when tested using a dyno test on an S.I. engine automatic type compression ratio 10:1 with a speed gap of 4000-9000 rpm. During testing, torque and MEP experienced an optimal increase in MBE3 fuel of 10.78% and 10.55% compared to commercial fuel (RON-90). Engine power and thermal efficiency increased respectively by 10.03% and 10.69%. This condition is inversely proportional to SFC, which decreased by 21.05%. Furthermore, carbon monoxide (CO) and hydrocarbon (HC) exhaust emissions were reduced by 12.12% and 4.60% respectively. This phenomenon shows that MBE fuel shows environmentally friendly performance and exhaust emissions for S.I. engines in daily activities.

Keywords: *Emission, Combustion, Performance, Methanol-Butanol-Ethanol, Mixture.*

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INTRODUCTION

Energy from fossil fuels in the form of liquid fuel has been decreasing in recent years [1], [2]. Many researchers are exploring renewable Energy from biofuels as a candidate to replace commercial fuels [3], [4]. The problem of air pollution is increasing from year to year in several countries; the impact of vehicle exhaust emissions is expanding along with the use of commercial fuels that are used daily so that the quality of the surrounding environment will decrease the health of the human [5]. Emissions released from vehicle exhaust are hazardous for the environment, especially carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxide (NOx) emissions [6]. Increasing transportation causes fossil energy consumption to grow every year, so there is a need for bright ideas to create biofuel energy. Competent alternative fuels for S.I. engines are Methanol, natural gas, propane, ethanol, hydrogen, and butanol [7], [8]. Several biofuels are used as additives to commercial fuels so that they are effective in improving vehicle performance and emissions. The addition of biofuels to fossil fuels can improve their characteristics [9]. Effective fossil fuels mixed with biofuels such as alcohol can be used in spark ignition (S.I.) and compression ignition (CI) engines [10]. The relatively high oxygen content of biofuel will reduce emissions, which is what encourages its use in the combustion chamber of S.I. engines [11]. One of the advantages of biofuel, apart from its zero carbon and high oxygen characteristics, is that biofuel is optimally used in S.I. engines without modifying the dimensions and construction of the engine combustion chamber. So, biofuel is a very adequate substitute for existing commercial fuels [12].

Properties of Methanol-Butanol-Ethanol

Alternative Energy at affordable costs, such as Methanol, can be produced from natural gas, biomass and coal. Methanol produces an effective combustion process in engines because it has reliable physical and chemical characteristics, so it has an impact on environmentally friendly emissions. The low reactive nature of Methanol compared to gasoline results in reduced smog formation and evaporative emissions. The characteristic of Methanol, which has a lower heating value compared to gasoline, causes the combustion temperature to decrease; the decrease in combustion chamber temperature means the formation of NOx emissions is reduced [13], [14]. Methanol has the potential to be an alternative fuel for vehicles. The addition of Methanol to fuel is significant in improving engine performance and reducing emissions. Engine performance has increased in Power, and average pressure has experienced a considerable increase of between 20% to 30%. Meanwhile, specific fuel consumption decreased along with increasing methanol concentration in the fuel. Exhaust gas emissions of CO_2, HC and CO have declined by 30% to 40%. This phenomenon shows that Methanol can manoeuvre in high-compression engine conditions, thereby significantly increasing performance [15], [16].

The addition of ethanol and methanol additives to fuel has a tremendous influence on increasing performance and optimizing emissions. Methanol, as an additive compound in fuel, will have an impact on increasing specific fuel consumption by 10% compared to ethanol. Fuel added with Methanol will result in a reduction in NOx, HC, CO and CO_2, respectively of 9%, 5%, 27% and 6.5% compared to the use of ethanol because the oxygen content in Methanol is higher than in ethanol. This phenomenon shows that Methanol is suitable for use as an additive to fuels other than ethanol [17]. The use of butanol in S.I. engines with a combined injection system has a significant impact on increasing performance and optimizing emissions. Butanol has high oxygenation characteristics compared to other alcohols. A direct injection ratio of 20% will affect the increase in torque, maximum cylinder pressure and peak heat release rate. It describes that a direct injection ratio of 20% shows optimal performance. The direct injection ratio has a minor influence on CO. formation, while HC. emissions decrease by 40% to 60%, especially in lean burn situations. Increasing the direct injection ratio will affect the expansion of NOx. Therefore, the use of butanol with an appropriate combined injection ratio can significantly produce optimal performance and emissions [18].

