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Research Paper

Performance of a Single-Cylinder Four-Stroke Engine with High Concentrations of Gasoline-Ethanol-Methanol (GEM)

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Abstract

Several types of alternative fuels have been developed to replace fossil fuels. Alcohols, such as ethanol and methanol, can be blended with gasoline for spark ignition (SI) engines. High octane number and oxygen content in alcohol can increase combustion efficiency. Therefore, our current research investigates the effect of high concentrations of ethanol and methanol mixed in RON 90 gasoline. The mixture was implemented in a 150 cc single-cylinder four-stroke spark ignition (SI) engine without any modifications. Engine testing was carried out with wide-open throttle (WOT) and different engine speeds from 4000 to 10000 rpm. Torque, power, and Air Fuel Ratio (AFR) were measured during experiments on a chassis dynamometer. Our test results found that the higher the methanol fraction in the mixture, the lower the torque generated. To improve engine performance, further research is needed on modified engines so that optimal conditions can be identified.

Keywords: Gasoline; Methanol; Ethanol; SI Engine

1. Introduction

In recent decades, several types of alternative fuels have developed related to the decline of fossil fuels and emission regulation by renewable energy sources, including natural gas, propane, methanol, ethanol, buthanol, and hydrogen [1]–[8]. Alcohols, such as ethanol and methanol, have gained significant attention as viable alternatives for use in conjunction with gasoline in spark ignition (SI) engines [9]. Most commonly they can be configured as binary mixtures of one of the alcohols with gasoline, or sometimes jointly together as ternary mixtures [10]. In this paper, the term ‘EXX’ refers to a binary mixture of ethanol in gasoline with XX volume percentage of ethanol, ‘MXX’ is used as the corresponding case for a binary mixture of methanol in gasoline, and ‘GEMXX’ is used as the corresponding case for a ternary mixture of ethanol-methanol in gasoline.

Alcohols have higher octane numbers, hence the addition of ethanol in the gasoline increases the octane number of the blends. A higher octane number reduces the knocking problem in the engine. However, increasing alcohol content in gasoline increases fuel consumption due to its lower energy content [11], [12]. Nowadays, a lower fraction of alcohol is used with gasoline in SI engines without any engine modification, while the application of higher concentration alcohol in gasoline fuels needs significant modifications in the engine. Blending alcohol with gasoline causes to improves the complete combustion and combustion efficiency [13]–[15]. The combustion of low carbon alcohol in SI engines can generate higher combustion pressure than gasoline due to their greater octane number [16], [17]. Moreover, alcohols cause an increase in burning velocity which leads to more constant-volume combustion and complete combustion [18]–[20].

Iliev [21] conducted a simulation using 1-D engine models to predict the effects of various types of fuel on engine performance and fuel consumption in a wide variety of operating conditions. AVL BOOST is used as a simulation software. The types of fuel used are E0, E5, E10, E20, E30, E50, M0, M5, M20, M30 and M50. The results showed that power decreased and brake-specific fuel consumption (BSFC) increased when using a mixture of ethanol and methanol compared to gasoline fuel. Gravalos, et al. [22] conducted research on the E10, E20, E30, M10, M20, and M30 using dynamometer chassis to measure power, torque, and brake-specific fuel consumption (BSFC). Test results showed mixing methanol into gasoline lowered power and torque and raised BSFC. The mixing effect of methanol compared to ethanol has a worse impact, it is related to its combustion properties.

Waluyo [23] conducted a torsion test for the homogeneous gasoline-methanol-ethanol fuel blend, which showed that the G-90 and G-95 fuel blends achieved the highest maximum and average torque, respectively. In the engine power test, the G-70, G-80, G-90, and G-95 fuel blends outperformed pure gasoline in all working conditions. This increase in power output was attributed to the higher laminar combustion speed of the fuel blend, which facilitated faster energy conversion and combustion rates. Overall, this study indicates that the G-90 and G-95 fuel blends exhibit promising performance characteristics in terms of torque and engine power compared to pure gasoline.

