Investigation of the Emission Characteristics of Iso-Butanol Additives on Methanol-Gasoline Blends using Spark Ignition Engine

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ABSTRACT

Lower emissions of spark ignition engine can be achieved by using alcohol fuels such as methanol as it is more environmental advantage over fossil fuel. The methanol fuels can be further improved by added with iso-butanol as it have higher energy content and able to displace more gasoline fuel. Nevertheless, the research on the addition of lower ratio iso-butanol in methanol-gasoline blends specifically on exhaust emission is still not investigated thoroughly. Therefore, this study will focus on investigating the effect of iso-butanol additive on methanol-gasoline blends on the emission characteristics of spark ignition engine. The lower percentage (5%) of methanol-gasoline fuels was added with lower ratio of iso-butanol (5-15%) with 5% of volume increment. The experimental test were carried out on a 1.6-litre four-cylinder spark ignition engine at a fixed speed of 4000 rpm with increasing engine load form 10 Nm until 100 Nm. The results showed that the iso-butanol additive in methanol-gasoline blends was efficient to reduce the

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carbon monoxide (CO) and unburned hydrocarbon (HC) formation compared to base fuel. Among all tested fuels, M5B15 (Iso-butanol 15% + Methanol 5% + Gasoline 80%) blend gave lower CO and HC emissions by 12.45% and 16.18% at 100 Nm. Meanwhile, oxides of nitrogen (NOx) and carbon dioxide (CO2) emissions were higher for all methanol-gasoline blends with iso-butanol additives compared with that base gasoline. M5B15 blends gives higher emissions of NOx and CO2 by 11.45% and 11.74% at 100 Nm. This study summarized that iso-butanol additives can be applied in low percentage methanol-gasoline blends without any modification on the current existing engine, therefore reducing any serious environment impact.

Keywords: *Methanol, Iso-Butanol, Fuel Properties, Spark Ignition Engine, Exhaust Emissions*

Introduction

Rapid growth in the industry and society, especially in the urbanisation and industrialisation has driven more demand for the fossil fuels. Figure 1 shows the world's average growth energy demands evolution per year from 2005 until 2030 [1]. The figure also shows the average growth per year for each type of energy demands as the oil and coal have the same percentage of growth with 0.7% each. Fossil fuel has been a global energy demand, especially when based crude oil has been the raw material for the transportation modes for the past 40 years and it has increased steadily [2]. This growth can explain the increasing level of activity and population of the world. This means that by referring to the report by International Energy Agency (IEA), in which there is about 53% of the increase in consumption of global energy by the year 2030 [3].

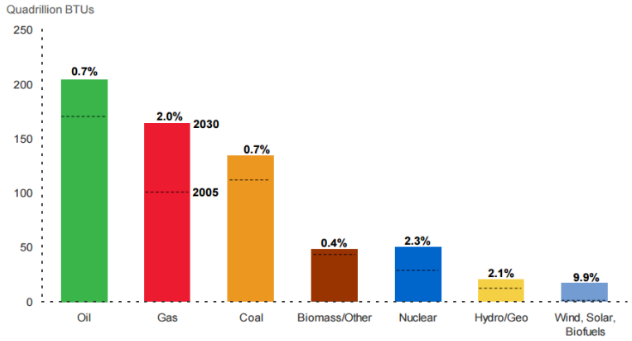

Figure 1: Energy demands evolution from 2005 – 2030 [1]

Fossil fuel has its own limitations that have raised concern about the shortages in the future. This rapid depletion of fossil fuel has caused uncertainties in world crude oil price where it directly affects the world economy [4]. The concern on the depletion of fossil fuels has led researchers to develop an alternative fuels which can meet present requirements of energy supply [5]. Thus, it is compulsory to establish an alternative fuel that is environment-friendly, locally available and feasible in terms of technical aspects. Alcohols are considered as alternative fuels for internal combustion engines and have been investigated comprehensively [6-9]. Adding alcohols into gasoline or diesel allows the fuel to have a complete combustion with the present of oxygen, which increases its combustion efficiency and reduces greenhouse gas emission. Moreover, its ability to be produced from renewable resources and able to give better engine performance with lower emission has attracted many interests on the market [10]. As an example, alcohols such as methanol (CH_3OH) and ethanol (C_2H_5OH) recently received public attention as both of materials are noted as low-polluting future fuels and considered as highly efficient through its lean operating ability [11]. The presence of oxygen in alcohol fuel allows soot-free combustion with low particulate level.