Fuel prices are increasing every year, exhaust emissions are growing, and health problems due to air pollution are rising in urban areas. These factors support the realization of new environmentally friendly fuels. Butanol added to fuel has been proven to optimize emissions. The high heating value of butanol has an impact on increasing its homogeneous mixing properties with gasoline. Butanol-ethanol added to gasoline at a ratio of 10% and 1.5% can increase thermal efficiency and reduce specific fuel consumption. Increasing the butanol ratio in gasoline can improve S.I. engine performance and optimize emissions. So, butanol-ethanol is an additive for fuel that is worthy of being considered an alternative energy [19]. Selective government regulations on vehicle emissions require a shift to environmentally friendly innovative Energy. Fuel-containing alcohol has been proven to reduce pollution levels in vehicles optimally [19], [20]. Butanol as a fuel additive has been proven to optimally increase specific fuel consumption by 10% compared to commercial fuel. The greater concentration of butanol in the fuel can reduce the pressure in the combustion chamber by 20% and the heat release rate by 21% at the highest load. The high concentration of butanol in the fuel also resulted in a reduction in CO emission levels by 36%, CO_2 by 12% and NO emissions increased by 8% at the highest load [21].

The amount of fossil fuels, namely petroleum, is minimal. The massive exploitation that has been carried out so far has made its amount continue to dwindle. The formation of this fossil fuel takes millions of years before it can be used. If we continue to rely on this type of fuel, we will experience difficulties because the fuel sources used are depleted. Therefore, it is necessary to research the effect of Methanol-Butanol-Ethanol (MBE) additives on commercial fuels (RON-90) on the performance and exhaust emissions of SI-CV-Transmission engines. Methanol-butanol-ethanol (MBE) is a product of the bio-alcohol fermentation process and is an alternative fuel to replace fossil energy and Power with high oxygen levels. Methanol-butanol-ethanol (MBE) fermentation is overgrowing, so control of the capacity of bio-solvents contained in the fuel can be more optimal. In this study, MBE additive fuel was used with varying volumetric ratios, namely MBE1 (5:2:1) v/v, MBE2 (8:4:1) v/v, and MBE3 (10:6:1) v/v with a Port Fuel Injection fuel supply system on a 109.5cc matic-SI engine. Engine testing with a non-constant engine speed of 4000-9000rpm. Engine performance testing using a Super-Dyno 50L type dyno test chassis. The test result data is in the form of engine performance indexes: torque, Power, specific fuel consumption, mean effective pressure and thermal efficiency. Exhaust emissions produced using the EPSG4 gas analyzer test tool are HC and CO.

METHODS AND ANALYSIS

The characteristics of the fuel mixture used

MBE fuel was tested at the Energy and Environment Laboratory-Sepuluh Nopember Institute of Technology, Surabaya, and several characteristics were produced, including low heating value, density, and viscosity; the test results are shown in Table 2. Furthermore, the composition of MBE fuel used in S.I. engines includes MBE1 (5:2:1)v/v, MBE2 (8:4:1)v/v, and MBE3 (10:6:1)v/v are described in Table 1.

The SI Engine Performance and Exhaust Emissions Tests

The performance and exhaust emissions tests in this research used a 109.5 cc engine, SOHC 4-stroke, air-cooled, eSP, PGM-FI, with automatic and V-Matic transmission. This machine can produce a maximum power of 6.7 kW at 7500 rpm and 9.3 Nm at 5500

