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# Effects of Ethanol Blends on Gasoline Engine Performance and Exhaust Emissions

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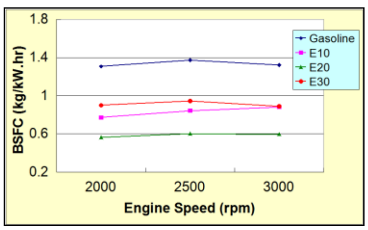
**Graphical abstract**




**Abstract**

Automotive sector is one of the major contributors to air pollution and global warming due to the carbon residue and smoke opacity emission. Today, the trend of decreasing sources of petroleum fuel has led to innovation of other resources such as alternative fuel. Alternative fuel can be produced from biomass such as alcohol in which it is produced by fermentation of sugar, cane and corn. This experiment was conducted to investigate the effects of ethanol on gasoline engine performance and exhaust emissions. A four-stroke, single cylinder engine was tested by different range of ethanol volume percentages i.e. 10% (E10), 20% (E20) and 30% (E30) blended with fossil gasoline. The experiment was carried out at variations of engine speed and constant load. The engine speeds used for a constant load at 2 Nm were 2000rpm, 2500rpm and 3000rpm. From the results obtained, it shows that the brake specific fuel consumption for the blended fuel is better than gasoline fuel. Combustion efficiency of gasoline engine has improved with the use of ethanol-gasoline blends. Exhaust emissions such as CO and smoke opacity are decreased due to the presence of oxygenated properties of ethanol in blended fuel. However, emissions of $CO_2$ are increased due to the high combustion temperature. In overall, the E20 shows the best results for all measured parameters at all engine test conditions.

*Keywords:* Internal Combustion engine, ethanol-gasoline blends, engine performance, exhaust emissions, smoke opacity.



## 1.0 INTRODUCTION

The global demand for cheap, clean and efficient fuel has been driven by the decreasing trend of amount of petroleum based fuel, high polluted air and for more economical purpose. Thus, these factors become inspiration and motivation to carry out research in alternative fuels. It is considered important that the alternative fuels that being used should be produced from renewable resources and able to be used in engine which without major modifications. Since 19th century, ethanol has been used as a replacement fuels for engines and being considered as one of more suitable, renewable, bio-based and eco-friendly fuels available [1].
Emission that is produced from the exhaust of motor vehicles and combustion of fossil fuels contributes to air pollution. All kind of internal combustion engines i.e. Spark Ignition (SI) and Compression Ignition (CI) are equally responsible for the emission of gaseous such as nitrogen oxide ($NO_x$), carbon monoxide (CO), carbon dioxide ($CO_2$), hydrocarbon (HC) and smoke opacity. Some of the gaseous emitted would have direct hazardous effect. They are also polluting the surrounding atmosphere and cause acid rain, global warming, greenhouse effect and other hazardous effects [2].

### 1.1 Properties of Ethanol

Ethanol is one of renewable fuels that can be produced by fermentation of sources like sugar, cane, and many types of biomass materials. Ethanol has a higher research octane number (RON) that could improve anti-knock characteristics, which enables higher compression ratios to be used [1]. It also has characteristics of wide flammability and oxygenated content. Ethanol with chemical equation of $C_2H_5OH$, contains oxygen atom [3]. Therefore, it could lead to complete combustion and thus decrease emission of carbon monoxide (CO) and hydrocarbon (HC).

**Table 1**: Properties of gasoline and ethanol [4]

| Fuel | Gasoline | Ethanol |
|---|---|---|
| Chemical Formula | $C_4 – C_{12}$ | $C_2H_5OH$ |
| Composition (C, H, O) (mass %) | 86, 14, 0 | 52, 13, 35 |
| Lower Heating Value (MJ/kg) | 42.7 | 26.8 |
| Density (kg/m$^3$) | 715-765 | 790 |
| Octane Number ((R+M)/2) | 90 | 100 |
| Stoichiometric Air/Fuel Ratio | 14.7 | 9.0 |
| Latent Heat of Vaporization (kJ/kg) | 380-500 | 919 |

Thomas Wallner et al.[4] have investigated the impact of ethanol and butanol as oxygenated fuel on spark ignition direct injection (SIDI) engine efficiency and emissions using steady state and transient test procedures. The experiment has been conducted using a SIDI 4-cylinder engine, in which they concluded that blends of gasoline and alcohol either ethanol or iso-Butanol could improve cold-start engine operation and reduced the thermal losses.

