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Optimizing the performance of gasoline-ethanol-methanol-fueled engines with variations in the air-fuel ratio

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Abstract. A 125 cc, four-stroke, air-cooled, electronic fuel-injection SI engine for motorcycles was used to compare the effects of mixing methanol and ethanol with gasoline on engine power, fuel efficiency, and emissions. The test took place on the engine test bench. The fuel blend variation is 80% gasoline with various methanol-to-ethanol ratios. The result shows that the maximum torque across all fuel-mixture variants is achieved in the M20 mixture at λ = 0.9 and 6000 RPM, namely 8.52 Nm. The power value shows the highest value in the M20 mixture with λ= 1.1, namely 6.45 kW, and the lowest value of SFC is 266.3 g/kWh obtained by the E10M10 mixture at 6000 RPM engine speed at λ=1.3

Keywords: biofuel; performance

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INTRODUCTION

Indonesia is currently facing an energy problem. The number of internal combustion motorized vehicles, which continues to increase every year, increases fuel demand; meanwhile, fuel production in Indonesia cannot meet this demand. This increased fuel imports. The low utilization of renewable energy is also a problem that must be faced. The use of fossil fuels influences environmental damage1). The production and distribution of fossil fuels, and their combustion in engines, emit greenhouse gases into the atmosphere. Renewable energy is a potential choice for energy security and energy sustainability19). In connection with these problems, the Government of Indonesia implemented several policies to utilize bioethanol as a gasoline blending agent in the transportation sector.

In recent years, researchers have turned their attention to alternative fuels due to the decline of fossil fuels and tightening emission regulations3-5). Alternative fuels for SI engines already widely used include gaseous fuels such as compressed natural gas (CNG)6), liquefied petroleum gas (LPG)7), hydrogen8), and liquid fuels such as alcohol methanol9), ethanol10), propanol11), and butanol12). Authors are expected to submit carefully written, proofread material. Careful checking for spelling and grammatical errors should be performed. The paper should be 4 to 8 pages long.

Bioethanol is a biofuel produced from plants that contain starch, such as corn, sugarcane, cassava, and tubers. Its use as a fuel is either by mixing it with other fuels (such as diesel or gasoline) or by using it on its own. The Research Octane Number (RON) of bioethanol ranges from 108-109, much higher than Pertalite, which has an RON of 90, and Pertamax with an RON of 92. This means that mixing bioethanol in the two types of fuel will be able to increase the RON value of the mixed fuel2). Thus, the use of mixed fuel is expected to increase the combustion chamber pressure ratio, thereby improving engine thermal efficiency.

As an economical, clean-burning fuel, methanol is regarded as a promising alternative to conventional fossil fuels. The development of methanol as an additive for spark-ignition engines has several desirable properties, including its higher octane rating, which allows the engine to run at higher compression ratios without knocking. The high vaporization heat of methanol can cool the incoming fuel-air mixture, enabling methanol port injection to improve intake efficiency and engine performance. Methanol has a higher oxygen content and a higher laminar flame speed (LFS) than other hydrocarbon fuels, such as methane and gasoline. Mixing methanol with other hydrocarbon fuels may improve combustion velocity and reduce emissions in spark-ignited engines. Methanol is a liquid at standard pressure and temperature, which facilitates storage and transportation. Various studies have therefore been conducted to analyze the combustion properties of methanol as a replacement for fossil fuels or as a fuel additive in both internal combustion engine applications and laboratory flames3).

Each fuel has its own physical and chemical properties that significantly control engine characteristics such as performance, combustion, and emissions. The physical properties of the fuel can affect vaporization and atomization, while its chemical properties can affect ignition and combustion. The physical-chemical properties of gasoline and Low Carbon Alcohol (LCA) are listed in Table 1 (1)

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Tabel 1. Fuel properties.