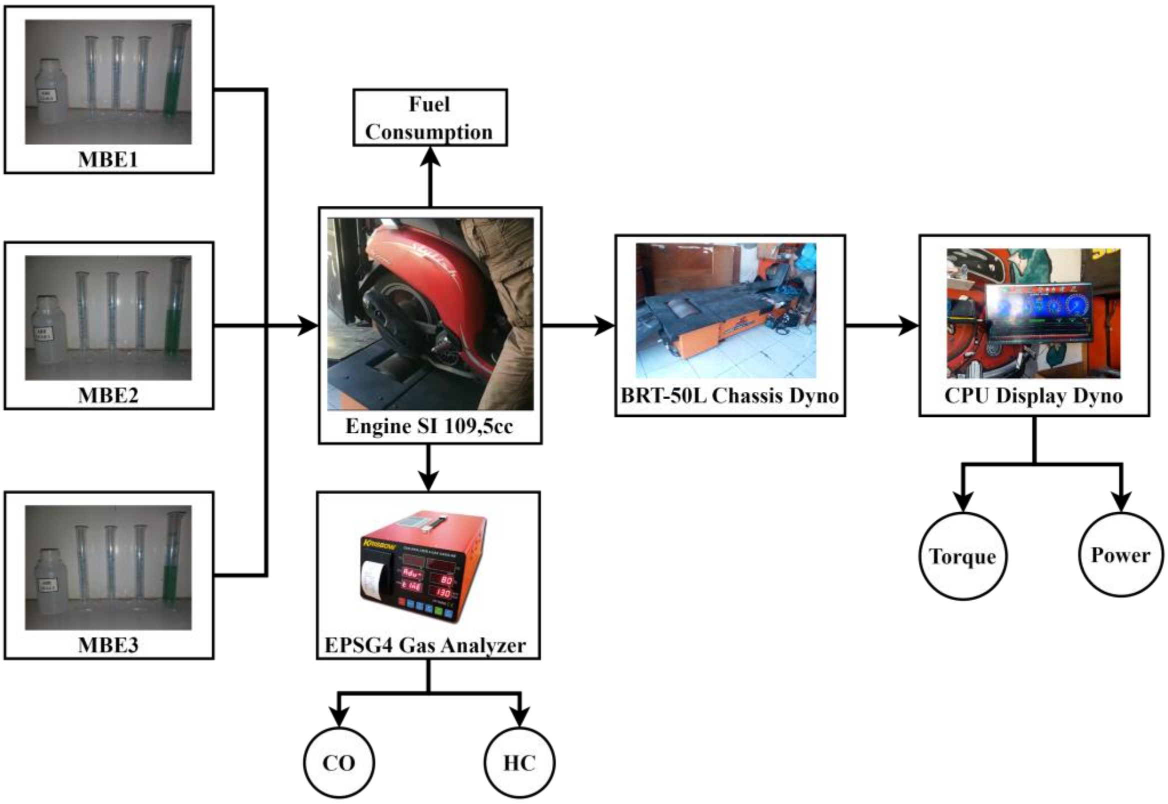

Figure 1. S.I. engine performance and exhaust emission test scheme

Table 1. MBE fuel mixture capacity used

Index Blends	Methanol	Butanol	Ethanol	RON-90
MBE1	50 ml	20 ml	10 ml	920 ml
MBE2	80 ml	40 ml	10 ml	870 ml
MBE3	100 ml	60 ml	10 ml	830 ml

Table 2. MBE fuel mixture characteristics

Component	Unit	Ref.	RON-90	MBE1	MBE2	MBE3
Low Heating Value	Kal/Kg	ASTM D-240	10621	10579	10567	10556
Density	g/cm^3	ASTM D-1298	0,732	0,754	0,788	0,797
Viscosity	mm^2/s	ASTMD 445-97	0,61	0,59	0,56	0,52

Table 3. S.I. engine configuration used

Engine Details	Specifications
Cylinder Capacity (cm^3)	: 109,5
Engine Stroke Type	: 4-Stroke.
Compression Ratio "C.R."	: 10 : 1
Engine Configuration	: SOHC-eSP.
Fuel Supply System	: PGM-FI.
Maximum Torque (Nm)	: 9,3 Nm / 5500 rpm
Maximum Power (kW)	: 6,7 kW / 7500 rpm.
Cooling System	: Air cooling.
Transmission	: CV-Transmission.
Spark Plugs	: Cold-Sparkplug Iridium

rpm torque. A description of the S.I. engine used can be shown in Table 3. Furthermore, the emissions test equipment used is the EPSG4 Gas Analyzer type, which aims to analyze the composition of CO, and HC from vehicle exhaust. The test was carried out with variable engine speed control of 4000-9000rpm with predetermined fuel variations, namely RON-90 and MBE.