Gasoline available on the Indonesian market has a wide range of octane number values, thus offering consumers choices such as RON 90, RON 92, and RON 98 gasoline. Advances in vehicle engine technology have led to the widespread adoption of fuel injection systems that have compression ratios exceeding 1: 10. RON 90 gasoline, in particular, has become the main choice for consumers, especially for the latest generation of vehicles equipped with compression ratios ranging from 9:1 to 10:1 or equipped with advanced Electronics Fuel Injection (EFI) features.

Although there is extensive research on the use of gasoline-alcohol mixtures, especially ethanol, in multi-cylinder or water-cooled Spark Ignition (SI) engines, references regarding the application of gasoline-ethanol-methanol (GEM) mixtures in single water-cooled engines are still limited. This research gap underscores the need for further exploration and investigation in this specific domain to exploit the potential benefits and challenges associated with this unique fuel blend in motorcycle engines. Understanding how these blends perform in single-cylinder engines could have significant implications for motorcycle manufacturers and consumers, ultimately contributing to the advancement of sustainable and efficient transportation solutions.

Hence, the current work aims to investigate the effect of the application of Gasoline 90 blends, with methanol and ethanol, on the performance of a four strokes 150 cc single-cylinder spark-ignition (SI) motorcycle engine without any modifications, using a dynamometer chassis. Iso-stoichiometric ternary blends GEM were based on binary blends that have the same AFR [24]. To determine the volume fraction of the GEM mixture, the Air to Fuel ratio equation is used with the other parameters namely density, volume fraction, and AFR values, as shown in Eq. (1).

$$AFR = AFRa.Xma + AFRb.Xmb + AFRc.Xmc \tag{1}$$

Where, AFR is the air-to-fuel ratio, Xm is the mass fraction, XV is the volume fraction and a,b, and c are gasoline, ethanol, and methanol [19]. While,

$$Xma = \frac{XVa.\rho a}{XVa.\rho a\ +\ XVb.\rho b\ +\ XVc.\rho c} \tag{2}$$

From the substitution of the two equations above (1) and (2), the volume fraction value of each component can be obtained by Eq. (3). Where, XV_M is volume fraction of methanol, XV_E is volume fraction of ethanol, ρ_M is density of methanol, ρ_E is density of ethanol, ρ_G is density of gasoline, AFR_{Blend} is air to fuel ratio of blend, AFR_M is air to fuel ratio of methanol, AFR_E is air to fuel ratio ethanol and AFR_G is air to fuel ratio gasoline.

$$XV_M = \frac{\left(XV_E\left(\left(\left(-AFR_{Mix}(\rho_E-\rho_G)\right)+(AFR_E.\rho_E)-(AFR_G.\rho_G)\right)\right)-(AFR_{Mix}.\rho_G)+(AFR_G.\rho_G)\right)}{(AFR_{Mix}(\rho_M-\rho_G))-(AFR_M.\rho_M)+(AFR_G.\rho_G)} \tag{3}$$

2. Materials and Methods

In this experiment, three distinct fuel components, namely Gasoline RON 90, ethanol, and methanol, were investigated. These fuel components were readily available in the Indonesian market, making them easily accessible for research purposes. The essential properties of these fuels are detailed in Table 1 and Table 2, providing valuable insights into their characteristics and composition.

