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Research Paper

Prediction of Performance and Emission of Gasoline Engine Fueled with a Gasoline-Ethanol-Methanol Mixture Using One Dimensional Engine Modelling Based on Engine Test Results

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Abstract

The depletion of petroleum reserves as the basic raw material for gasoline production has driven studies into alternative fuels. One of the alternative fuels is alcohol, both ethanol and methanol. Due to their liquid form and physical-chemical properties similar to gasoline, small modifications to the engine are required. This paper will explain the effect of using a mixture of gasoline (in this case, RON 98 gasoline with methanol or methanol on engine performance and emissions. The fuel mixtures are as follows: G100, E10, E20, E30, M10, M20, M30. AVL Boost simulation software was used as a tool for 1-dimensional engine modelling, where the modeling is based on engine testing with G100 fuel. The results show that with increasing ethanol-methanol composition, torque and power decrease, and SFC increases. On the emission side, CO, CO_2, and HC were decreased and NOx increased..

Keywords: Prediction; Modelling; Performance; Emission; Ethanol; Methanol

1. Introduction

The dominant use of liquid fuel derived from petroleum in internal combustion engines causes a reduction in petroleum reserves in the world. This encourages the discovery of alternative fuels. Alternative fuels commonly used are: natural gas, propane, hydrogen, ethanol, and methanol [1]. Research on alternative fuels has been widely conducted [2]–[5]. Currently, there is also extensive research and development on alternative fuels derived from renewable sources, including alcohols (methanol and or methanol), which can be produced through fermentation processes [1], [6], [7]. The advantage of ethanol and methanol, due to their liquid form, is that they require minimal changes to the engine fuel supply system. Physical and chemical properties of ethanol and methanol are different from gasoline, including higher autoignition temperature and flashpoint, making them safer for storage and transportation, Lower Heating Value (LHV), meaning that the engine power will be lower at the same fuel supply, and lower stoichiometric Air-Fuel Ratio (AFR), meaning that less oxygen is needed to achieve a more complete combustion process [8]. Studies on the impact of using ethanol and methanol have been extensively conducted, usually in the form of mixtures, for example, gasoline-methanol gasoline-ethanol, gasoline-methanol-ethanol, or other mixtures [9]–[12].

Hanifuddin [13] conducted a study on Gasoline-Ethanol-Methanol blends as the fuel of a four-stroke gasoline motorcycle on a chassis dynamometer testing. Increasing the ethanol and methanol content results in a decrease in produced torque and power. Mokhtar [14] conducted a study on various Gasoline-Ethanol-Methanol fuel mixtures on a motorcycle engine by installing a combustion chamber pressure sensor to obtain data on potential knocking and cycle stability. The research also varied the lambda for each fuel. Other studies on the impact of using Gasoline-Ethanol-Methanol mixtures have also been extensively studied [15]–[18].

In addition to direct testing on engine test facilities, studies on the impact of using ethanol-methanol mixtures in gasoline can be conducted using simulation or modelling methods, one of which is one-dimensional simulation. This method involves creating a virtual engine, with AVL Boost software being a suitable tool. This method can save time and costs as the simulation process is run quickly, and it also allows for easy variations in engine configurations.

Iliev [19] performed simulations using a one-dimensional model, the tool AVL Boost, to determine the effect of several variations of gasoline-ethanol and gasoline-methanol mixtures on the performance of an engine, including torque, power, SFC, emissions (CO, HC, NOx). Fuel mixture compositions are as follows: Gasoline (E0), ethanol blends (E5, E10, E20, E30, E50), methanol blends (M0, M5, M10, M20, M30, M50). The results indicate that with increasing ethanol or methanol content, torque and power decrease, BSFC increases, CO emissions decrease, HC emissions decrease, and NOx emissions increase.

One of the propulsion systems for aircraft is the piston internal combustion engine combined with a propeller. This engine is commonly used in light aircraft, and one of its advantages is its low Specific Fuel Consumption (SFC). Gasoline and alcohol (ethanol and/or methanol) mixtures, can also be used for this type of engine., as demonstrated in Brazil [20], currently, the limit given is around 10% [21].

Research on the effect of using a mixture of gasoline and alcohol on engine performance and emissions needs to be carried out, where this research is carried out using simulation or modeling of AVL Boost software to save time and costs. Although research using simulation with Avl Boost has been conducted, for land vehicle engines Iliev [19], as well as aircraft engines Otkur [22] and Grabowski [23]. where each has not been validated with experimental/testing results. In this study, the default engine model built was validated directly with experimental data from the Rotax 915iS engine test, which used default fuel (RON 98). The developed model not only aims to predict engine performance such as power, torque, and specific fuel consumption (SFC), but also to evaluate the resulting combustion emissions, including carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). Engine testing is carried out at the LTMP BRIN engine test facility, the data collected includes fuel flow rate, power, and exhaust gas emissions (CO, HC, NOx). Testing is conducted to evaluate engine performance on the ground under the highest operational temperature conditions (40 °C), according to the engine manual [22].