The fuel tested in the chassis dyno test has three fuel variations, namely MBE1, MBE2, and MBE3. The fuel must be mixed with RON-90 and MBE variations before testing. The test was carried out in four stages: the first stage tested RON-90 fuel, the second stage tested the MBE1 variation, the third stage tested the MBE2 variation, and the fourth stage tested the MBE3 variation. All fuel samples tested were carried out at a speed setting of 4000-9000 rpm. So, the test results can be seen on the chassis dyno test display in the form of torque and power data. The same thing is done sequentially to take samples of fuel consumption from the four stages and exhaust emissions with the EPSG4 Gas Analyzer, which is connected to the vehicle exhaust during the test. The emissions obtained on the EPSG4 Gas Analyzer display are CO and HC. All processes are shown in Figure 1.

RESULTS AND DISCUSSIONS

Torque is an essential engine performance parameter. Torque is an energy mechanism that is described from rest to movement. This movement is obtained from the piston's movement during the combustion process. This torque indication is what differentiates one vehicle from another. Engine capacity, fuel characteristics, and combustion process also influence the torque difference of each vehicle [22]–[24]. This research shows the phenomenon of an optimal increase in torque, shown in Figure 2. MBE3 fuel experienced an optimal increase compared to RON-90 of 9.28 Nm at an engine speed of 5000 rpm. The same happened when the torque in the MBE2 and MBE1 variations increased. respectively 8.92 Nm and 8.58Nm. So, the largest increase in torque occurred in the MBE3 variation of 10.78%, followed by the MBE2 and MBE1 variations of 5.09% and 2.47%. The average increase in torque due to the use of MBE1, MBE2, and MBE3 fuel mixtures is 6.11%. This phenomenon shows that increasing the MBE fuel ratio can increase the vehicle's torque. Other factors that influence torque are the characteristics of the MBE mixture, namely a lower viscosity value, greater density, and lower heating value than commercial fuel. The calorific value indicates the maximum amount of heat energy released by a fuel through a perfect combustion reaction per unit

