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Research Paper

# Exhaust Gas Emissions of Homogeneous Gasoline-Methanol-(Ethanol) Blends

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## Abstract

In recent years, one of the most logical efforts made to reduce the dependence on fossil energy sources is the use of a gasoline-methanol fuel blend. However, the problem in using a gasoline-methanol blend as fuel is that the methanol will eventually separate itself from the gasoline unless they are properly blended together, this is because methanol has a polar hydroxyl group called monohydric that binds water vapor together, causing the mixture to separate. Previous research showed that adding a small amount of ethanol to the gasoline-methanol blend makes it a homogeneous blend. Therefore, this research aims to identify the exhaust emissions of the homogeneous gasoline-methanol-(ethanol) blend. For each blended fraction was tested on a single-cylinder four-stroke engine. The emission test is carried out in two stages which include the gasoline mode, and the alcohol mode. These two measurement modes undergo a validation process to correct the differences in the measurement results of the gasoline-methanol-ethanol blends. The test results show that increasing the methanol fraction in the gasoline-methanol-(ethanol) fuel blend results in reduced emission of carbon monoxide and unburnt hydrocarbon because methanol has a high enthalpy of evaporation, which increases both volumetric efficiency and complete combustion. In addition, the increase in the methanol fraction in the gasoline-methanol-(ethanol) blend showed a higher increase in carbon dioxide emissions. This is because methanol and ethanol have a much lower energy content than gasoline. Therefore, its energy production per unit time requires more fuel molecules.

**Keywords:** Exhaust emissions; Homogeneous; Gasoline; Methanol; Ethanol

## 1. Introduction

The majority of energy conversion engines still use the carbon cycle that utilizes fossil fuels as the main energy source [1], [2]. This fuel produces high levels of greenhouse gases and seriously impacts global climate change [3], [4]. Biofuels with oxygen content are expected to replace the dependence on fossil fuels and also reduce greenhouse gases [5]. Furthermore, the possibility of using short-chain alcohols such as methanol, ethanol, and propanol either individually or as a mixture to substitute for fossil fuels is still being explored [6], [7]. One of the important considerations is that the use of biofuels does not upset the balance of food supply and has a low cost of production [8]. Methanol is a group of short-chain alcohols that is easily synthesized from coal and other abundant sources that ensure the low cost of production is maintained. The octane number of methanol exceeds gasoline but can also be used in gasoline and diesel engines without any modification in the engine geometry [9], [10]. The use of methanol has also been shown to reduce the emissions of Nitrogen Oxides (NOx) and soot [11]. Several research has also showed that the use of methanol as a fuel is more environmentally friendly than fossil fuels [12]–[14]. Although there was a separation problem in the gasoline-methanol fuel blend, this situation was solved by adding a certain amount of ethanol [15], [16]. The gasoline-methanol blend separates because methanol molecules interact more strongly with water vapor molecules from the air environment than the molecules of aromatic hydrocarbon (benzene groups) in liquid gasoline [17]. Further research also revealed that the G-70, G-80, G90, and G-95 fuel blends perform better than pure gasoline because the mixture fraction has a higher laminar combustion speed [16]. This speed results in a higher torque (energy) generation rate per unit time. Another beneficial feature of using ethanol and methanol as fuels is their high rate of heat evaporation, which cools the air entering the engine and results in increased volumetric efficiency and power output [18].

An exhaust gas analyzer is a tool for measuring the concentration of carbon monoxide and other gases in the tailpipe of an internal combustion engine. While using fuel mixtures such as gasoline-alcohol, it generates some problems while measuring the exhaust gas, as the analyzer is only intended for specific fuel types (Gasoline, Alcohol, and Vigas).