2. Methods

The methodology used is conducting engine tests at a test facility to obtain performance and emission data. The gasoline fuel used was RON 98 gasoline. This data will used as reference for creating a virtual engine within a 1-dimensional engine modelling. the modelling tool is AVL Boost Subsequently, simulations will be performed for various fuel mixtures of gasoline with ethanol or metha. The fuel mixture compositions are as follows in **Table 1**.

Table 1. Fuel mixtures composition

Code	Gasoline (%)	Ethanol (%)	Methanol (%)	LHV (kJ/kg)	Density (15°C) (kg/m³)
G100	100	0	0	43951	747
E10	90	10	0	42251	751
E20	80	20	0	40551	756
E30	70	30	0	38851	760
M10	90	0	10	41565	751
M20	80	0	20	39179	756
M30	70	0	30	36793	760

Determination of the mixture composition is based on the maximum ethanol /methanol content permitted by the engine manufacturer(10%) plus two compositions with levels of 20% and 30%. In this study simulations were carried out for all fuel compositions under standard setting conditions, where the fuel supply for all fuel compositions was the same, based on the settings for G100 fuel. Gasoline properties is shown on **Table 2**, ethanol and methanol properties are shown on **Table 3**, respectively.

2.1. *Engine Testing*

The engine testing is conducted at the engine test facility located in the BJ Habibie Science and Technology Park, specifically in the Thermodynamics and Propulsion Laboratory. The engine is mounted on a platform using mounting equipment, and The engine power output is connected to the dynamometer with a drive shaft and vibration damper. The dynamometer is used to apply a load to the test engine, with load settings controlled by a computer system. The testing process involves running the engine at the desired RPM, then adjusting the throttle to achieve the desired fuel flow rate. Fuel supply and speed settings refer to the data in the engine manual.

The dynamometer hold the engine at the desired rpm. The force exerted by the dynamometer represents the engine load and is measured using a load cell, which is positioned at a specific distance from the center of the dynamometer shaft. The measured force, multiplied by the distance from the load cell, results in engine torque. This torque, when multiplied by the dynamometer speed, gives the engine power. The engine is equipped with measuring instruments to record test parameters, as detailed in the table below. These data will then be automatically recorded by the data acquisition system. Fuel setting is describe in **Table 4** and equipment and test parameters is describe in **Table 5**. The engine testing layout is presented in **Figure 1** and **Figure 2**. Test engine specification is presented in **Table 6**.

Table 2. Gasoline characteristic (RON 98)

Properties	Values	Units
Density at 15OC	747	kg/m^3
LHV	43951	kj/kg
RON	98.5	
Reid Vapor Pressure	57.4	kPa

Table 3. Ethanol and methanol characteristic [24], [25]

Properties	Ethanol	Methanol	Units
Purity	99.7	99.8	(%)
Chemical formula	C_2H_5OH	CH_3OH	
Boiling Temperature at 1 bar	79	65	[°C]
Density at 20 OC	790	790	[kg/m^3]
Vapour density at 20 OC	2.06	1.42	[kg/m^3]
Vaporization Heat of	838	1100	[kJ/kg]
Surface tension at 20 OC	22.3	22.1	[mN/m]
Dynamic viscosity at 20 OC	1.2	0.57	[mPas]
Molecular weight [kg/kmol]	46.07	32.04	
Content of Oxygen by mass	34.73	49.93	[%]
Hydrogen content by mass	13.13	12.58	[%]
Content of carbon by mass	52.14	37.48	[%]
Lower heating value	26950	20090	[KJ/kg]
Higher heating value	28950	22880	[KJ/kg]
Content Volumetric energy	15871	21291	[MJ/kg]
AFR Stoichiometric	9.0	5.5	[kg/kg]
AFR Stoichiometric	14.36	7.22	[kmol/kmol]

Table 4. Engine speed and fuel flow setting

No	Engine Speed (rpm)	Fuel Flow (l/h)	Fuel Flow (kg/h)
1	3000	10.09	7.54
2	3500	14.09	10.53
3	4000	18.38	13.73
4	4500	22.95	17.14
5	5000	27.64	20.65

Table 5. Equipment and test parameters

No	Equipment	Test Parameters
1	Flowmeter	Liquid fuel flow
2	Pressure sensors	Pressure parameters: fuel, oil, ambient air, manifold air)
3	Temperature sensors	Temperature Parameters : (ambient air, manifold air, oil,coolant, exhaust gas)
4	Horiba Emission Analyser	CO_2,CO, HC, Nox