Property	Units	Gasoline	Methanol	Ethanol
Chemical formula		$C_{5-10}H_{12-22}$	CH_3OH	C_2H_5OH
Composition (C, H, O)	Mass %	86, 14, 0	37, 12.5, 50	52, 13, 3
Molecular weight	g/mol	95–120	32	46
Density	kg/m^3	737	792	785
Viscosity @ 40 °C	mm^2/s	0.4–0.8	0.59	1.13
Research octane number		90–100	108.7	109
Motor octane number		81–84	88.6	89.7
Boiling point	C	27–225	64.5	78.4
Flash point	C	—13 to 45	12	13
Specific gravity	kg/m	0.71–0.77	0.791	0.787
Lower heating value	kJ/kg	44300	20100	26800
Latent heat of vaporization	kJ/kg	349	1100	900–920
Autoignition temperature	°C	257	463	420
Stoichiometric A/F ratio		14.6	6.46	8.97
Oxygen content		0	50%	34.80%

Abikusna13) studied the emissions of gasoline-ethanol mixtures and oxygenated additives in COVIMEP and different fuel mixtures at different engine speeds. The results of the study show that gasoline-ethanol blends and oxygenated additives decrease variation in combustion pressure. It also reduces exhaust emissions: CO and HC decrease, while CO2 and O2 increase.

Turcan14) has performed the experimental procedure using the effect of direct injection. This was done in two stages. The machine's performance was checked at a high compression ratio and constant speed. Different injection ratios (gasoline, E10, E20, M10, and M20) were used for the first injection at the suction step and the second injection at the end of the compression step. The results showed that the timing of the first injection significantly affected the cylinder gas pressure and the heat release to gasoline-ethanol, but these effects were observed only with gasoline fuel. Also, the second stage injection had a significant impact on combustion and performance compared to the first injection, but the injection rate was changed. The maximum cylinder gas pressure, which indicates the effective IMEP and thermal efficiency, can be controlled using the second injection timing. Ignition timing for E10 and M20 occurred earlier than for gasoline. Increasing the ethanol concentration decreased Pmax, whereas increasing the methanol concentration increased Pmax.

Abikusna15) has investigated the use of ethanol at various percentages to reduce cyclic variation in an SI 125 cc engine fueled by a mixture of gasoline and bioethanol (E0, E5, E10, and E15), and in a mixture with the addition of a cyclohexanol additive. An impact on both power and torque performance is also tested.

Abikusna16) also investigated the effect of a fuel blend with added oxygenated cycloheptanol on a 150cc premixed single-cylinder gasoline engine at 100% throttle position. Tests were run using E5, E10, and E15, with 0.5% oxygenated cycloheptanol added to each fuel mixture, and with engine speed varying over 4000 rpm. Performance tests are performed by connecting the machine to a dynamometer. The study aimed to improve engine performance by adding additives, resulting in an average 9% increase in horsepower and 6% increase in torque.

Sugiarto17) conducted Experiments using an engine dynamometer to measure engine power, cylinder pressure, and exhaust gas. Adding 18 ml of oxygenated cyclohexanol to the 80% gasoline and 20% bioethanol blend (E20) produced the best results among all the blends tested. Reduced specific fuel consumption (SFC) and coefficient of variation (COV) value to minimize power and torque loss while reducing toxic gas production.

Optimization of the performance of spark ignition (SI) engines using gasoline with variations in research octane numbers (88, 92, and 98) with 40% volume bioethanol has been carried out by adjusting the spark plug ignition timing (2° CA advanced) and fuel injection duration (10% reduction) of the engine control module. Performance testing was carried out on an engine dynamometer at shaft rotations of 1000, 1500, 2000, and 2500 RPM and wide-throttle opening conditions. The results showed that optimizing the engine control strategy can lead to a greater increase in engine power, torque, and specific fuel consumption when using fuel with a higher octane number (18).

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2. MATERIALS AND METHOD

2.1 Fuel

The fuels used in research is RON 90 gasoline as the base fuel and a mixture of gasoline and low carbon alcohol (ethanol and methanol). The fuel composition used in this research is listed below

Tabel 2. Test Fuel Variation.