Exhaust emissions of gasoline-methanol changes need to be carried out to complement the performance of the fuel mixture. The difference in exhaust gas emissions of the gasoline-methanol blend is due to changes in the physical properties of the fuel mixture, related to the oxygen content and the carbon-hydrogen ratio of fuel blends [15], [16], [19], [20]. This research aims to buildup on previous research findings on exhaust emission. This study also reveal the differences in results and strategies for validating measurements with an exhaust gas analyzer on gasoline-alcohol mixtures. This is necessary because alcohol is a promising next-generation fuel in Spark Ignition (SI) engines [21], [22]. Furthermore, the use of alcohol has a strong potential to overcome the over-dependence on fossil fuels in the future [23], [24].

The homogeneous fraction of the gasoline-methanol-(ethanol) mixture is based on Waluyo et al. [16]. The gasoline-methanol-(ethanol) blend fractions are G-95, G-90, G-80, G-70, and G-60. The abbreviations G-95, G-90, G-80 and so on mean that the fuel mixture contains 95% - 5%; 90% -10%; 80% - 20% (v/v) and so on of respectively of gasoline-methanol.

**Table 1** shows that there are two types of fuel (gasoline and alcohol) that give different measurement results in each mode. In order to obtain accurate measurement results, a validation of the difference needs to be carried out. The percentage of gasoline-alcohol needs to be taken into account as a correction factor for each measurement mode.

**Table 1.** Fuel blend compositions [16]

| Fuel blend | Gasoline (mL) | Methanol (mL) | Ethanol (mL) |
|---|---|---|---|
| G-95 | 9.500 | 0.500 | 0.50 |
| G-90 | 9.000 | 1.000 | 0.50 |
| G-80 | 8.000 | 2.000 | 0.30 |
| G-70 | 7.000 | 3.000 | 0.20 |
| G-60 | 6.000 | 4.000 | 0.10 |

## 2. Method

### 2.1. *Fuel Blends Preparation*

Pertamax with RON 92 produced by PT Pertamina in Indonesia is used in this research. Furthermore, methanol ($CH_3OH$) and ethanol ($C_2H_5OH$) used alcohol fuel are cosolvent liquids obtained from PT. Smart-Lab, Indonesia, with a molecular weight of 32.04 and 46.07 grams.mol$^{-1}$, respectively.

The gasoline-methanol-(ethanol) blends used in this research are G-100 (pure), G-95, G-90, G-80, G-70, and G-60, which is consistent with the homogeneous gasoline-methanol-(ethanol) blend fraction data from previous [16]. Each gasoline-methanol-(ethanol) blend fraction was added to a 1000 cm$^3$ reaction glass. The stirring process was carried out using a magnetic stirrer for 60 seconds with a spinning speed of 500 rpm, as shown in **Figure 1**. Furthermore, the fuel blend was closed and kept for 12 hours to ensure there was no separation of the blend. This blending and storage process was carried out at room temperature and pressure, with relative humidity (RH) of 55-60%. The fuel blend preparation is presented in **Figure 1** and properties of fuel is presented in **Table 2**.