Table 6. Engine specification

Model	Rotax 915 iS
Type	Gasoline, 4 stroke, with turbocharger
Cylinder Configuration	4 cylinder opposite
Fuel Supply System	Electronic Control Fuel Injection
Bore (mm)	84
Stroke (mm)	61
Capacity (cc)	1352
Compression Ratio	8.2:1

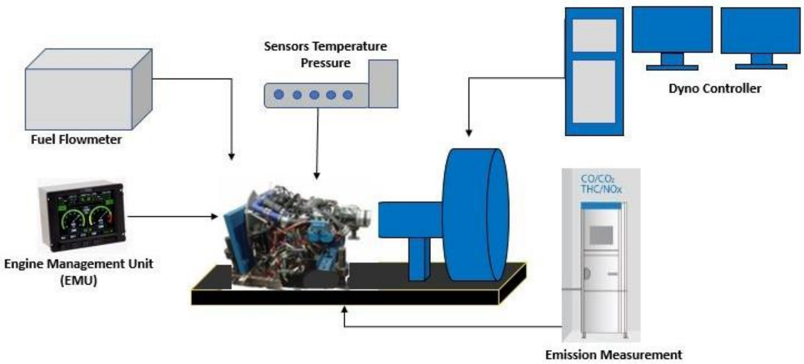

Figure 1. Test system layout

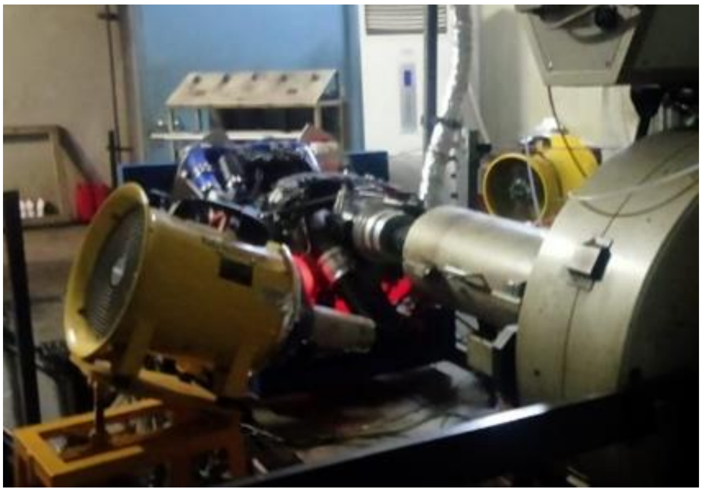

Figure 2. Engine testing

2.2. *One Dimensional Modelling*

The first stage of engine modelling is The first step is to create a virtual engine that represents the test engine conditions. The virtual engine is constructed as a template of the engine's component layout (**Figure 3**).

The second step involves entering simulation parameters, which include:

- The type of fuel used, which can be either a single fuel or a mixture of various fuels.
- Time step control settings for the simulation.
- Firing order.
- Engine friction data.

The third step is to input data for each engine component. One of the important data here is the cylinder data, as detailed in the **Table 7**.

Another of the important data from the cylinder is the valve lift profile (**Figure 4**), because this component regulates the 4 stroke engine cycle, this data is processed from the image in Grabowski's paper [23].

The input data can be obtained from various sources, including:

- Data from the engine manufacturer or other sources.
- Measurement data of engine components.
- Testing of engine components.
- Typical data of engine components.

The next step is to enter operational condition data based on test results from the test facility. The data used includes temperature and plenum pressure, as detailed in the **Table 8**.