	RON 90 (%)	Methanol (%)	Ethanol (%)
RON 90	100	0	0
M10E10	80	10	10
E20	80	0	20
M20	80	20	0
GEM80	80	15	5
M5E15	80	5	15

2.2. Engine specification

The engine used in this study is a single-cylinder, 125 cc SOHC Honda SI AFX12U21C07 with an electronically controlled fuel injection system. The general specifications of the test engine are shown in Table 3.

Table 3. Engine specification.

General Specification	Parameter
Engine type	4 stroke, SOHC, single cylinder
Displacement	125 cc
Bore x stroke	52.4 mm x 57.9 mm
Compression ratio	9.3:1
Max output	7.4 kW / 8000 RPM
Max torque	9.3 Nm / 4000 RPM
Fuel system	Fuel injection (PGM-FI)
Lubricant capacity	0.7 l at periodic maintenance
Clutch type	Multiple wet clutch with coil spring
Transmission type	4-Speed manual, Rotary
Starter type	Electric and kick starter

2.3. Test method

The combustion pressure in the cylinder is measured by a Kistler 6617B piezoelectric sensor (maximum pressure 200 bar) and recorded by the LabVIEW acquisition system. The crank position angle (up to 720 crank angles) is recorded by the rotary encoder. The sequence is adjusted to synchronize the cylinder combustion pressure signal with the crankshaft angle. The K-type thermocouple temperature sensor assembly is used to monitor the temperature of exhaust fumes, fuels, and lubricants. The machine is connected to an engine dynamometer for power, torque, and fuel consumption analysis. To regulate the fuel-to-air ratio, a Juken 5 programmable ECU and an oxygen sensor are used. The data are taken with the throttle valve wide open, and the engine speed varies from 4000 to 8000 rpm in 1000-rpm increments. This test is conducted with the SNI 8051:2014 standard. The experimental setup is as seen below.

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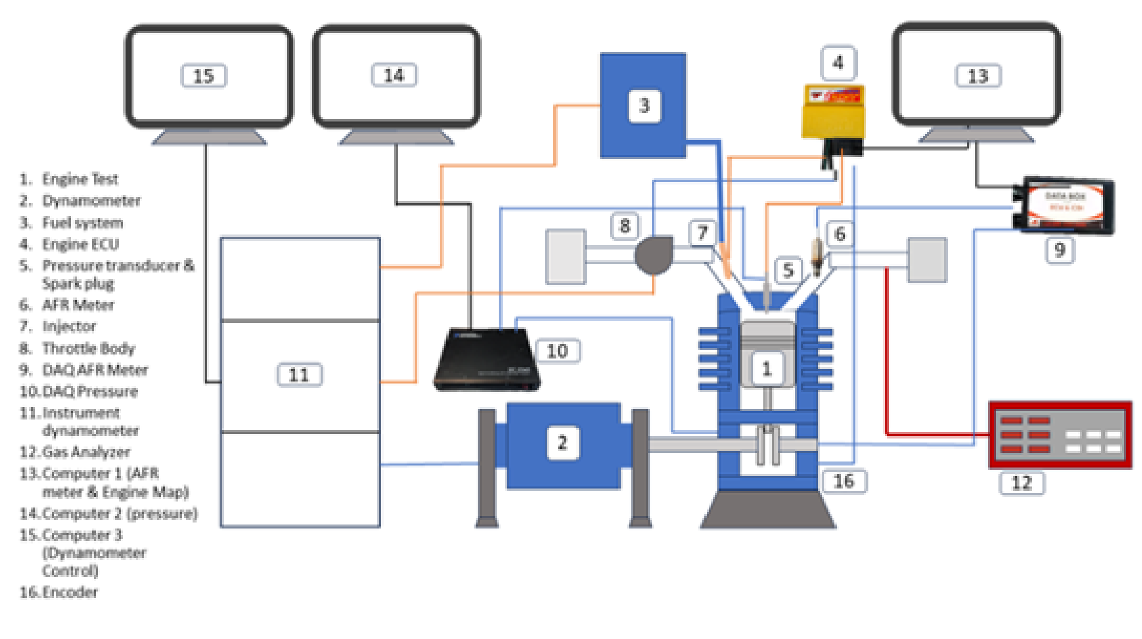