This research was conducted at the Center for Oil and Gas Technology (LEMIGAS), located in Jakarta, Indonesia. The primary focus of this investigation involved conducting a series of experiments on a single-cylinder, four-stroke engine. This engine was subjected to various gasoline blends, specifically gasoline RON 90 mixed with ethanol and methanol in different ratios, denoted as GEM50, GEM60, and GEM70 as presented in Table 3. To assess the performance of these fuels, an extensive tests was undertaken using a four-stroke 150 cc single-cylinder spark-ignition (SI) water-cooled motorcycle engine. The comprehensive specifications for this engine is presented in Table 4. These rigorous tests were executed in a chassis dynamometer at maximal load or wide-open throttle (WOT). Engine speeds varied at intervals of 4000, 6000, 8000, and 10000 rpm, ensuring a thorough examination of engine performance across different operating regimes. The entire experimental setup, meticulously designed and executed, is visually depicted in Figure 1. Throughout each experiment, meticulous measurements were taken, including engine power, torque, and air-fuel ratio (AFR), offering invaluable insights into the performance characteristics of the GEM under various conditions.

Table 1. Properties of Gasoline RON 90 [25]

Fuel Properties	Gasoline 90
Density at 15 °C (kg/m^3)	753
Stoichiometric Air Fuel Ratio	14.8
Lower Heating Value (MJ/kg)	42.7
Research Octane Number (RON)	91.3
Reid Vapor Pressure (kPa)	58.4

Table 2. Properties of methanol and ethanol [23], [26], [27]

Characteristics	Methanol	Ethanol
Formula	CH_3OH	C_2H_5OH
Molecular weight, kg/kmol	32.04	46.07
Purity, %	99.8	99.7
Carbon content by mass, %	37.48	52.14
Hydrogen content by mass, %	12.58	13.13
Oxygen content by mass, %	49.93	34.73
Specific Gravity at 15.6 °C /15.6 °C	0.796	0.794
Density 20 °C, kg/m^3	790	790
Boiling Point, °C	65	79
Vapor Pressure at 20 °C, kPa	13.02	5.95
Reid Vapor Pressure, kPa	32	16
Heat of Vaporation, kJ/kg	1100	838
Lower Heating Value, MJ/kg	20.09	26.95
Higher Heating Value, MJ/kg	22.88	29.85
Volumetric energy content, MJ/m^3	15.871	21.291
Stoichiometric Air-Fuel Ratio, kg/kg	5.5	9
Stoichiometric Air-Fuel Ratio, kmol/kmol	7.22	14.36
Oxygen content, %wt	50.0	34.8
Specific energy, MJ/kg per Air-Fuel Ratio	3.08	3.00
Research Octane Number (RON)	108	108.7
Autoignition temperature, °C	465	425
Adiabatic flame temperature, °C	1870	1920

Table 3. Properties of blended fuels

No	Methanol (%)	Ethanol (%)	Gasoline (%)	Target AFR	Content (mass)			Mass Fraction (%)			Mol			Density	AFR	RON	Gravimetric LHV (MJ/kg)
					M	E	G	M	E	G	M	E	G				
1	0.00	50.000	50.000	11.82	0.00	397.20	376.50	0.00	51.34	48.66	0.00	8.62	3.42	773.70	11.82	103.25	31.20
2	11.07	34.000	54.930	11.82	88.16	270.10	413.61	11.42	34.99	53.59	2.76	5.86	3.76	771.87	11.82	103.08	31.43
3	17.30	25.000	57.700	11.82	137.75	198.60	434.49	17.87	25.76	56.37	4.30	4.31	3.95	770.84	11.82	102.99	31.57
4	28.37	9.000	62.630	11.82	225.92	71.50	471.60	29.38	9.30	61.33	7.06	1.55	4.29	769.01	11.82	102.83	31.81
No	Methanol (%)	Ethanol (%)	Gasoline (%)	Target AFR	Content (mass)			Mass Fraction (%)			Mol			Density	AFR	RON	Gravimetric LHV (MJ/kg)
					M	E	G	M	E	G	M	E	G				
1	0.000	60.000	40.000	11.25	0.00	476.64	301.20	0.00	61.28	38.72	0.00	10.34	2.74	777.84	11.25	104.50	30.24
2	13.130	41.000	45.870	11.25	104.54	325.70	345.42	13.48	41.99	44.53	3.27	7.07	3.14	775.66	11.25	104.28	30.51
3	20.730	30.000	49.270	11.25	165.06	238.32	371.01	21.31	30.77	47.91	5.16	5.17	3.37	774.40	11.25	104.15	30.68
4	33.860	11.000	55.140	11.25	269.60	87.38	415.23	34.91	11.32	53.77	8.43	1.90	3.77	772.21	11.25	103.95	30.96
No	Methanol (%)	Ethanol (%)	Gasoline (%)	Target AFR	Content (mass)			Mass Fraction (%)			Mol			Density	AFR	RON	Gravimetric LHV (MJ/kg)
					M	E	G	M	E	G	M	E	G				
1	0.000	70.000	30.000	10.68	0.00	556.08	225.90	0.00	71.11	28.89	0.00	12.06	2.05	781.98	10.68	105.57	29.28
2	15.870	47.000	37.130	10.68	126.36	373.37	279.60	16.21	47.91	35.88	3.95	8.10	2.54	779.33	10.68	105.28	29.62
3	24.150	35.000	40.850	10.68	192.29	278.04	307.62	24.72	35.74	39.54	6.01	6.03	2.80	777.95	10.68	105.14	29.80
4	39.330	13.000	47.670	10.68	313.16	103.27	358.98	40.39	13.32	46.30	9.79	2.24	3.26	775.41	10.68	104.88	30.12