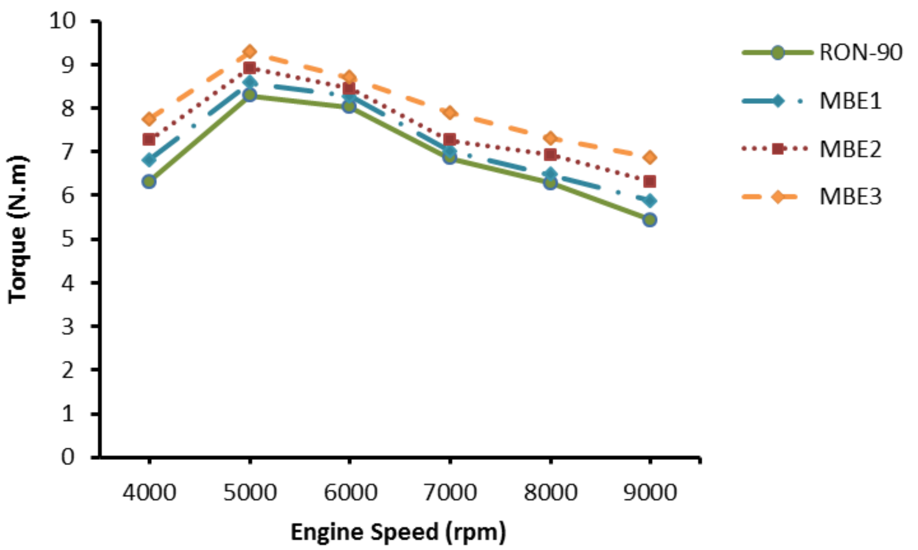

Figure 2. Comparison of the function of engine speed to torque occurs

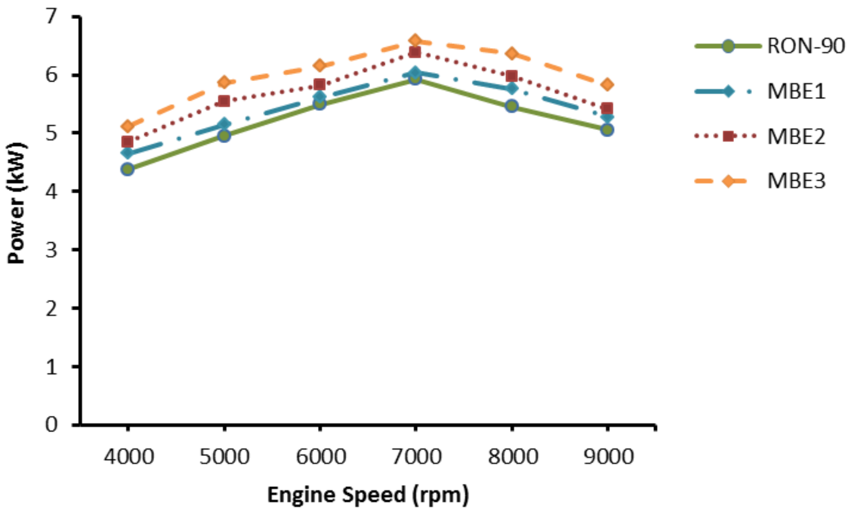

Figure 3. Comparison of the function of engine speed to Power occurs.

mass or volume of the fuel. The low heating value will produce the correct chemical mixture to perfect combustion. Perfect combustion will provide greater torque, so the power produced is also greater. Low density and viscosity will impact fuel injection, which decreases, affecting the combustion process. In addition, it can also be caused by better fuel atomization so that fuel atomization is better and produces greater torque and power. This phenomenon shows that fuel with the MBE mixture is optimal and ideal for everyday vehicles.

Power is an essential factor in identifying S.I. engine performance. Several things influence power fluctuations in S.I. engines, including the phenomenon of increasing turbulence in the combustion process and the characteristics of fuel that has a low heating value and optimal density and viscosity values. Another factor that can increase Power is the cylinder construction in the engine [22]–[24]. This phenomenon is directly proportional to the research conducted; Figure 3 shows the characteristics of variations in MBE fuel, which have increased compared to the use of commercial fuel. The optimal increase occurs in the MBE3 variation with a power of 6.58 kW operating at an engine speed of 7000 rpm. The rise in Power is in line with the MBE2 and MBE1 variations of RON-90 fuel. The MBE3 fuel variation had a percentage increase of 10.03% compared to commercial fuel, followed by the MBE2 and MBE1 variations, which increased by 7.21% and 2.12%. The rise in Power was caused by the increasing ratio of the MBE mixture to RON-90 fuel. Other factors that influence the increase in Power due to the impact of the characteristics of the MBE fuel are the high oxygen content in the MBE fuel so that it forms complete combustion, the optimal composition of the C-H atoms of the MBE fuel, which influences the rapid reduction in adiabatic flame temperature, the high-octane value of MBE when supplied to the combustion chamber. Hence, it has an impact on optimal compression resistance before detonation. The significant MBE latent heat results in a faster heat absorption process in the environment, thereby helping the combustion chamber cooling process. The MBE saturation pressure is low so that it can reduce vapor locking and cavitation in the combustion chamber.

Mean effective pressure (MEP) is a phenomenon in engines that concerns the release of Energy in the engine cylinder. MEP can also be referred to as the total Energy per cycle, which can be described as a pressure value synergistic with the instantaneous energy release at the crank angle in the form of an integral or rate curve [13], [14], [23]. This research shows the phenomenon of increasing optimal MEP, which is shown in Figure 4. MBE3 fuel experiences an optimal increase compared to RON-90 of 886.26 kPa at an engine speed of 5000 rpm. The same thing happened in variations MBE2 and MBE1, which experienced a rise of 862.41 kPa and 832.32kPa, respectively. MEP's highest percentage capacity increase occurred in the MBE3 variation at 10.55%, followed by the MBE2 and MBE1 variations at 8.07% and 4.75%. The average increase in torque due to the use of MBE1, MBE2, and MBE3 fuel mixtures is 7.79%. The rise in MEP is proportional to the torque that occurs, and the greater the ratio of MBE addition to commercial fuel, the more MEP will increase. Other factors that influence the fluctuation of MEP include the high-octane value of MBE when supplied to the combustion chamber, which has an impact on optimal compression resistance before detonation, the low saturation pressure of MBE, which can reduce vapor locking and cavitation in the combustion chamber and the high oxygen content of MBE fuel creating complete combustion.