Fig. 1 Engine Test Set Up

Engine cylinder pressure is an essential engine parameter required for almost all engine types and combustion analyses (32). Cycle-to-cycle variations (CCV) are frequently evaluated using the coefficient of variation of the effective mean pressure (COV_{IMEP}). The most commonly utilized parameter for analyzing CCV is COV_{IMEP}. The following is how COV_{IMEP} is defined:

$$COV_{Imep} = \frac{\sigma_{Imep}}{\mu imep} \times 100 \ (1)$$

Where μIMEP is the average pressure per cycle, and the standard deviation of combustion pressure per cycle is represented by σIMEP. The torque values in testing using an engine dynamometer are calculated by the following formula:

$$T = F.L \ (2)$$

Where L is the length of the torque arm in meters and F is the reading of the balance with the additional weight given in Newtons. Engine power is calculated from the torque value:

$$Pe = \frac{2\pi.n.T}{60} \ (3)$$

Where Pe is the engine's power output, expressed in Watts, n is the engine's rotational speed (rpm), and T is the torque produced by the engine. The SFC (Specific Fuel Consumption) is calculated using the engine power:

$$SFC = \frac{mf \ x \ 10^3}{Pe} \ (4)$$

The mass rate of fuel flow required to produce each unit of power output is known as the specific fuel consumption. SFC is stated as g/kWh, where mf is the fuel mass flow rate, and Pe is the engine's output power, as in Equation 4.

3. RESULT AND DISCUSSION

To find out the effect of using alcohol fuel on SI engine performance, it can be seen from the results of engine performance testing, namely power, torque, and Brake-specific fuel consumption. The method for collecting performance data from the test machine in this research follows the standard specified in UN ECE R85.

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Performance testing is carried out at 4000-8000 rpm, with increments of 1000 rpm. At each rpm, the lambda value was varied from 0.9 to 1.3.

3.1. Engine Torque

Torque is measured in Newton-meters (Nm) and is an important parameter for assessing engine performance. Higher torque allows the engine to produce more power at low speeds, which is beneficial for acceleration and load towing capability.