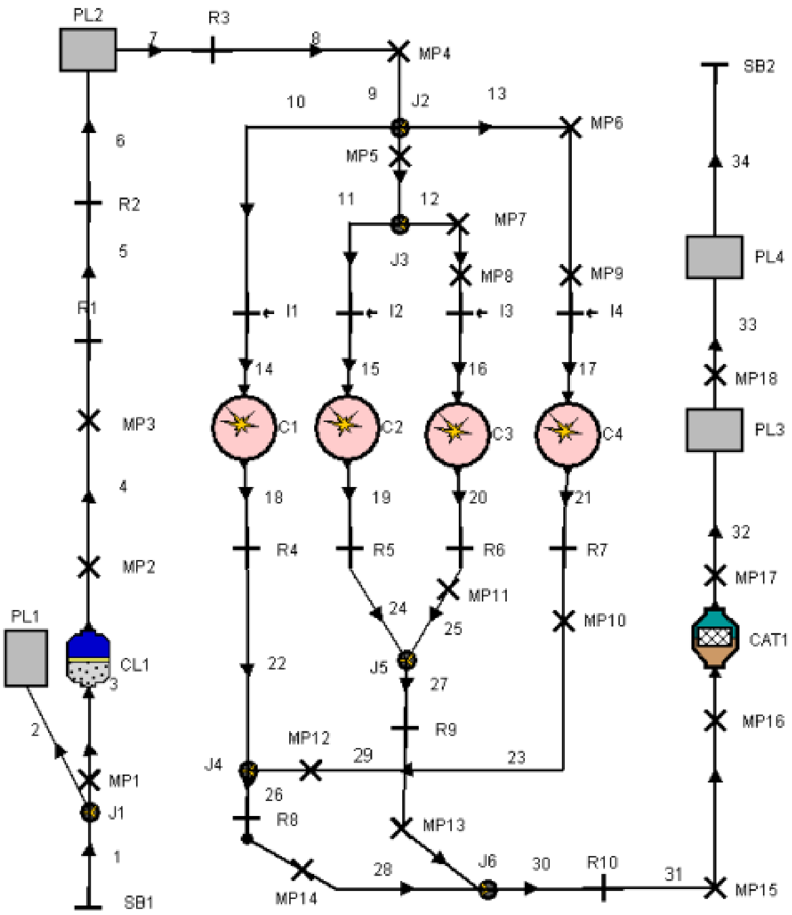

Figure 3. Virtual engine

Table 7. Component of virtual engine

Component	Symbol	Component	Symbol
Cylinder	C	Pipe	________
System Boundary	SB	Juction	J
Air Fiiter	CL	Measuring Point	MP=
Plenum	PL	R	Restriction
I	Injector	CAT1	Catalitic Converter

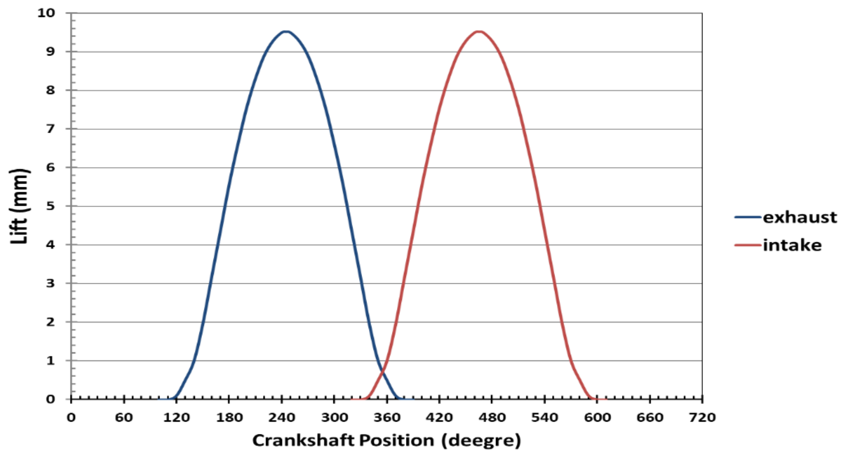

Figure 4. Valve lift profile

Table 8. Engine operation condition

No	Engine Speed (rpm)	Plenum Temperature (°C)	Plenum Pressure (bar)
1	3000	47.9	0.98
2	3500	51,6	1.12
3	4000	58.5	1.31
4	4500	65.2	1.38
5	5000	62.5	1.46

The simulation process is as follow, based on the above data, the air will be simulated as it flows through the intake system to the injector. The injector will spray fuel according to the engine's requirements or settings. In this simulation, the fuel injection quantity is controlled by entering the initial Air to fuel Ratio (AFR), AFR is air mass flow rate divided by fuel mass flow rate. This process is repeated for all engine speeds to achieve a fuel flow rate that aligns with the test data.

2.3. *The Combustion Model*

The combustion model used is Vibe Two Zone, where the combustion chamber is divided into two zones, namely: the unburned gas zone and the burnt gas zone. Where the first law of thermodynamics applies to both zones, as formulated in Eq. (1) and Eq. (2), respectively.

$$\frac{dm_b u_b}{d\alpha} = -p_c \frac{dV_b}{d\alpha} + \frac{dQ_F}{d\alpha} - \sum \frac{dQ_{Wb}}{d\alpha} + h_u \frac{dm_b}{d\alpha} - h_{BB,b} \frac{dm_{BB,b}}{d\alpha} \quad (1)$$

$$\frac{dm_b u_u}{d\alpha} = -p_c \frac{dV_u}{d\alpha} - \sum \frac{dQ_{Wu}}{d\alpha} - h_u \frac{dm_b}{d\alpha} - h_{BB,u} \frac{dm_{BB,b}}{d\alpha} \quad (2)$$

where, u is unburned zone, b is burned zone, $p_c \frac{dV_b}{d\alpha}$ is work of piston, $\frac{dQ_F}{d\alpha}$ is input of fuel heat, $\frac{dQ_W}{d\alpha}$ is heat losses to the wall, $h_u \frac{dm_b}{d\alpha}$ is the fresh charge to combustion products conversion enthalpy (the unburned zone to the burned zone), and $h_{BB,b} \frac{dm_{BB}}{d\alpha}$ is blowby enthalpy.