For the past few years, many researches and scientist had conducted engine testing using pure alcohol or blended with gasoline in order to study the effect of alcohol on engine operation [12-13]. Ozsezen et al. [12] have examined the effects of the gasoline and low ratio ethanol–gasoline and methanol–gasoline blends on a four-cylinder gasoline engine for the vehicle performance and exhaust emissions. The results of experiment show a slight increase observed in the brake specific fuel consumption (BSFC) in the alcohol–gasoline blends when compared to the gasoline fuels due to lower heating value (LHV) of alcohol fuels [12]. Pourkhesalian et al. [13] studied the effects of gasoline, and alternative fuels including hydrogen, propane, methane, ethanol and methanol to understand the performance and emission characteristics of a spark ignition engine using the fuels. According to their results, the emissions of CO and NO_x decreased when pure ethanol and methanol were used instead of gasoline This is due to the higher methanol flame speed that leads to lower spark advance and combustion temperature. The emission characteristics of higher alcohol-gasoline blends were investigated further by Gautam. et al. [14]. The result shows that all of the higher alcohol-gasoline blends give lower brake specific emissions. This is due to alcohol-gasoline blends having greater knock resistance which allows higher compression ratios to be used in having the increase of power output. It was also noted that the brake specific emissions were 15-19% lower for the alcohol-gasoline blends than the base gasoline due to increase in engine power output.

Using alcohol fuels as an alternative for spark ignition engines has started widely accepted as blended fuel with gasoline. Nevertheless, certain properties of lower molecular weight alcohol, especially methanol fuel have made it less desirable as an alternative for gasoline fuel. One of the negative effects related to the use of methanol fuel has higher NO_x and CO_2 emissions due to higher combustion temperature and complete combustion of the fuel. If the current application is still resisting in using methanol fuel as an alternative fuels to the gasoline fuels, a few problems such as higher exhaust emissions will occur, which are still unable to solve and remain a problem to the user. The initial problems of using lower molecular alcohol fuels can be overcome by using several methods. One of the suggested methods is by applying iso-butanol additive into the methanol–gasoline fuel blends that will eventually overcome the problems that have been mentioned before. Nonetheless, not much research have been made on considering blending lower and higher molecular weight alcohols with gasoline at a specific percentage and the effect on engine performance and emissions. Therefore, this research will be directly focused on improving existing alternative fuel which is methanol-gasoline blends by adding an additive such as iso-butanol. Analysis will be carried out on this alcohol-gasoline blends by investigate the exhaust emissions specifically on carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbon (HC) and oxides of nitrogen (NO_x).

Experimental Setup

Material Preparation and Method of Blends

Methanol and iso-butanol were acquired from locally supplied company. These two types of alcohols with purity 99.5% of laboratory grade chemical additives were used in this research. Base fuel that will be used in this study is gasoline with octane number 95 from a local commercial company. Table 1 shows the properties of the base fuel, methanol and iso-butanol that are used in the current study. Blended fuels consisting of base fuel, methanol and iso-butanol were prepared through the blending method based on volume percentages basis and mechanical mixing. For each fuel blends, the total amount accounted that 100% volume percentage is equal to 1 liter of fuel. The fuel mixture was stirred continuously until it reach equilibrium as it will be used for engine testing and this method also recommended by previous researchers [15, 16]. It is noted that all the properties value obtained by the addition of iso-butanol in methanol-gasoline blends is still within the range of the specified standard (DIN Standard EN228 and ASTM 4814).

Table 1: Target plate configuration

Properties	Base Fuel	Methanol	Iso-Butanol
Chemical formula	C_8H_{18}	CH_3OH	C_4H_9OH
Molecular weight (g/mol)	114	32.04	74.11
Density (Kg/m^3)	736.8	792.0	806
Net lower heating value (MJ/kg)	43.92	20.10	35.69
Stoichiometric A/F ratio	15.05	6.40	11.17
Oxygen content, mass %	0	49.90	21.60
HoV (kJ/kg)	349	1178	683
Reid Vapor Pressure at 37.8^{o}C (kPa)	63.9	31.72	6.6
Research Octane Number	95	108.7	105.1

Engine Setup

For the engine testing, the tests were conducted at the Engine Laboratory of the Faculty of Mechanical Engineering at the University of Malaya. The engine used for testing was a 1.6L four-cylinder spark ignition engine coupled with eddy current dynamometer (Froude Hoffman AG150) with a maximum power of 150 kW. The spark ignition engine used in this research was a natural aspirated, water cooled, 1.6L spark ignition engine. The engine specification has been listed in Table 2.