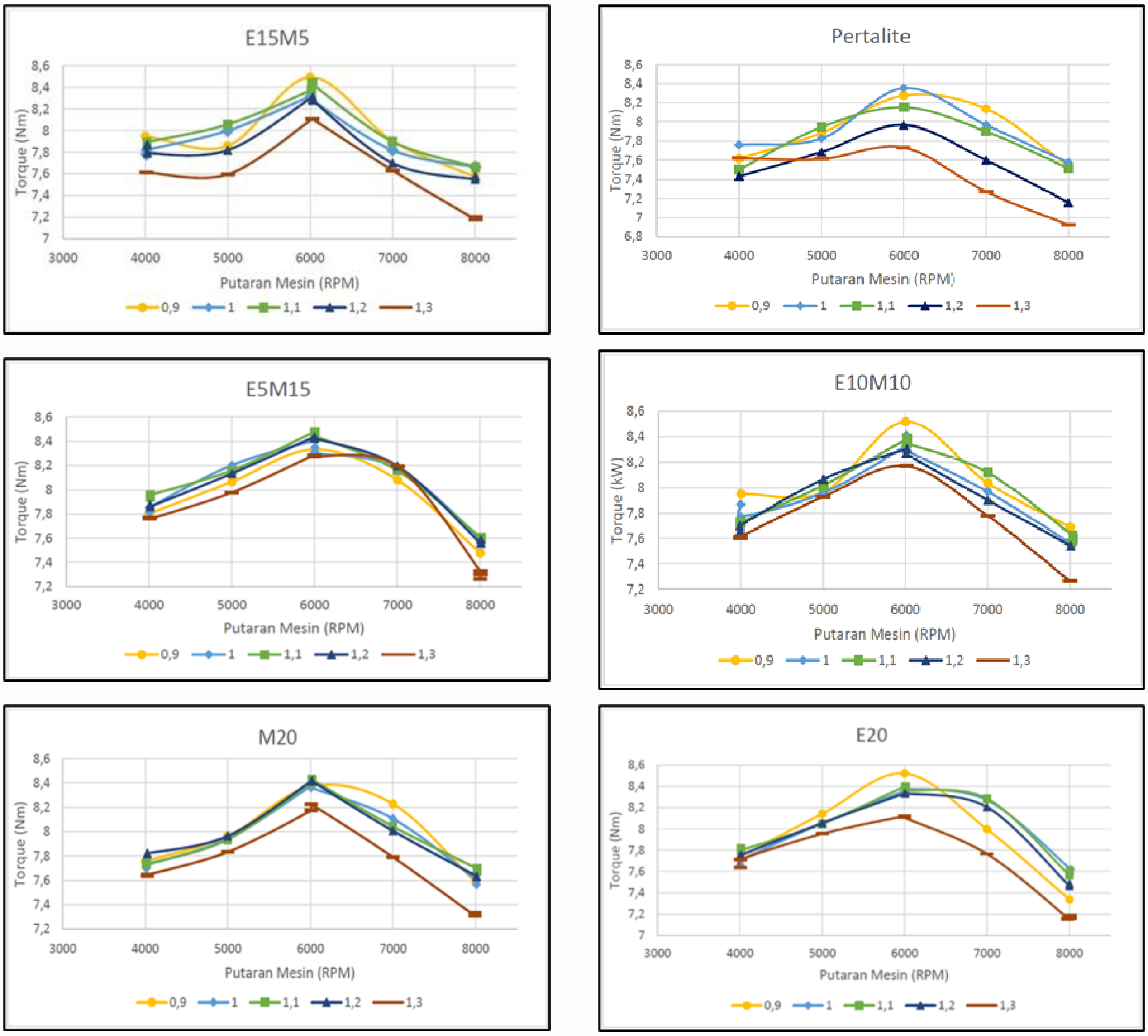

Fig. 2 Torque vs lambda test chart.

Figure 2 is a torque graph from performance testing with a gasoline-ethanol-methanol fuel mixture. Peak torque is achieved at 6000 RPM across all mixtures and fuel ratios. Specifically, the highest torque was achieved in the E10M10 mixture at λ=0.9 and RPM 6000, with a value of 8.51 Nm. This is clearly because lambda 0.9 has a greater calorific value due to the amount of fuel sprayed into the combustion chamber, but of course, it will consume more fuel. However, if we look at the conditions with a lean mixture, where the air concentration is higher at λ=1.1 at RPM 6000, we find a torque of 8.46 Nm in the E5M15 mixture. Among the three mixtures, in one frame λ=1, the E5M15 mixture has a slightly higher average torque. Torque here is related to pressure: higher pressure increases the compression ratio and combustion temperature. Under optimal combustion conditions, this results in better energy conversion from heat to mechanical power, thereby increasing torque. The GEM fuel pressure is higher than the pressure produced by the basic fuel, namely pertalite. This is also consistent with previous research, which found that adding alcohol groups can improve engine performance (28).

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If taken at an engine speed of 6000 RPM (6000 revolutions per minute, or 100 revolutions per second), and assuming a maximum combustion time of 0.01 seconds per cycle (because combustion is assumed to occur at only 180 ° CA), then combustion occurs half a revolution, namely 0.005 seconds. Meanwhile, the LFS of methanol is 52.3 cm/s (Gong et al., 2018) and ethanol is 39 cm/s (Liang et al., 2012). If in the combustion process, Laminar Flame Speed (LFS) will affect the initial combustion process, namely when 0-10% of the fraction is burned, where in this process methanol can burn completely 10% of the fraction at less than 24o CA at λ=1.1 and with As the λ value increases, methanol still has a lower value than ethanol or n-butanol, the same condition also occurs in the combustion process of fractions from 10-90%, and when the mass fraction burned is 50%29). This is what affects COV in fuel with a high methanol content, which is more resistant to lean-mixture combustion conditions.