Related to zones volume and cylinder volume the Eq. (3) applies and for zones, volume changes and cylinder volume changes, the Eq.(4) applies.

$$V_b + V_u = V \quad (3)$$

$$\frac{dV_b}{d\alpha} + \frac{dV_u}{d\alpha} = \frac{dV}{\alpha} \quad (4)$$

The Vibe function and specified by the user determines the mixture amount burned at each time setup. An engine actual characteristics of heat release can be estimated using the vibes function, as formulated bu Eqs. (5)-(7).

$$\frac{dx}{d\alpha} = \frac{a}{\Delta\alpha_c} \cdot (m+1) \cdot y^m \cdot e^{-a \cdot y^{m+1}} \quad (5)$$

$$dx = \frac{dQ}{Q} \quad (6)$$

$$y = \frac{\alpha - \alpha_0}{\Delta\alpha_c} \quad (7)$$

where, Q is total input of fuel heat, α is angle of crank, α_0 is start of combustion, $\Delta\alpha_c$ is duration of combustion, m is shape parameter (1.6), and a is vibe parameter (6.9).

Burned fuel mass fraction (x) since combustion start is calculated based on the Eq. (8).

$$x = \int \frac{dx}{d\alpha} \cdot d\alpha = 1 - e^{-a \cdot y^{(m+1)}} \quad (8)$$

2.4. Emission Model

The default calculation model available in AVL boost is used for calculating CO_2, CO, HC and NOX emissions. Onorati et.al [26] model is used for CO formation, with 2 main reactions and involving 6 species. The Pattas and Häfner model is used in the formation of NOx, with the Zeldovic mechanism consisting of 6 main reactions and involving 8 species.

The calculation of hydrocarbon emission formation in AVL Boost consists of several mechanisms, including:

- Crevise mechanism, crevise is a narrow volume where the flame cannot reach because the heat is transferred to the cylinder wall, this crevise volume is found in the gap between the cylinder liner and the piston ring, and in the topland crevices.
- HC absorption/desorption mechanism. Another source of HC emissions is the presence of lubricating oil in the fuel and combustion chamber wall. In the compression process, the fuel vapor pressure increases, causing the fuel to be absorbed into the oil. The concentration of fuel vapor in the burned gas will be used up during the process of combustion, and then the fuel vapor absorbed by the oil will be desorb into the burned gas.
- Partial burn effect, the formation of HC emissions is caused by the unburned charge fraction remaining in the cylinder.
- HC post oxidation, finnaly due to the high combustion chamber temperature, a complex oxidation process occurs on all hydrocarbons released into the burnt gas. Lavoie and Blumberg [27] accounted for this process with a simplified approach, taking into account the slow post-oxidation process the Arrhenius formula was used.

3. Results and Discussion

3.1. Fuel Mass Flow

The fuel supply settings during testing refer to the data from the manual book. The **Figure 5** shows a very small difference between the manual data and test data, it's about below 1%. The fuel mass flow rate from the simulation results differs slightly from the test fuel mass flow data, with a very small difference of approximately 1%.

3.2. Lambda

Lambda is the ratio of the actual AFR to the stoichiometric AFR. Lambda is considered rich if the value is below 1, and considered lean if the value is above 1. From **Figure 6**, it can be seen that for gasoline, the lambda value is slightly below 1 or slightly rich. Lambda value of the fuel mixture increases if ethanol or methanol content increases, due to the lower stoichiometric AFR of ethanol and methanol. The similar results were also obtained in research conducted by Hanifudin [13], which explained that with increasing alcohol content, the actual AFR value would increase, in other words, the lambda value would increase.

3.3. Torque

From **Figure 7**, it can be seen that the torque results from testing and simulation show a relatively small difference of around 0.5 to 1%. As the proportion of ethanol in the fuel mixture increases, the engine torque decreases. The torque reduction is approximately 1.5% for E10, about 4.3 % for E20, and 7.4 % for E30. Similarly, increasing the proportion of methanol in the fuel mixture also causes a decrease in engine torque. The torque reduction is about 1.8 % for M10, about 6.7 % for M20, and 12.4% for M30.

The torque reduction is due to the lower heating value (LHV) of ethanol and methanol, which are lower than that of gasoline. Consequently, the lower heating values of the fuel mixtures decrease as the concentration of ethanol or methanol increases. The torque reduction is greater with methanol compared to ethanol because methanol has a lower LHV than ethanol.

The similar results were also obtained by simulations conducted by Iliev [19] where the addition of ethanol or methanol would reduce the torque produced by the engine. Research using the testing method by Hanifudin [13] also showed the similar results where the torque produced decreased with increasing levels of ethanol or methanol. Different results were obtained by Masum [18] where the addition of ethanol or methanol increased engine torque, this was due to the addition of fuel supply during testing.