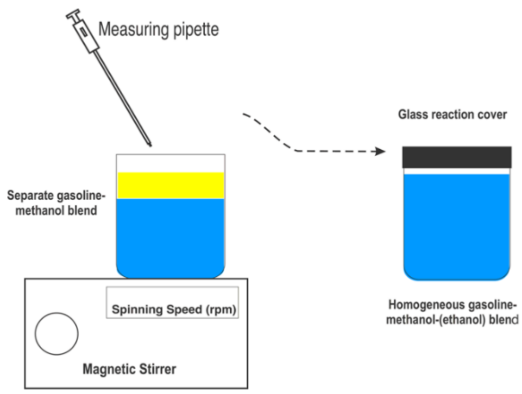


**Figure 1.** The fuel blend preparation

**Table 2.** Physical and chemical properties of the selected fuel [19], [25], [26]

| Properties | Methanol | Ethanol | Gasoline |
|---|---|---|---|
| Purity (%) | 99.8 | 99.7 | n/a |
| Chemical formula | $CH_3OH$ | $C_2H_5OH$ | Various |
| Boiling Temperature at 1 bar [°C] | 65 | 79 | 25-215 |
| Density (STP) [kg/m$^3$] | 790 | 790 | 740 |
| Vapor density (STP) [kg/m$^3$] | 1.42 | 2.06 | 3.88 |
| Heat of vaporization [kJ/kg] | 1100 | 838 | 180-350 |
| Surface tension (20 °C) [mN/m] | 22.1 | 22.3 | 21.6 |
| Dynamic viscosity (20 °C) [mPas] | 0.57 | 1.2 | 0.6 |
| Solubility in water | Soluble | Soluble | Insoluble |
| Molecular weight [kg/kmol] | 32.04 | 46.07 | 107.00 |
| Oxygen content by mass [%] | 49.93 | 34.73 | 0 |
| Hydrogen content by mass [%] | 12.58 | 13.13 | ~ 14 |
| Carbon content by mass [%] | 37.48 | 52.14 | ~ 86 |
| Lower heating value [MJ kg$^{-1}$] | 20.09 | 26.95 | 42.9 |
| Higher heating value [MJ kg$^{-1}$] | 22.88 | 29.85 | 48.00 |
| Volumetric energy content [MJ/m$^3$] | 15871 | 21291 | 31746 |
| Stoichiometric AFR [kg/kg] | 5.5 | 9.0 | 14.7 |
| Stoichiometric AFR [kmol/kmol] | 7.22 | 14.36 | 54.49 |
| Specific $CO_2$ emission [g/MJ] | 68.44 | 70.99 | 73.95 |
| Specific $CO_2$ emission relative to gasoline | 0.93 | 0.96 | 1 |
| Vapor pressure at 20 °C [kPa] | 13.02 | 5.95 | n/a |
| Autoignition temperature [°C] | 465 | 425 | 192-470 |
| Adiabatic flame temperature [°C] | 1870 | 1920 | ~ 2000 |

### 2.2. *Exhaust Emission Measurement*

The measurement of the exhaust gases emitted for the homogeneous gasoline-methanol-(ethanol) blend was carried out in a single-cylinder engine of 125 cm$^3$, with the use of pure gasoline as a reference fuel. The measurements were carried out on a gasoline-methanol mixture with the addition of a small amount of homogeneous ethanol at 1500 rpm (idle speed), 2500, and 3500 rpm. The measurements of the exhaust gases are shown in **Figure 2**. An exhaust gas analyzer was carried out on a KEONG KEG-500. The test engine specifications were presented in **Table 3**.