For E20 and M20 fuels, the highest torque was observed in the E20 mixture with λ=0.9 at 6000 RPM, namely 8.52 Nm. This is also due to the air-to-fuel ratio: the fuel has slightly more volume than in stoichiometric conditions, resulting in faster combustion, higher compression, and increased torque. However, it must be remembered that these conditions will definitely affect fuel consumption and exhaust emissions.

3.2 Engine Power

The next parameter taken in this test is Engine Brake Power. Engine brake power is a measure of the effective power produced by an engine after power losses that occur within the engine itself, such as internal friction, pumps, and other engine accessories. This measurement is usually carried out using a dynamometer directly connected to the engine's crankshaft to determine the actual usable power output.

Figure 3 shows the results of power testing on a test engine over a range of 4000-8000 RPM, with an interval of 1000 RPM, for all fuel variations. In this graph, the power produced by each fuel mixture varies with lambda at engine speeds of 4000-8000 RPM. The addition of methanol and/or ethanol increases the oxygen concentration in the fuel mixture. Increasing the oxygen concentration in the fuel can improve combustion quality, resulting in higher power output. The maximum power or power output of an internal combustion engine is usually at 8000 RPM. In the mixture of three GEM fuels, the highest engine power was found at 8000 RPM of the E10M10 mixture with λ=0.9, with a value of 6.43 Nm. This is because at λ=0.9, a higher fuel ratio can result in greater energy release. More fuel burned efficiently means more energy is produced, which, under appropriate conditions, can result in increased power.

However, the highest power was achieved at 8000 RPM on the M20 mixture with λ=1.1, namely 6.45 kW. This is because methanol can initiate combustion at a burning mass fraction of 0-10%, thereby influencing the later-burning gasoline and causing it to react more quickly. Because gasoline has a higher heating value than other alcohol fuels, the M20 mixture achieves the highest power output. In addition, because it has a faster reaction rate, methanol can release heat more quickly at higher speeds. Apart from that, the addition of λ will have a significant effect on power at λ=1.3, because the amount of fuel is very low when it burns completely, yet there is still a lot of oxygen present, which reduces the heat released. Apart from that, the resulting emissions are cleaner, as evidenced by the decrease in NOx concentration. Between λ=1.0 and λ=1.2, the power released is high, but complete combustion does not occur at λ=1.0; it occurs at λ=1.1 and λ=1.2. This is because combustion in lean conditions can promote more efficient oxidation of the fuel. After all, the oxygen becomes more abundant, and the fuel is more easily oxidized.

3.3 Specific Fuel Consumption

Specific fuel consumption (SFC) is a measure of the efficiency with which an engine or combustion device uses fuel to produce a given power. BSFC measures the amount of fuel required to produce one unit of power at the engine shaft in a given time. It is commonly used for internal combustion engines such as those found in cars, trucks, and industrial equipment.

Figure 4 shows that the SFC is optimal at 6000 RPM for the E10M10 fuel mixture with λ=1.3, at 266.3 g/kWh. Looking at the λ variations, the E15M5 mixture has the lowest average SFC of around 321.23 g/kWh. This is also influenced by combustion chamber pressure. Consistent combustion chamber pressure or low COV tends to produce a more stable SFC. When the combustion chamber pressure is relatively constant, fuel combustion is more consistent, resulting in better fuel efficiency. If the combustion chamber pressure varies significantly across measurements, this can lead to an imbalance in combustion and fuel-consumption efficiency.