3.4. Power

From **Figure 8**, it can be seen that the power results from testing and simulation show a relatively small difference of around 0.5 to 1%.

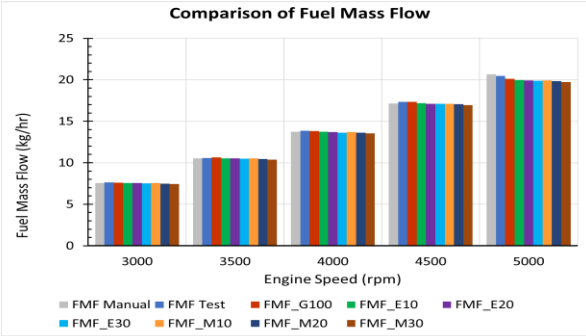

Figure 5. Comparison of fuel mass flow

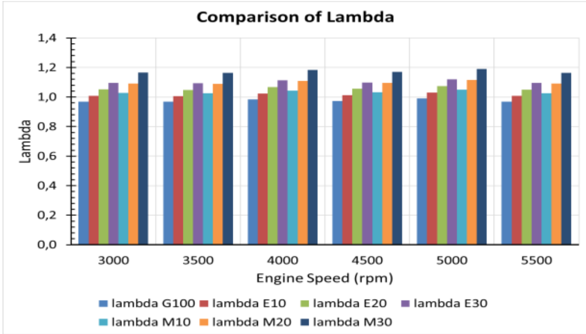

Figure 6. Comparison of lambda

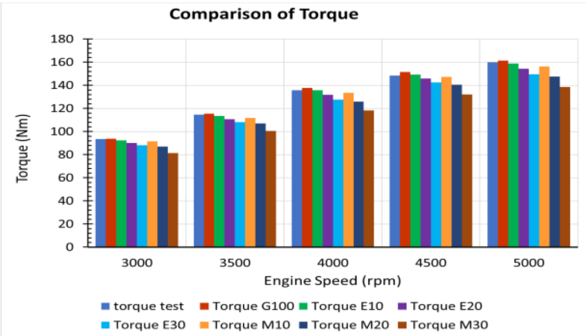

Figure 7. Comparison of torque

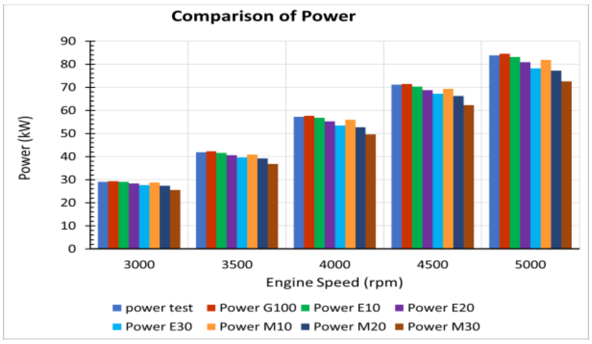

Figure 8. Comparison of power

The engine power is decreases if the ethanol content in the fuel mixture increase. The power reduction is approximately 1.9% for E10, about 4.8% for E20, and 8.1% for E30. Similarly, increasing the content of methanol in the fuel mixture also causes a decrease in engine power. The power reduction is about 3.2% for M10, about 7.8% for M20, and 13.5% for M30. The power reduction caused by lower heating value of ethanol or methanol which are lower than gasoline.

The similar results were also obtained by simulations conducted by Iliev [19] where the addition of ethanol or methanol would reduce the power produced by the engine. Research using the testing method by Hanifudin [13] also showed the similar results where the power produced decreased with increasing levels of ethanol or methanol. Different results were obtained by Masum [18] where the addition of ethanol or methanol increased engine power, this was due to the addition of fuel supply during testing.

3.5. *Spesific Fuel Consumption*

From **Figure 9**, it can be seen that the power results from testing and simulation show a relatively small difference of around 0.4 to 1%. Specific Fuel Consumption (SFC) increase if the content of ethanol is increase. The increase in SFC is approximately 1.2% for E10, around 3.4 % for E20, and 5.8 % for E30. Similarly on the methanol mixture. The increase in SFC is approximately 1.2 % for M10, around 5.6 % for M20, and 11.8 % for M30. This is because the mass of fuel injected remains relatively the same, while the power output decreases with the increasing ethanol or methanol content. The similar results were also obtained from simulations carried out by Iliev [19] where the addition of ethanol or methanol would increase the SFC, The test carried out by Masum [18] also obtained the similar results.

3.6. *Spesific Fuel Energy Consumption*

From **Figure 10**, it can be seen that the Specific Fuel Energy Consumption (SFEC) results from testing and simulation show a relatively small difference of around -1 to 1%. SFEC decrease if the content of ethanol is increase. The decease in SFEC is approximately 2.7% for E10, around 4.5 % for E20, and 6.3 % for E30. Similarly on the methanol mixture. The decrease in SFEC is approximately 4.6 % for M10, around 5.9 % for M20, and 6.5 % for M30. This parameter describes the efficiency of fuel energy conversion into engine power, the smaller the SFEC value indicates better fuel energy conversion, although the addition of ethanol or methanol will cause a decrease in the LHV value as shown in the **Table 1** however the decrease in power that occurs is not as large as the decrease in the LHV value.