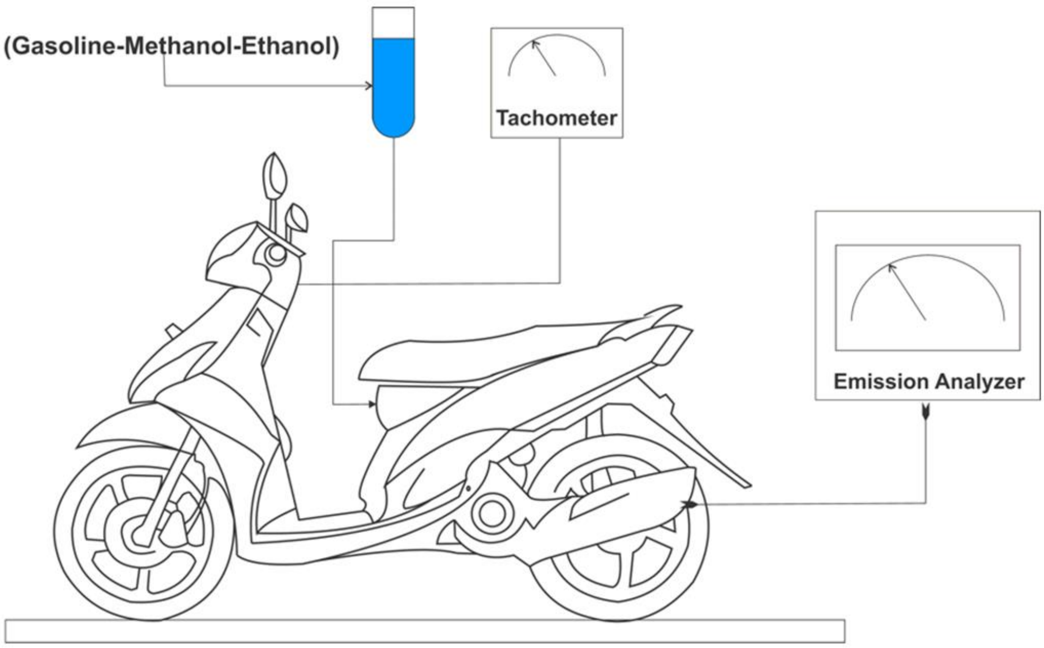


**Figure 2.** Exhaust gas measurement apparatus

**Table 3.** Engine specifications

| Item | Specification |
|---|---|
| Type | 4 Stroke, SOHC, eSP, Liquid Cooling |
| Cylinder volume | 124.8 $cm^3$ |
| Bore x stroke | 52.4 × 57.9 mm |
| Compression ratio | 11:1 |
| Power (max) | 8.2 kW/8.500 rpm |
| Torque (max) | 10.8 N.m/5.000 rpm |
| Fuel system | PG-MFI |

### *2.3. Validation of Exhaust Emission*

The purpose of validating the measurements of exhaust emission is to correct the differences in the measurement results of exhaust gas emissions of the fuel blend (gasoline-alcohol). The fraction of each fuel mixture was calculated for each measurement mode, and the total sum for each fuel mixture becomes the final results of the exhaust gas emission measurement of the fuel blend.

## 3. Result and Discussion

A gas engine analyzer was used to perform exhaust gas tests for several gasoline-methanol-(ethanol) blend fractions at engine speeds which motorcycles often move with namely 1500, 2500, and 3000 rpm. This test was carried out in two stages, namely gasoline and alcohol mode at each engine speed. The exhaust emissions tested include carbon monoxide (CO), unburnt hydrocarbons (UHC), and carbon dioxide ($CO_2$). Furthermore, the test was carried out at a working temperature (70–80 °C), and the air to fuel ratio (AFR) was set to 1.0+0.05 in a test environment with atmospheric pressure and relative humidity of 65-70%.

### *3.1. Carbon Monoxide (CO) Emission*

CO is a hazardous emission that causes serious health challenges for humans, thereby controlling these emissions is crucial for IC Engine researchers [27]. CO is a gas emission caused by incomplete combustion [28], and an increase in the alcohol fraction, specifically methanol with a high oxygen content of 49.93% m/m (**Table 2**) in fuels blends, makes the Gasoline-Methanol-(ethanol) fuel blend generate more complete combustion. **Figure 3** presents CO emissions of various homogeneous gasoline-methanol-(ethanol) blends at different engine speeds.

The low CO emissions in all gasoline-methanol-(ethanol) blend fractions are due to the low carbon content in alcohol fuels, which is about 37.48% m/m for methanol and 86% m/m for gasoline (**Table 2**). In the internal combustion engine, the perfection of combustion is influenced by the combustion speed, which correlates with the fuel's vaporization rate [16]. The combustion speed of methanol is higher (63 $m.s^{-1}$) than gasoline (47 $m.s^{-1}$) [20], [29], thereby enabling more complete combustion in the combustion chamber of the IC engine. Furthermore, the reduction in CO emissions using gasoline-alcohol fuel mixtures is in accordance with the alcohol blend fraction used by Elfasakhany, A & Mahrous, A. F, 2016 [30]. **Figure 3** shows that CO emissions for all mixed fractions increase as the engine speed increases. However, depending on the mixed alcohol fraction, the gradient of increasing CO emission is lower than pure gasoline. This phenomenon is caused by the high enthalpy of vaporization of methanol and ethanol. Hence, the higher the engine speed, the greater the cooling of the intake manifold, which increases the IC engine's volumetric efficiency as the fuel mixture's alcohol fraction increases. The reduction of CO emissions in the fuel mixture with increasing engine speed is in accordance with Kenanoğlu et al. [31].