Table 4. Engine specification

Model	Specification
Engine Type	4 Stroke, SI Engine, DOHC 4 valve, Liquid Cooled
Cylinder	1 (Single)
Bore x Stroke	57.3 mm x 57.8 mm
Volume	149.16 cc
Compression Ratio	11.3:1
Fuel Supply System	Injection (PGM-FI)
Power max.	12.4 kW (16.9 HP) / 9000 rpm
Torque max.	13.8 Nm (1.41 kgf.m) / 7000 rpm

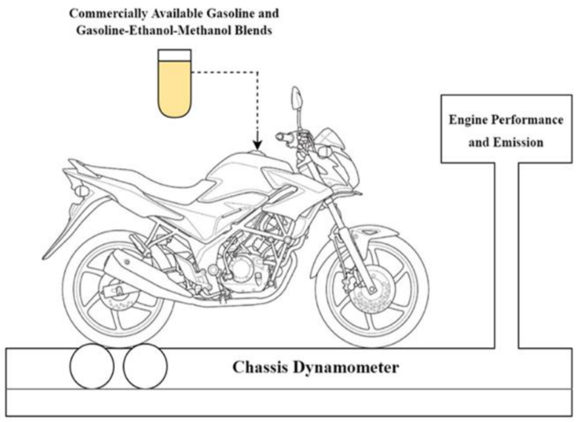

Figure 1. Engine performance test bed

The Mainline Dynolog MCD400L Series Motorcycle Dyno is presently employed to assess and gauge motorcycle performance. It boasts impressive specifications, including a power rating of 700 kW (equivalent to 940 hp), a roller torque rating of 1700 Nm (equivalent to 1254 ft. lbs), and a maximum test speed of 300 km/h.

3. Results and Discussion

The determination of fuel composition in this study relied on a meticulous calculation involving the evaluation of the air-to-fuel ratio (AFR) through the utilization of two critical parameters: density and AFR values. These pivotal parameters were derived either from rigorous experimentation or were drawn from reliable references within the field. The resultant fuel mixtures, which were primarily structured in relation to their volume proportions, are meticulously depicted in the graphical representations found in **Figure 2**. Within these illustrative graphs, one can discern a comprehensive array of fuel mixtures that encompass various combinations of gasoline, ethanol, and methanol, all meticulously engineered to maintain an identical AFR value for each specific composition. These graphical representations effectively encapsulate the entire spectrum of targeted variations in fuel mixtures, shedding light on the intricate relationship between fuel components and their corresponding AFR values.