Table 2: 1.6L spark ignition engine specification

Description	Specification
Engine cylinder	4
Engine capacity	1596cc
Bore & Stroke	78mm x 84mm
Compression ratio	10:1
Engine weight	138kg
Peak power	78 kW @ 6000rpm
Peak torque	135 Nm @ 4000rpm
Fuel system	Multipoint electronic port fuel system

The test engine is connected with test fuel by using an integrated fuel system as shown in Figure 2. Stainless steel fuel tanks were built to differentiate between gasoline and blended fuels. All the fuel flows were measured by AVL 730 Dynamic Fuel Balance and the calibration of the device was carried out before performing the test under real test bed condition.

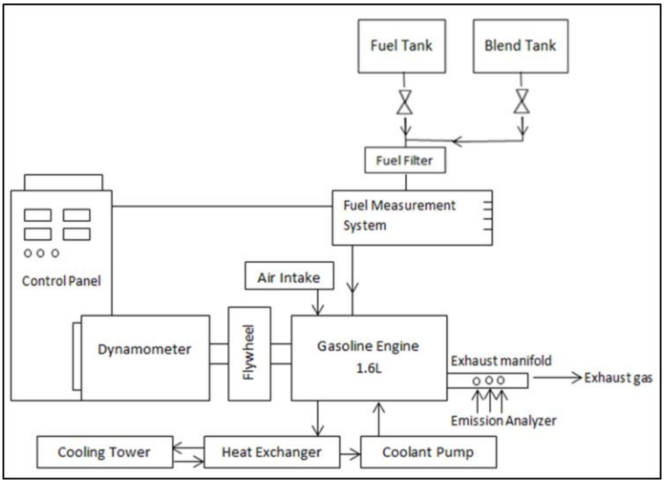

Figure 2: Schematic diagram of experimental setup

AVL DICOM 4000 exhaust gas analyser was used for measurement of engine emission. Among of the measured emission are carbon dioxide (CO_2), nitrogen oxide (NO_x), carbon monoxide (CO) and unburned hydrocarbon (HC). This instrument uses infrared measurement detector to determine CO, HC and CO_2 emissions while electrochemical measurement detector to determine NO_x emissions. In order to obtain an accurate data, the system has to be calibrated by suitable bottled span and zero calibration gases. The probe from the gas analyser was inserted into the exhaust sample line. The initial stage is purge, sample and then measurement for every engine test condition. The data were taken for every test as the engine was held for 10 minutes in order to achieve stability of exhaust emission. A set of five experiment results for every test was averaged. Table 3 shows the detailed description and specification of gas analyser. This type of gas analyser is capable to interpret exhaust emissions composition in volume percentage (%) and parts per million (ppm).

Table 3: Description of exhaust gas analyser

Specification	**Resolution**	**Measurement range**
Carbon monoxide (CO)	0.01 %	0-10 %
Carbon dioxide (CO_2)	0.1 %	0-20 %
Unburned hydrocarbon (HC)	1 ppm	0-20,000 ppm
Oxides of Nitrogen (NO_x)	1 ppm	0-5,000 ppm
Oxygen (O_2)	0.01 %	0-25 %

Results and discussion

This section presents the emission results from the experimental engine testing of the test fuels. This test had been sought to investigate and to determine the trends of the emissions of methanol and iso-butanol additive in gasoline. The experimental tests were conducted for base fuel, blended gasoline with methanol (M5), and iso-butanol (M5B5, M5B10, and M5B15). All tests were conducted at constant engine speed at 4000 rpm and varying engine torque from 10-100 Nm. The collected emission data for the base fuel was used as baseline data to evaluate the changes in emissions of blended alcohol-gasoline. The results of the exhaust emissions, such as carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbon (HC), and oxides of nitrogen (NO_x) are discussed in this section.