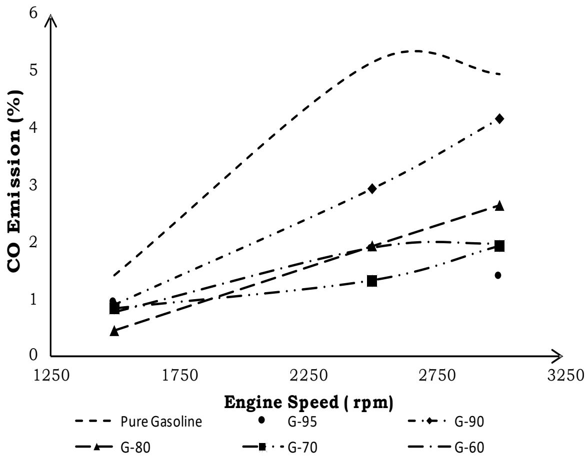


**Figure 3.** CO emissions of various fractions of homogeneous gasoline-methanol-(ethanol) blends

### 3.2. *Unburnt-hydrocarbons (UHC) Emission*

Hydrocarbons are toxic emissions that are generally colorless and hydrophobic. UHC emissions have diverse molecular structures that make generalization difficult, but most hydrocarbon emissions emanate from the combustion of fossil fuels and incomplete combustion of biofuels. The impact of long-term exposure to hydrocarbons on human health contributes significantly to diseases such as asthma, liver disease, lung disease, and cancer. UHC are hydrocarbon molecules released by internal combustion engines as a combustion product, and these emissions are generally produced by incomplete combustion, such as CO emissions [32]. The perfection of the combustion process in the IC engine combustion chamber involves many crucial parameters.

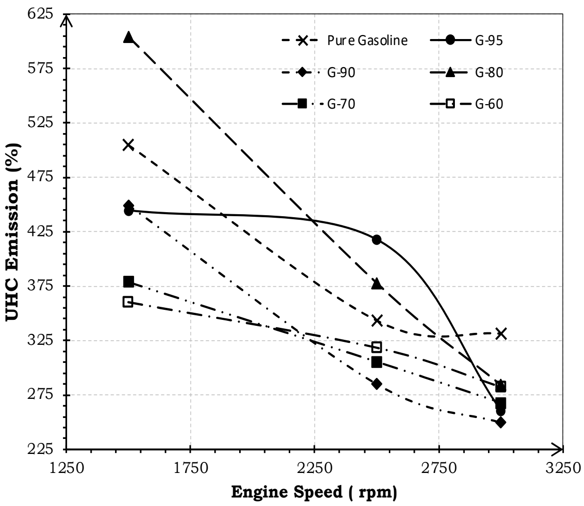


**Figure 4.** Unburnt hydrocarbon emission of various fractions of homogeneous GME blends

**Figure 4** shows UHC emissions of various gasoline-methanol-(ethanol) mixture fractions on the engine level. It shows the downward trend of all test fuels. However, UHC emission reduction gradient of gasoline-alcohol mixtures was inversely proportional to the increase in the alcohol mixture fraction. Furthermore, an extreme deviation occurs in the fuel mixture fraction G-95 because the separated gasoline-methanol mixture only required a small amount of ethanol to become a stable mixture (**Table 1**). The stability of each mixture was observed at room temperature and pressure. This stability occurs because gasoline has delocalized phi electrons in their aromatic ring. The electron cloud (phi electrons) delocalization for the benzene molecule as a gasoline representation is shown in **Figure 5**.

These delocalized phi electrons have the potential to form hydrogen bonds with the hydroxyl groups of fuel alcohols [16]. However, this hydrogen bonding force is very unstable, hence, it is quickly released with little energy interference from the fuel blend into the environment. The gasoline-methanol-(ethanol) blend became more stable with increasing proportions of the methanol and ethanol fractions because the hydrogen bonds between the delocalized phi electrons in the aromatic ring with the alcohol hydroxyl group became stronger.