3.1. Air to Fuel Ratio

By using the AFR equation, the AFR value for the iso-stoichiometric E50 mixture is 11.82; E60 is 11.25; E70 is 10.68. Air to fuel ratio were tested by Exhaust Gas Analyzer. The results of these tests are presented in the graphs in **Figure 3**. From the test, it was found that the AFR value was increasing in each iso-stoichiometric E50, E60, and E70 mixture. This is because the oxygen content in methanol is 49.93% mass and ethanol is 34.73% mass, and the engine setting still uses gasoline fuel, so the oxygen content in methanol and ethanol is measured as fresh air. The higher the percentage of methanol compared to ethanol in the iso-stoichiometric mixture, the higher the AFR value of the mixture. This is because the oxygen content in methanol is higher than that in ethanol. The results of the AFR test can be seen in **Figure 3**, which shows that the AFR value in the mixture of each target is much higher than the AFR value in the RON 90. So, it needs to be re-optimized so that the mixed AFR value is not too high and is in accordance with calculations that have been carried out.

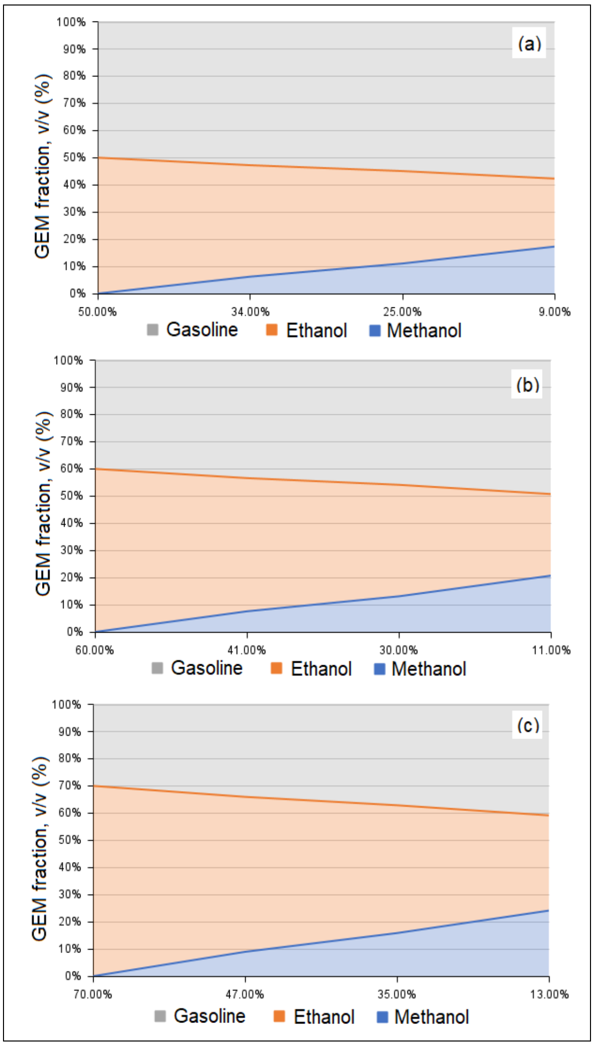

Figure 2. Composition of fuel blends based on targeted Iso-Stoichiometric: (a) E50, (b) E60, and (c) E70