Specific fuel consumption (Sfc) is the mass rate of fuel and air relative to the output power produced in an S.I. engine. An important parameter in analyzing a combustion process phenomenon in an S.I. engine is engine performance. This phenomenon is related to the research carried out; Figure 5 shows the characteristics of variations in MBE fuel, which have decreased compared to commercial fuel use. The optimal reduction occurs in the MBE3 variation with an Sfc of 0.45 kg/kW.h operating at an engine speed of 7000 rpm. The decrease in Sfc aligns with variations in MBE2 and MBE1 for RON-90 fuel. The MBE3 fuel variation had a percentage increase of 21.05% compared to commercial fuel; the same was followed by the MBE2 and MBE1 variations, which increased by 14.04% and 8.77%. The increasing ratio of the MBE mixture in RON-90 fuel caused the decrease in Sfc. Other factors that influence the reduction in Sfc are the impact of MBE fuel characteristics, namely the lower calorific value of MBE compared to commercial fuel and the more optimal density and Viscosity capacity contained in the MBE mixture. In addition, the high ratio of MBE laminar flame propagation increases thermal efficiency due to the effect of earlier completion of combustion in the engine.

Thermal efficiency is the value of output power to the supply energy in an S.I. machine. Essential parameters in analyzing a combustion process phenomenon in an S.I. engine as well as engine performance. This phenomenon is related to the research carried out; Figure 6 shows the characteristics of variations in MBE fuel, which have increased compared to the use of commercial fuel. The optimal increase occurs in the MBE3 variation with a thermal efficiency of 23.94% operating at an engine speed of 7000 rpm. The increase in thermal efficiency is accompanied by variations in MBE2 and MBE1 fuels compared to RON-90 fuel. The same thing was followed by variations MBE2 and MBE1, which increased by 8.90% and 4.85%, respectively. The increase in thermal efficiency is due to the increasing ratio of the MBE mixture to RON-90 fuel. Other factors that influence

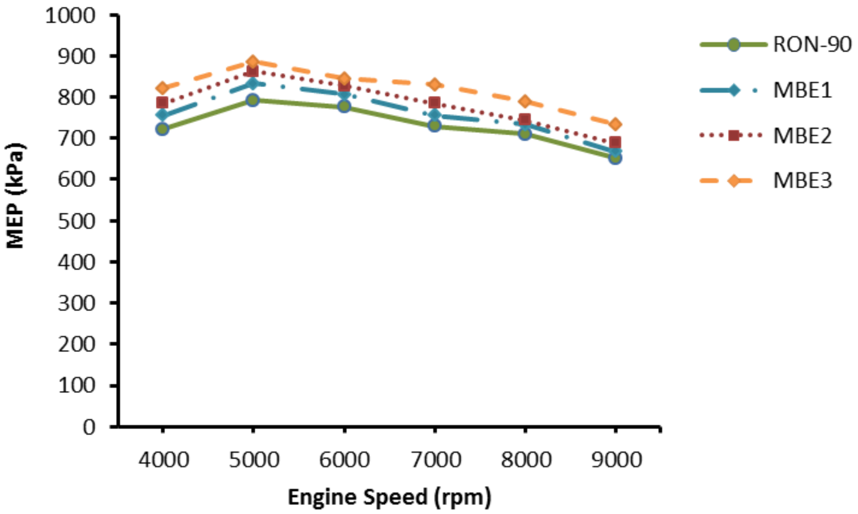

Figure 4. Comparison of the function of engine speed to MEP occurs.

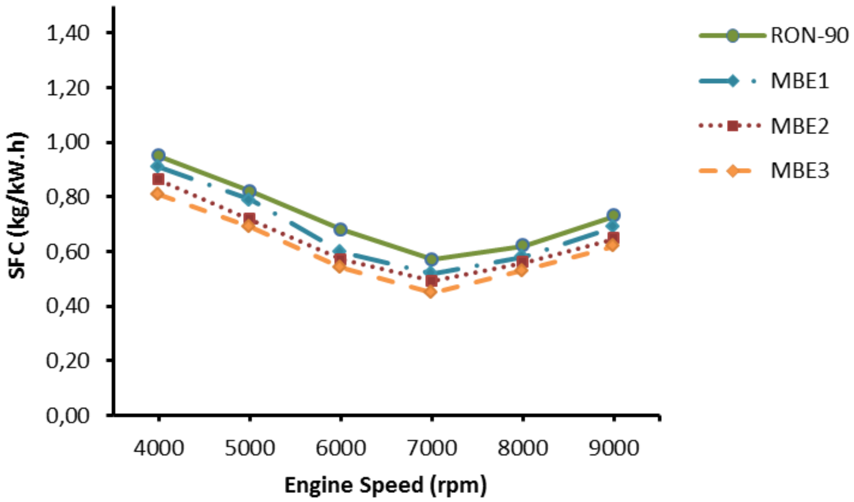

Figure 5. Comparison of the function of engine speed to Sfc occurs.