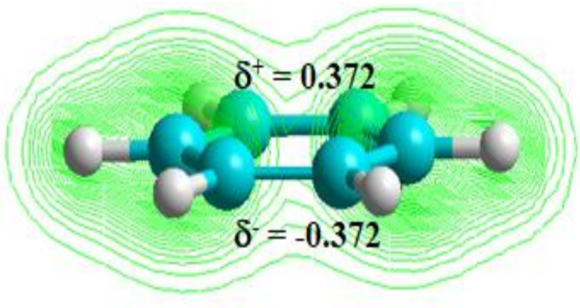


**Figure 5.** The electron cloud (phi electrons) delocalization for the benzene molecule

The blended fraction of G-80 shows the most significant gradient of UHC emission reduction with increasing engine speed (**Figure 4**). The gasoline-methanol-(ethanol) blend has the potential to form molecular clusters in the fuel blend [16], [26]. The molecular cluster potential from the gasoline-methanol is show in **Figure 6**. Previous research showed that the molecular cluster of a homogeneous gasoline-alcohol mixture has a lower boiling point than each of its constituent elements [33], hence, the clusters have a higher enthalpy of vaporization. This high enthalpy of vaporization has a significant effect on increasing the IC Engine's volumetric efficiency, thereby making combustion more complete and decreases UHC emission in accordance with an increase in the engine speed. The gasoline-methanol molecular cluster formed makes the mixture like a single substance with a lower boiling point. It's caused the bonds between the molecules to become very weak. The lower boiling point of this mixture results in a better evaporation rate so that the combustion process becomes complete. Complete combustion is what makes UHC emissions decrease.

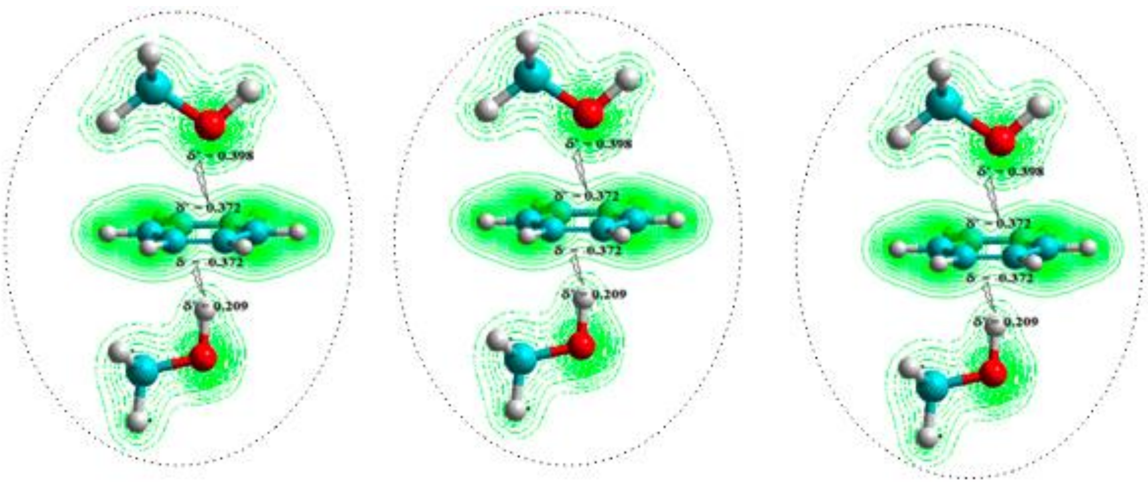

**Figure 6.** The molecular cluster potential from the gasoline-methanol

### 3.3. *Carbon dioxide ($CO_2$) Emission*

Carbon dioxide ($CO_2$) consists of a carbon atom that is double covalently bonded to two oxygen atoms. $CO_2$ is a gas needed to warm the earth's surface and make it comfortable to live in. However, excessive carbon dioxide emissions will strengthen the greenhouse effect and cause global climate change [34]. The extreme increase in energy consumption over the past decade directly impacts the risk of excessive $CO_2$ emissions. Therefore, efforts to find alternative energy sources that produce low $CO_2$ emissions are currently the focus of scientists all around the world [35]. The evaluation of homogeneous gasoline-methanol-(ethanol) blend use on the impact of carbon dioxide emissions is presented in **Figure 7**.