Carbon Monoxide

Carbon monoxide (CO) is one of the products of fuel combustion. As the fuel burns, most of the CO produces oxides to carbon dioxide (CO2). Carbon dioxide is generated when the engine is operated with fuel-rich equivalence ratio as there is not enough of oxygen to convert all the carbon into CO2. This explains why the CO emissions are greatly dependent on the air-fuel ratio and the capability of fuel to achieve complete combustion.

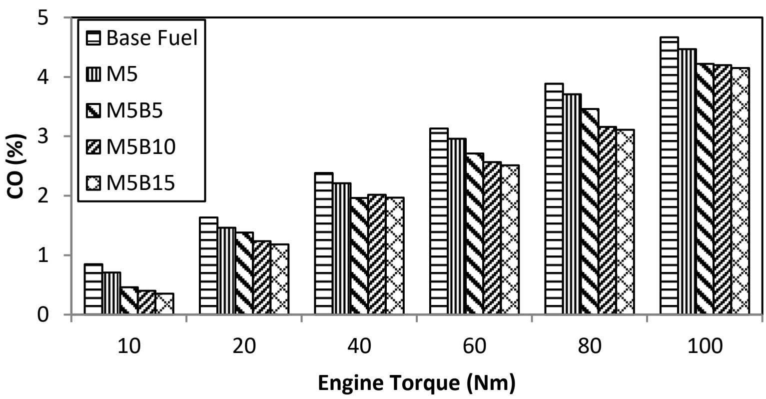

Figure 3: Variation of CO emission with engine torque at 4000 rpm

Figure 3 shows the variation of the CO emission for base fuel and blended alcohol-gasoline fuels at a constant engine speed of 4000 rpm. From the test results, the blend of alcohol-gasoline fuels produced lower CO emissions compare to base fuel. On average, M5B15 fuel blends produced the lowest CO emissions at about 12.45% compare to base fuel at 100 Nm.

As for the other blends of alcohol-gasoline fuels, the average decrease of CO emissions for M5, M5B5, and M5B10, in comparison to base fuel, had been 4.47%, 10.67%, and 11.11% respectively at 100 Nm. This was mainly due to the effect of high oxygen ratio of alcohol in blended fuels that led to better combustion process and resulted in the better conversion of CO to CO_2. The obtained result is in agreement with a number of previous research studies [21-23], which has shown a reduction in the CO emission with the usage of alcohol-gasoline blends as compare to that of base fuel and at various engine testing conditions. At 40 Nm, the CO emissions for M5B5 are lower than the M5B10 which shows an inconsistent trend with other engine torque. This is due to the increased crevice volume of the combustion chamber and mass of fuel vapour per unit volume of the air-quenching layer.

As shown in Figure 3, M5B15 fuel blends give lower CO emissions as compare to other blended fuels and base fuel as the engine load is increased. This is due to homogeneous in-cylinder charges that burnt effectively as the higher engine load requiring more injection of fuel quantity. Subsequently; a higher combustion temperature inside the engine cylinder is achieved. The reduction of CO emission level is mainly due to the leaning effect. Methanol and iso-butanol are oxygenated fuels and they have an oxygen atom in its basic form. When both of these alcohols have blended together with gasoline, more oxygen is available for combustion process and this phenomenon is known as “Leaning effect”. The leaning effect is an effect that enhances the presence of oxygen in fuel that improves combustion efficiency in cylinder [24]. Besides that, alcohol has higher laminar flame speed compare to base fuel which will assist in completing combustion in the blends that lower CO emission. The obtained results are also consistent with the findings obtained by previous researchers, which utilised alcohol blends [25, 26].

Unburned Hydrocarbon

Generally, the unburned hydrocarbon (HC) concentrations from the exhaust emission will be either partially burned or unburned due to insufficient oxygen content in the combustion and it depends on the original fuel components. HC emission also is the main contributor to ozone pollution and photochemical smog.

Figure 4 shows the emissions of unburned hydrocarbon by all test fuel blends at various engine torques ranging from 10 Nm to 100 Nm. The results shows that the HC emissions for alcohol-gasoline blends are lower than the base fuel. As for overall engine torque, HC emissions is decreased from 6.04% to 16.18% using all the alcohol-gasoline blends at 100 Nm. These findings are consistent with the findings obtained from other researchers. An investigation carried out by Ioannis et al. [27] shows that alcohol can be treated as a partially oxidized hydrocarbon when added to gasoline. These blends reduce the cylinder temperature as the heat of vaporization of methanol is higher compare to gasoline. However, lower temperature can cause misfire partial burn in the regions near the combustion chamber wall, which causes an increase in the HC emissions and a slight decrease in power [27].