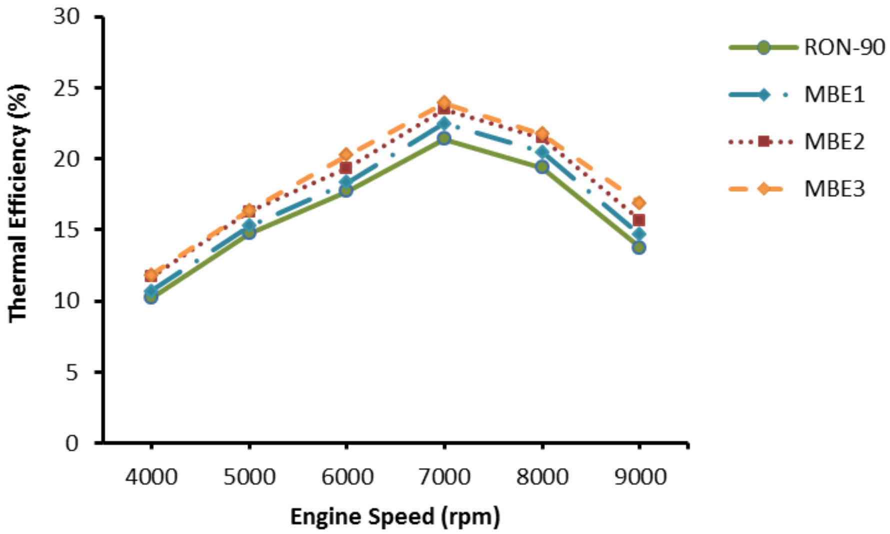

Figure 6. Comparison of the function of engine speed to thermal efficiency occurs.

the increase in thermal efficiency due to the impact of MBE fuel characteristics are the lower heating value of MBE compared to commercial fuel. In addition, the high ratio of MBE laminar flame propagation results in an increase in thermal efficiency due to the effect of earlier completion of combustion in the engine combustion chamber.

This research shows the phenomenon of optimal CO reduction, which is shown in Figure 7. MBE3 fuel experiences an optimal reduction compared to RON-90 at an engine speed of 5000 rpm. The same thing happened to variations MBE2 and MBE1, which experienced an increase of 8.33% and 3.03%, respectively. The optimal CO reduction percentage capacity occurs in the MBE3 variation of 12.12%. The average reduction in CO due to the use of MBE1, MBE2, and MBE3 fuel mixtures was 7.83%. The decrease in CO is proportional to the engine speed that occurs; the greater the ratio of MBE addition to commercial fuel will affect the reduction in CO at medium engine speed. Other factors that influence CO fluctuations in MBE fuel include high octane value, low saturation pressure, and high oxygen content.

Figure 8 shows the characteristics of variations in MBE fuel, which have decreased compared to commercial fuel. The optimal reduction occurs in the MBE3 variation with an HC of 249ppm operating at an engine speed of 7000 rpm. The decrease in HC is in line with variations in MBE2 and MBE1 for RON-90 fuel. The MBE3 fuel variation has a percen-