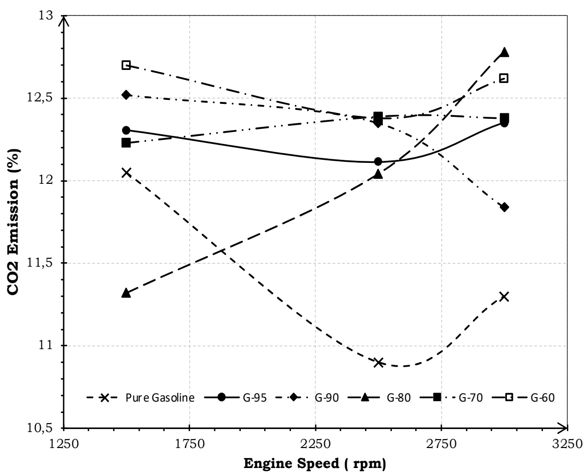


**Figure 7.** $CO_2$ emission of various fractions of homogeneous GME blends.

In general, the increase in the alcohol fraction of the gasoline-methanol-(ethanol) fuel blend correlates with an increase in $CO_2$ emissions. However, the carbon atom content in the alcohol fuel is smaller compared to pure gasoline (**Table 1**), and the energy content of methanol and ethanol is lower than gasoline (**Table 1**). Therefore, to produce the same energy as gasoline per unit time on the IC Engine, a gasoline-methanol-(ethanol) fuel blend must produce more $CO_2$ emissions. **Figure 7** also shows that the G-80 fuel mixture exhibits different behavior from all test blends. This outcome is in accordance with previous research, which stated that the 20% ethanol blend fraction (G-80) had the highest micro-explosion phenomenon of various gasoline-alcohol blends [36]. The occurrence of a micro-explosion during the IC Engine combustion process is beneficial because it brings about high combustion speeds, which makes the engine produce a large amount of energy per unit of time (powerful engine). However, the resulting CO2 emissions are even higher due to this high combustion speed. The use of a gasoline-methanol-(ethanol) blend has been shown to produce higher $CO_2$ emissions with increasing alcohol fraction (methanol and ethanol). Furthermore, the use of alcohol, specifically methanol, which has a wide range of production sources, is a logical choice because the growth in biofuel production will be compensated by plant growth as a counterweight to $CO_2$ emissions.

## 4. Conclusion

This research reveals the performance of exhaust emissions such as CO, HC, and $CO_2$, in the use of a gasoline-methanol-(ethanol) blend. Methanol as a cheap biofuel can homogeneously mix with gasoline by adding a small amount of ethanol. Test results show that increasing the fraction of methanol in the gasoline-methanol-(ethanol) fuel blend results in reduced carbon monoxide and unburnt hydrocarbon emissions because methanol has a high enthalpy of evaporation, which increases the volumetric efficiency as well as increases the complete combustion. In terms of $CO_2$ emissions, the use of the gasoline-methanol-(ethanol) blend showed a higher increase corresponding to the rise in the fraction of methanol. As a result, methanol and ethanol have a much more lower energy content than gasoline, and their energy production per unit time requires a higher number of fuel molecules. Further research related to the character of the combustion speed of various ratios of fuel and air using a mixture of gasoline-methanol-(ethanol) is needed. The combustion speed is correlated with the energy production rate of an engine. Gasoline-methanol-(ethanol) blend has a lower energy content and will produce equivalent or higher engine power if the combustion speed is faster than conventional fuels.

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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

No additional information from the authors.

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