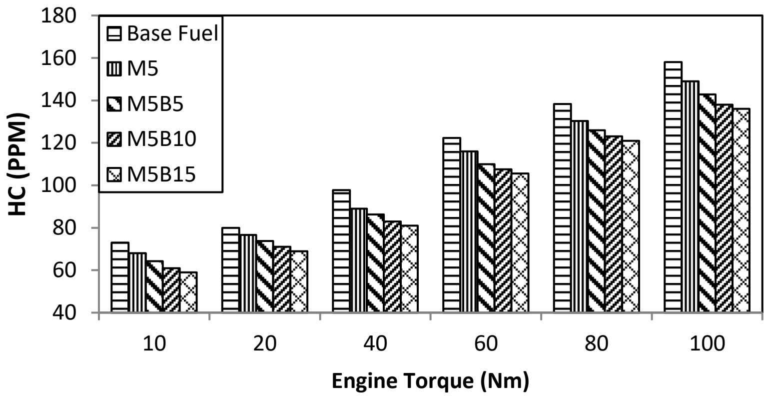

Figure 4: Variation of HC emission with engine torque at 4000 rpm

The reasons on why the test had been conducted at a fixed engine speed of 4000 rpm were because the engine achieved maximum engine torque at 4000 rpm, as illustrated in Table 2. Thus, the maximum engine response could be attained by using different types of fuel blends at a constant engine speed of 4000 rpm. The pattern of unburned hydrocarbon emission is related to design and operating variables [27]. The two important design variables were induction system design and combustion chamber design, whereas the main operating variables were an air-fuel ratio, speed, load, and mode of operation. An investigation was conducted by Yacoub et al. [28] on the alcohol-gasoline blends with carbon numbers C1 to C5 on the basis of the oxygen content of the fuel. The results showed that all alcohol-gasoline blends exerted lower CO and HC emissions due to leaning effect. Other than that, higher-alcohol blends with 5% of oxygen content emitted higher NO_x emissions due to higher flame temperatures, but lower enthalpy of vaporization of the fuels.

Carbon Dioxide

Carbon dioxide (CO_2) is one of the basic greenhouse gases, which is produced by the complete combustion of hydrocarbon fuel. The CO_2 formation is effected by the carbon-hydrogen (C/H) ratio in the fuel. The combustion of a hydrocarbon fuel stoichiometrically should produce only CO_2 and water (H_2O).