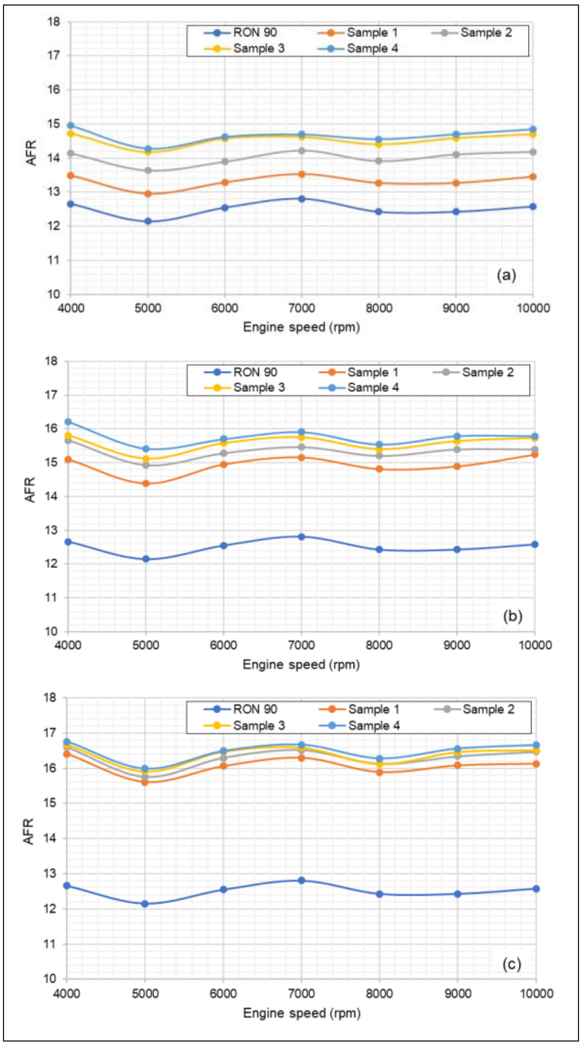

Figure 3. Comparison of AFR Values of each Targeted Iso-Stoichiometric (a) E50, (b) E60, and (c) E70 to the values resulted by RON 90 in the experiment (SAE J1349)

3.2. *Torque and Power*

The results of torque and power tests are presented in **Figure 4**. The maximum torque and power value were obtained by the use of Gasoline RON 90. When the methanol content in the blended fuel was increased, the engine brake power decreased. The heating value of the blended fuel decreases with the increase of the methanol content. This is due to the heating value of methanol being the lowest than others. As a result, a lower power output is obtained. Although ethanol's heat value is lower than gasoline, ethanol has octane numbers higher therefore the combustion can generate higher combustion pressure [13]. Similarly, the immense oxygen content of ethanol compared to gasoline