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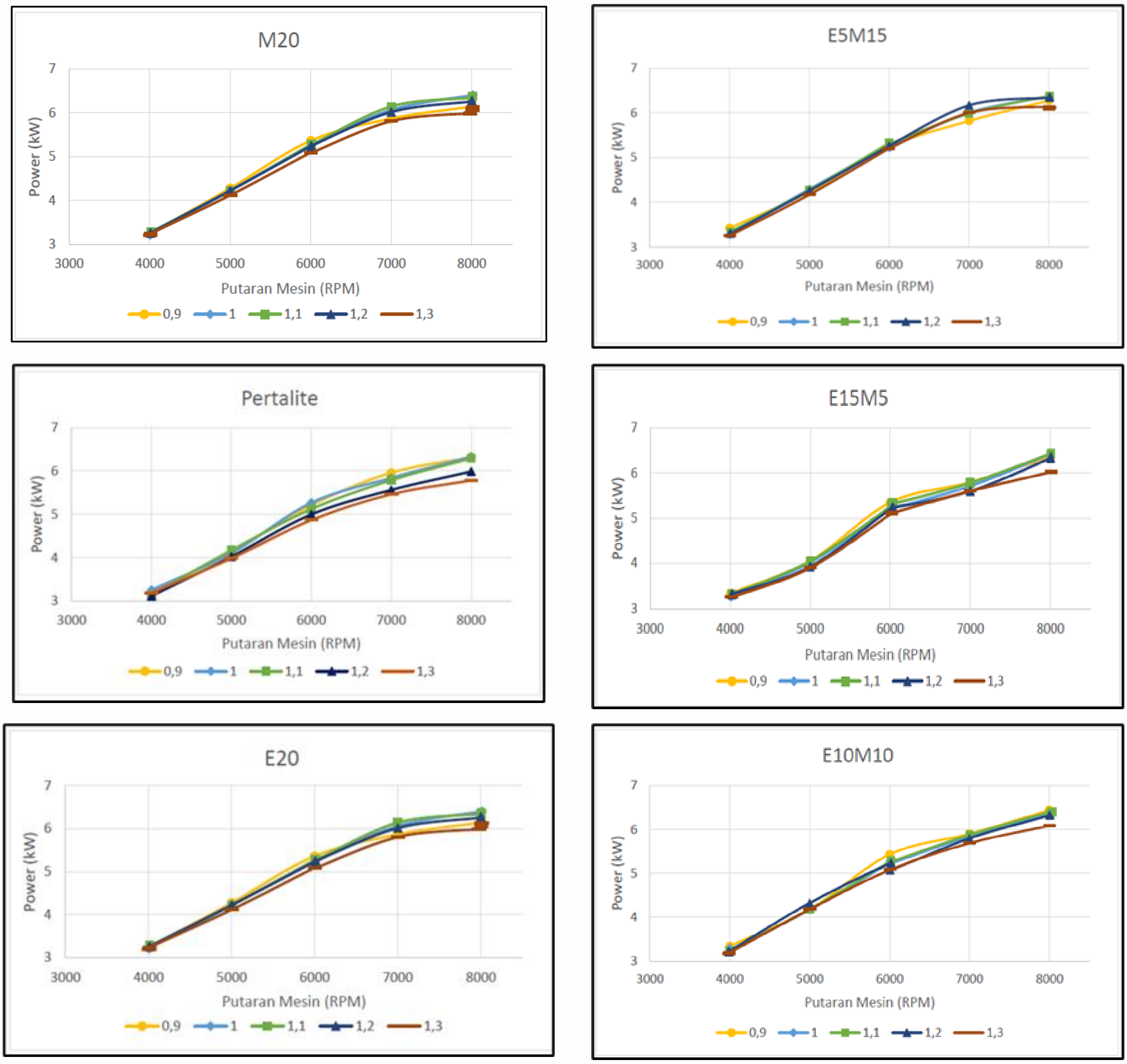
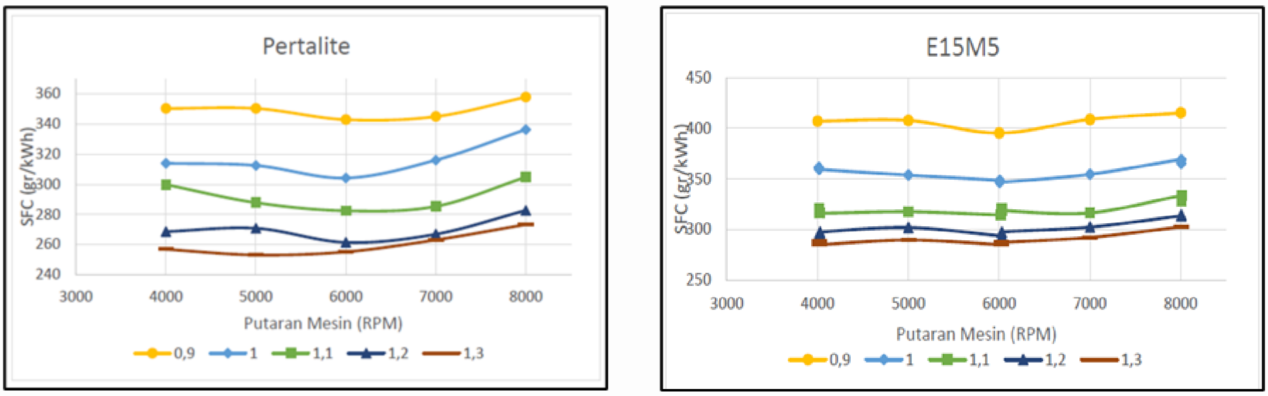