3.7. CO_2 Emission

From **Figure 11**, it can be seen that the test data and simulation results differ by about -1.4 to 1.6 percent, with an average difference of 0.01%. The simulation results show that if the content of ethanol increases, emissions of CO_2 decrease. Similarly, as the methanol content increases, CO_2 emissions also decrease. This is due to the oxygen enrichment contained in ethanol and methanol. The average reduction in CO_2 emissions is approximately 0.15% for E10, 2.8% for E20, and 6.6% for E30. Similarly, the reduction is about 1.2% for M10, 5.9% for M20, and 12.1% for M30. Tests conducted by Syarifudin [17] also obtained results with a similar tendency for a mixture of ethanol or methanol.

3.8. CO Emission

From **Figure 12**, it can be seen that the CO emission result from testing and simulation show a relatively small difference of around -0.87 to 1.89 percent, with an average difference of 0.83%. The simulation results show that CO emissions decrease drastically if the ethanol or methanol content increase. This is due to the oxygen enrichment contained in ethanol and methanol, The CO oxidation process will increase with increasing oxygen content. The carbon content in ethanol (C_2H_5OH) and methanol (C3H8OH) which is lower than gasoline ($C_{10}H_{22}$) lead to reduce CO emission. Average CO_2 emission reduction is approximately 86.9% for E10, about 96.5% for E20, and 97.1% for E30. The reduction in CO emissions is about 95.8% for M10, about 97.0% for M20, and 97.6% for M30. Results with a similar tendency were obtained from simulations carried out by Iliev [19] where the addition of ethanol or methanol would reduce CO emissions significantly. Tests conducted by Masum [18] and Syarifudin [17] also obtained results with a similar tendency for a mixture of ethanol or methanol.

3.9. HC emission

From **Figure 13**, it can be seen that the HC emission result from testing and simulation show a relatively small difference of around 6.6 to 9 percent, with an average difference of 0.4%. The simulation results show that as the ethanol content increases, emissions of HC decrease. Similarly, if the content of methanol increases, emissions of HC decrease. Like CO emissions, this is due to the oxygen enrichment contained in ethanol and methanol. Combustion process will be more completed as oxygen content higher, resulting the reduction of HC emission.