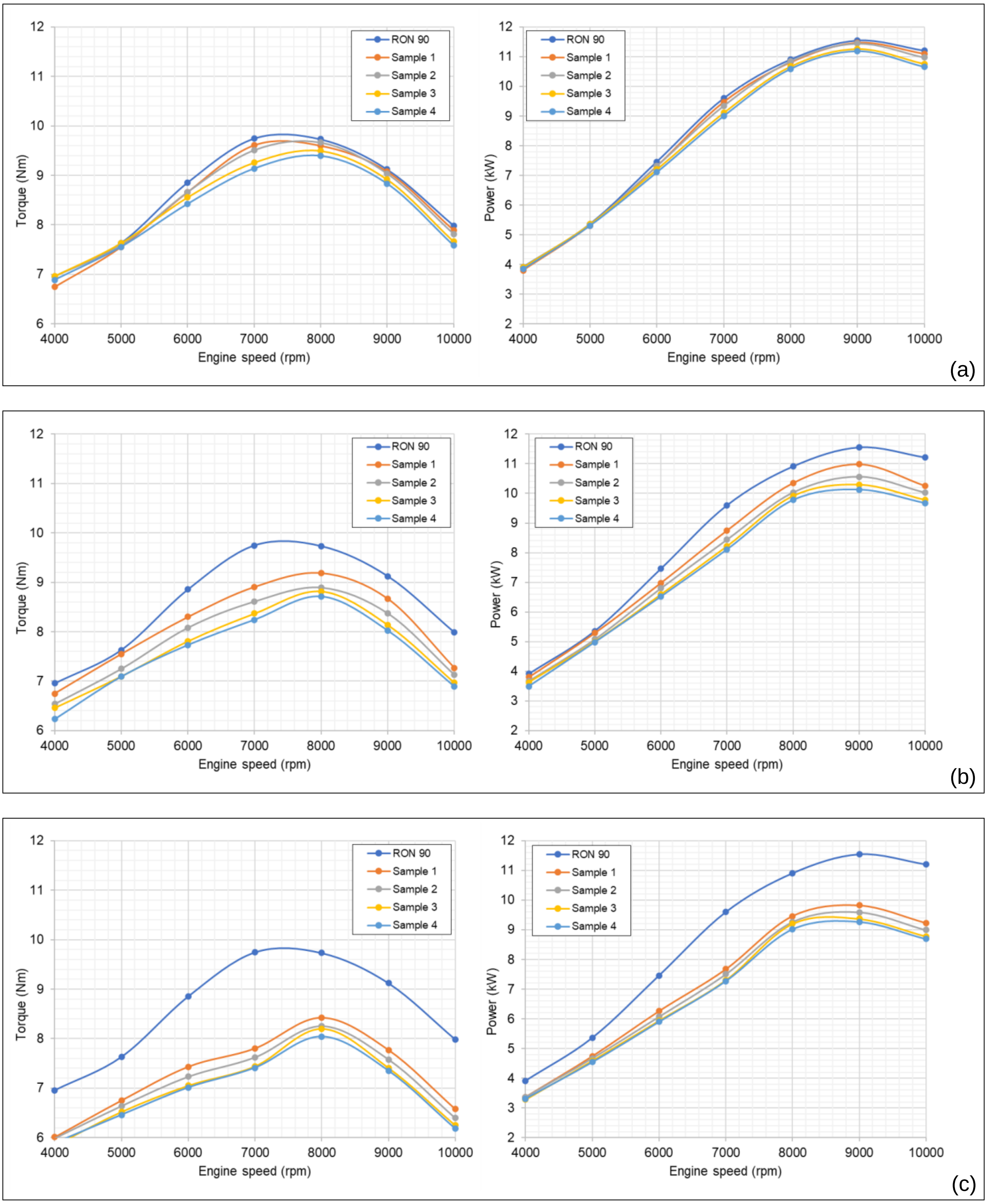

Figure 4. Comparison of torque and power of each targeted Iso-Stoichiometric (a) E50, (b) E60, dan (c) E70 to the values resulted by RON 90 in the experiment (SAE J1349)

can elevate combustion rate and combustion efficiency. In addition, combustion phasing and combustion efficiency can be improved owing to faster laminar flame speed than that of gasoline [28].

The result of the measurement of engine power and torque presented in Fig. 4, showed that all of the ternary mixtures resulted in lower power and torque in comparison with the power and torque produced by gasoline RON 90. Therefore, optimization is needed by engine modification and AFR setting to increase the power and torque of the ternary mixture of gasoline-ethanol-methanol [29], [30]. The results of the AFR test in Fig. 3 show that the AFR value in the mixture of each target is much higher than the AFR value in the RON 90 product. To obtain optimum combustion results.

4. Conclusion

In light of the results obtained from these experiments, it becomes abundantly clear that gasoline with a Research Octane Number (RON) of 90 consistently delivered the highest levels of power and torque in the engine tests. Furthermore, a noteworthy observation is the inverse relationship between the methanol fraction in the mixtures and the engine's torque output. Specifically, the ternary mixture denoted as GEM50 demonstrated superior torque performance when juxtaposed with GEM60 and GEM70. This stark correlation underscores the imperative for optimization measures, chiefly through engine modifications, to enhance the power and torque output when employing ternary mixtures of gasoline, ethanol, and methanol. These findings not only highlight the significance of fuel composition in engine performance but also pave the way for future research and innovation aimed at achieving optimal efficiency and power in internal combustion engines.

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Author's 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 are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

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