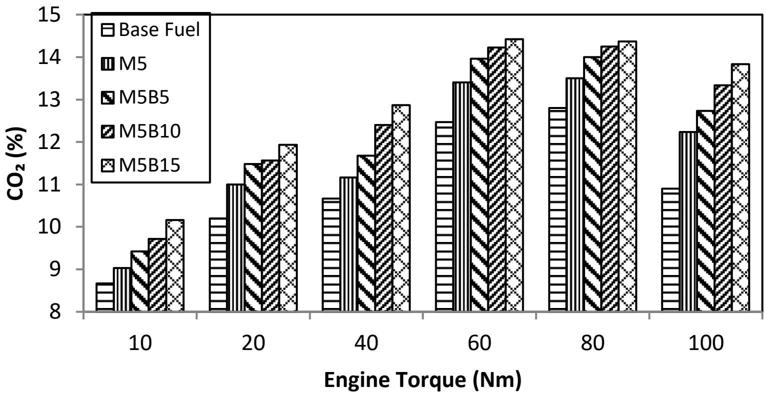

Figure 5: Variation of CO2 emission with engine torque at 4000 rpm

The variation of CO_2 emissions for engine load from 10 Nm to 100 Nm at a constant engine speed of 4000 rpm is shown in Figure 5. From the results obtained, CO_2 emission is significantly higher for alcohol-gasoline blends than the base fuel. M5B15 fuel blends give highest CO_2 emissions by 11.74% compare to base fuel. This is due to the higher oxygen content that reacted with carbon atoms that went unburned during combustion and thus, caused an increase in CO_2 emissions. Besides that, more formation of CO_2 indicated that it had achieved complete combustion of fuel. This result is consistent with the finding of a previous study [9], which determined an increase in CO_2 emission with ethanol and methanol alcohol fuels compared to that with base fuel. Carbon dioxide is the product of complete combustion where the oxygen (O_2) and the carbon (C) in the combustion chamber are sufficient to be converted into $CO_{2.}$ By adding alcohol into the blends to improve combustion, it is expected that alcohol-gasoline blends will have higher CO_2 emissions compared to base fuel. The alcohol additive will lead to more carbon being burned with oxygen to produce $CO_{2,}$ which further increases the production of CO_2 emissions. The conversion of carbon and oxygen into carbon dioxide rapidly occurs, thus leading to a higher percentage of CO_2 production. This also summarizes that CO_2 concentrations display an opposite behaviour when compared to CO concentrations, where all CO emissions are converted to CO_2.

Oxides of Nitrogen

An oxide of nitrogen (NO_x) is generated from the nitrogen in the air and can be found in the fuel blends. In terms of its hazards, NO_x has the most undesirable toxic as they possess the tendency to mix with the moisture in the lung to form dilute nitric acid. Also, the NO_x emissions to the atmosphere form ozone, which is one of the major causes of photochemical smog.

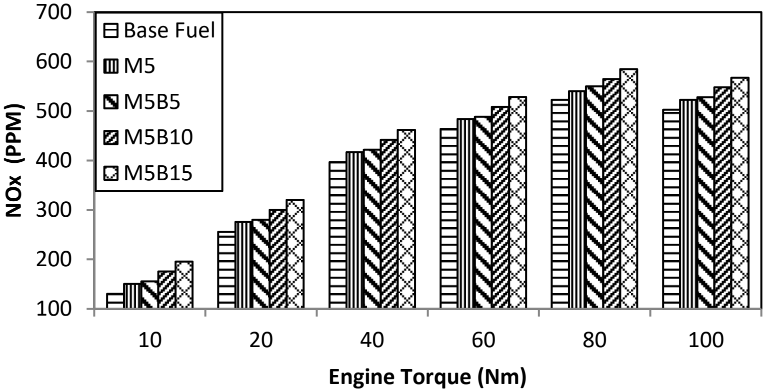

Figure 6: Variation of NOx emission with engine torque at 4000 rpm

Figure 6 shows the variation of emissions for oxides of nitrogen by all test fuel blends at engine torque ranging from 10 Nm to 100 Nm at a constant engine speed of 4000 rpm. The M5B15 blend produced higher NO_x emission by 567 ppm at 100 Nm. On average, NO_x emissions for M5, M5B5, M5B10, and M5B15 had been 3.82%, 4.74%, 8.21%, and 11.45% respectively at 100 Nm. As shown in Figure 6, the NO_x emission is higher for alcohol-gasoline blends compared to that of base fuel. This is due to the effect of higher oxygen content in the alcohol-gasoline blended fuel has increased the combustion temperature, which further resulted in higher NO_x formation. These results are in agreement with some previous studies [29, 30]. As the temperature in the combustion chamber increased, the NO_x emission also increased due to the chemical reaction that took place between nitrogen and oxygen at high temperature. Therefore, the NO_x emission is increased as the engine torque is increased.

Conclusion

In this research, the blended methanol-gasoline fuels (5%) with iso-butanol additives (5%, 10%, and 15%) in unmodified spark ignition engine were investigated to discover new knowledge to the current existing alternative fuels. Exhaust emissions were investigated to identify the effect of iso-butanol additives on methanol-gasoline blends. The measured exhaust emissions are carbon monoxide (CO), unburned hydrocarbon (UHC), carbon dioxide (CO_2) and oxides of nitrogen (NO_x). In general, additives of iso-butanol are found to efficiently reduce the formation of CO and HC compare to base fuel. Among of all test fuels, the M5B15 fuel blend has displayed lower CO and HC emissions. This is due to the higher oxygen content in fuels which will improve combustion efficiency in the cylinder. However, the increasing trend projected by NO_x and CO_2 emissions had been recorded in all iso-butanol additive in methanol-gasoline fuels with M5B15 exerting the highest emissions. The overall results showed that the effect of iso-butanol additive had indeed improved the exhaust emissions of the methanol-gasoline blends without modification on spark ignition engine. Further investigations are needed on the practicability and durability of alcohol additives as it should be able to identify the modification needed for the current existing spark ignition engine without costing too much money.

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