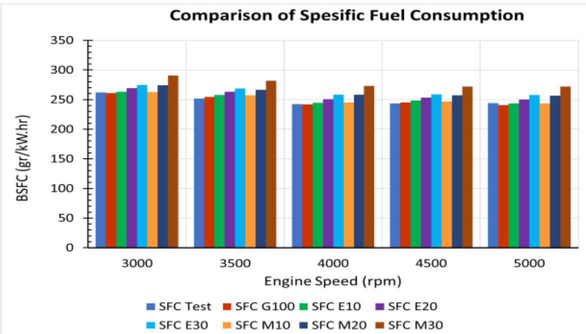

Figure 9. Comparison of SFC

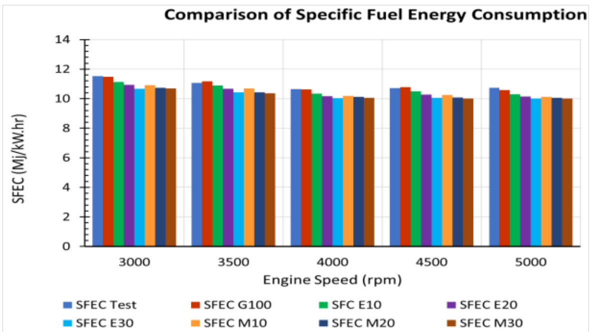

Figure 10. Comparison of SFEC

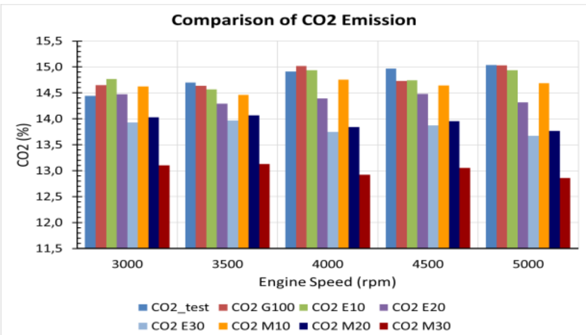

Figure 11. Comparison of CO_2

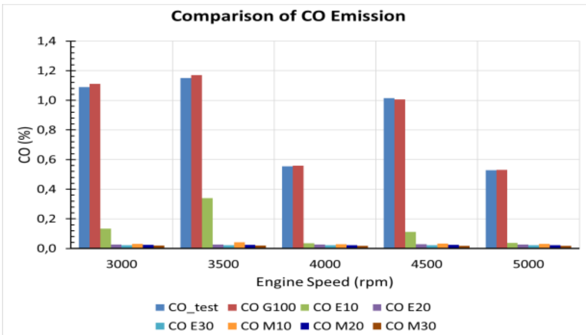

Figure 12. Comparison of CO

The reduction in HC emissions is approximately 50.4% for E10, about 69% for E20, and 72.2% for E30. HC emission reduction is approximately 62.6% for M10, around 72.5% for M20, and 70.8% for M30. Results with a similar tendency were obtained from simulations carried out by Iliev [19] where the addition of ethanol or methanol would reduce HC emissions significantly. Tests conducted by Masum [18] and Syarifudin [17] also obtained results with a similar tendency for a mixture of ethanol or methanol.

3.10. NOx Emission

From **Figure 14**, it can be seen that the NOx emission result from testing and simulation show a relatively small difference of around 6.6 to 9 percent 2.7 to 2 percent, with an average difference of -0.33%. The simulation results show that NOx emissions will increase with the addition of ethanol, with the following trend: at concentrations of 10% to 20%, NOx emissions increase by an average of 60% and 86%, respectively. For a 30% ethanol concentration, the increase in NOx emissions decreases to 72%.

Similarly, the simulation results show that the addition of methanol increases NOx emissions, with the following trend: at concentrations of 10% to 20%, the increase in NOx emissions is relatively the same, with an average increase of 78% and 80%, respectively. For a 30% methanol concentration, the increase in NOx emissions decreases to 23%.

There are two factors causing this phenomenon. On one side, ethanol or methanol addition will improves combustion process and increases combustion chamber temperature. On the other side, Ethanol and methanol have a higher latent heat evaporation value than gasoline, during the evaporation process in the cylinder, it will reduce the temperature of the combustion chamber. Since the formation of NOx occurs due to high combustion chamber temperatures the dominant factor will influence the formation of NOx. due to high combustion chamber temperatures

In the simulation conducted by Iliev [19], it was also found that at a certain mixture level, the NOx emission value would increase, then if the mixture level was increased, the NOx emission would decrease again. Tests conducted by Masum [18] obtained results with a similar tendency for a mixture of 20% ethanol or methanol.

From the results above, the default model with RON98 gasoline fuel with results that are not too different from the test/experiment results, can be used as a reference for conducting other simulations. As for applications with ethanol or methanol mixed fuels, it can provide a similar tendency to some existing literature, so it can be used to predict other mixture concentrations. These results can also be used by engine manufacturers to re-tune engines to compensate for power reduction.

4. Conclusion

The default model on Ron 98 gasoline fuel generally gives results with relatively small errors compared to experimental results with the following values: torque and power 0.5 to 1%, SFC 0.4 to 1%, SFEC -1 to 1%, CO_2 emissions 1.4 to 1.6%, CO_2 emissions -0.87 to 1.89, HC emissions -6.6 to 10%, NOx emissions -2.7 to 2%. The default model applied to the use of blended ethanol or methanol shows tendencies consistent with findings in the literature. The results indicate a decrease in torque, power, and specific fuel energy, accompanied by an increase in specific fuel consumption. CO2, CO, and HC emission levels decrease significantly, while NOx emissions increase. Overall, gasoline-ethanol blends generally yield better performance compared to gasoline-methanol blends. However, further validation through testing and experiments is required to obtain exact values.

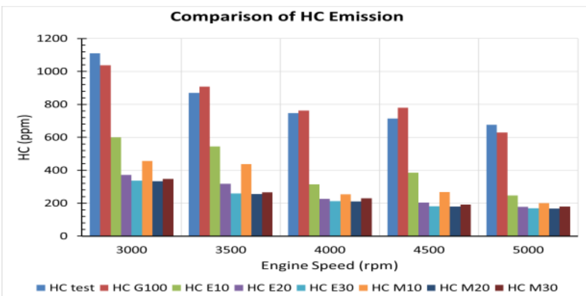

Figure 13. Comparison of HC

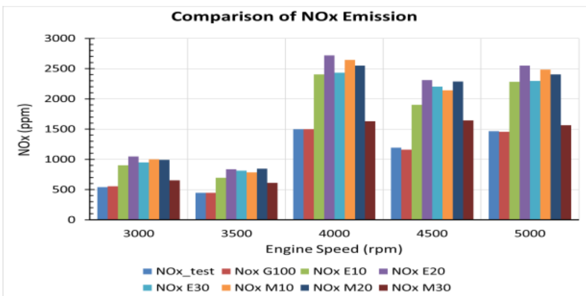

Figure 14. Comparison of NOx

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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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