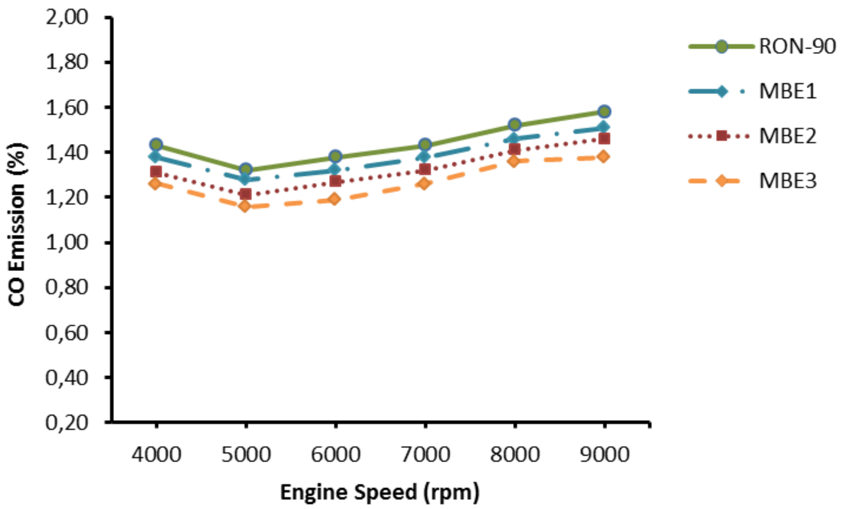

Figure 7. Comparison of the function of engine speed to CO occurs.

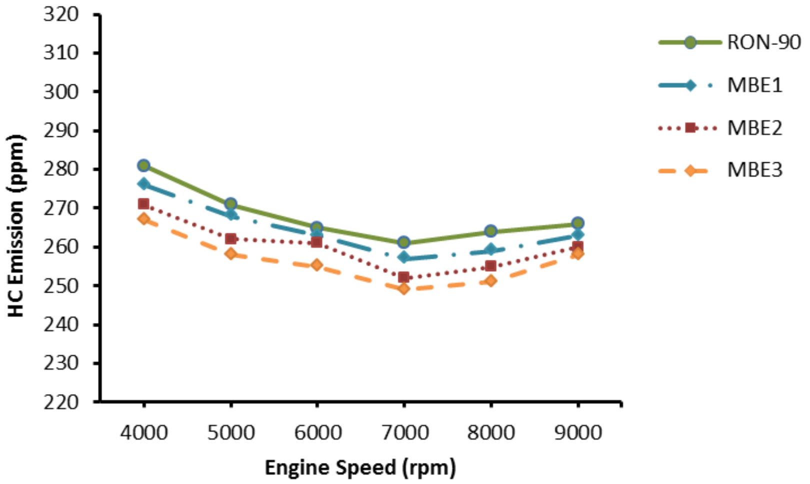

Figure 8. Comparison of the function of engine speed to HC occurs.

tage reduction of 4.60% compared to commercial fuel; the same thing is followed by the MBE2 and MBE1 variations, which increase by 3.45% and 1.53%. There are several causes of HC emissions, namely fuel that does not burn completely and comes out as raw gas. Next, the fuel is broken down due to the heat reaction and turns into other HC groups produced by the exhaust gas. The main reason for the emergence of HC in the combustion process is the low temperature around the walls of the combustion chamber, where the temperature is not capable of combustion, misfire, and the presence of both valves being open together, resulting in flushing gas [21], [25]. Excessive HC emissions can also cause photochemical haze phenomena. Because HC is fuel that does not burn, the higher the HC value, the less Power and increased fuel consumption. High HC content is caused by damage to the catalytic converter and mechanical damage to engine internal parts such as valves, engine rings or cylinders.

CONCLUSIONS

The characteristics of MBE fuel are similar to gasoline, making it suitable for use as a substitute for fossil energy. A significant increase in the use of MBE1, MBE2 and MBE3 fuels compared to the use of gasoline can be described from this research. Identification of the increase in engine torque is shown in torque when testing the torque experienced an optimal increase on MBE3 fuel of 10.78% compared to gasoline (RON-90). The increase in torque is directly proportional to the average adequate pressure (MEP) of 10.55% at an engine speed of 5000 rpm. The Power and thermal efficiency of the engine increased at a speed of 7000 rpm with a capacity percentage of 10.03% and 10.69%, respectively. This condition is inversely proportional to the specific fuel consumption (Sfc), which decreased at an engine speed of 7000 rpm by 21.05%. Furthermore, CO and HC exhaust emissions during the combustion process respectively reduced by 12.12% and 4.60%. The phenomenon shows that the MBE fuel with several variants used can show optimal performance and reduce emissions, so this MBE mixed fuel is suitable for use in S.I. engines in daily activities and is guaranteed to be environmentally friendly.

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DECLARATION OF CONFLICTING INTERESTS

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