Fig. 3 Power vs Lambda Chart.



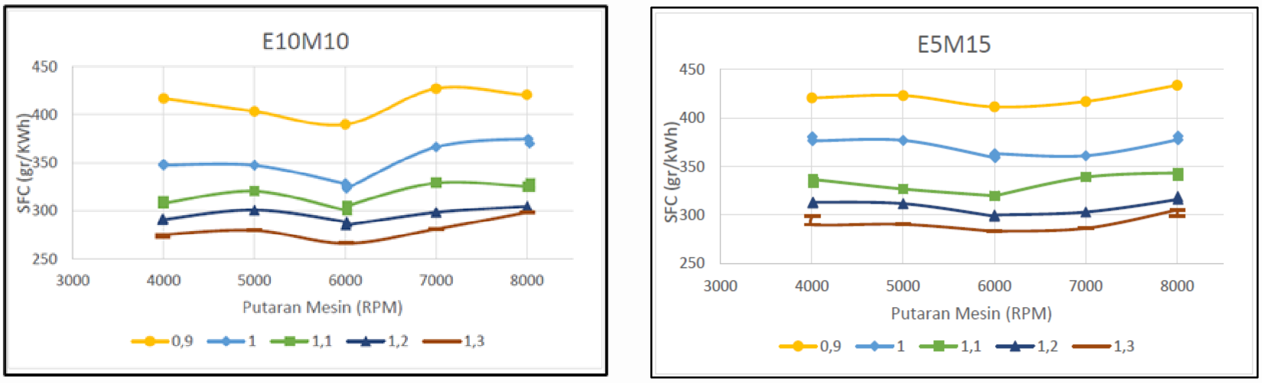


Fig 4. SFC vs Lambda Chart.

CONCLUSION

The maximum torque for all fuel-mixture variants is achieved with the M20 mixture at λ = 0.9 and 6000 RPM, namely 8.52 Nm. The power value is the highest in the M20 mixture with λ = 1.1, namely 6.45 kW. This is because methanol can initiate combustion earlier, namely at a burning mass fraction of 0-10%, thereby influencing the gasoline burned later to react more quickly. Judging from the SFC, excess-air combustion conditions further reduce the SFC, with the lowest value of 266.3 g/kWh obtained for the E10M10 mixture at 6000 RPM and λ=1.3. The use of GEM has similar performance or even tends to increase compared to pertalite (base fuel RON 90) if the air-to-fuel ratio is adjusted appropriately

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