### 1.2 Combustion Characteristics of Gasoline Engine on Ethanol Fuel Blends

Mustafa Kemal Balki et al. [5], had performed an experiment to study the effects of different alcohol fuels on the performance, emission and combustion characteristics of a gasoline engine. In their study, a low power single-cylinder engine was investigated and differentiated with conventional gasoline operation. The results showed that the use of alcohol as fuel additive has increased the combustion efficiency and improved the cylinder gas pressure and rate of heat release. In addition, it showed that the alcohol-gasoline blended fuel that being used at high compression ratio resulted in improved combustion characteristics and higher engine power.

Turner D. et al. [6], had conducted a study on the effects of gasoline and gasoline-ethanol blended fuel in a fuel-injected engine. The purpose of the study is to investigate the combustion efficiency. According to the results, the increase ethanol percentage in the blended fuels has increased the burning velocity and in-cylinder gas pressure. When the in-cylinder pressure increased, the engine power also increased. Referring to the previous research done by Eyidogan M et al.[7] about the effects of unleaded gasoline, ethanol-gasoline and methanol-gasoline blends at low ratios on engine performance, combustion characteristics and exhaust emissions, showing that the usage of blended fuels has improved the rate of heat release.

According to the research done by Hsieh WD et al[3] on the use of ethanol-gasoline blends at different percentages i.e. 10%, 20% and 30% in spark ignition (SI) engine, it showed that the ethanol blends has slightly increased the engine torque compared with fossil gasoline. It would result in increase of engine power because when engine torque is increased, the engine power will also increase. In addition, the ethanol-gasoline blends also contain higher auto-ignition temperature and higher flash point compared to the gasoline fuel. Besides that, it also has 3-5 times higher latent heat of evaporation compared to the gasoline fuel, thus producing lower temperature of intake manifold and increase the volumetric efficiency.

### 1.3 Effects of Ethanol Fuel Blends on Gasoline Engine Performance

M. Al-Hasan [8] investigated the effect of using gasoline-ethanol blended on spark ignition (SI) engine performance and exhaust emission. TOYOTA TERCEL-3A, a four stroke, four cylinder SI engine was used in this study. The experiment was conducted using unleaded gasoline-ethanol blends with the different percentages of fuel at constant throttle opening position and different engine speed ranging from 1000-4000 rpm. The study's parameters of engine performance were the equivalence air-fuel ratio, fuel consumption, volumetric efficiency, brake thermal efficiency, brake power, engine torque and brake specific fuel consumption [8].

#### *1.3.1 Brake Specific Fuel consumption (BSFC)*

Generally, Brake Specific Fuel Consumption (BSFC) is a comparison ratio which looks at an engine's fuel efficiency in terms of how much power it can produce. K.B. Siddegowda and J. Venkatesh [9] had investigated the performance and emission characteristics of MPFI engine by using gasoline-ethanol blends. In this experiment, multi-port fuel injection (MPFI) engine was used with ethanol blended with 10%, 20% and 30% by volume with gasoline fuel tested by varying the value of loads. The parameters recorded on this experiment are brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC). The obtained results showed that by adding 20% of ethanol into fossil gasoline fuel has increased the BTE and could also increase slightly the BSFC as compared with fossil gasoline fuel [9].

### 1.4 Effects of Ethanol Blends on Gasoline Engine Emissions

Exhaust emissions is one of the important characteristics in automotive industries, in which the gas emissions from vehicle could lead to air pollution and increase of Earth temperature. C. Argakiotis et al. [1], had tested a 1.4 litre four-cylinder, four-stroke SI engine with a compression ratio of 9:1, for a different loads and engine speed conditions. The study had focused on the effects of unleaded gasoline and ethanol-gasoline blended on engine performance and exhaust emissions. The results shows that the blend E30 at full throttle gives reduction of carbon monoxide (CO) and hydrocarbons (HC) while increase emissions in carbon dioxide ($CO_2$) and nitrogen oxide ($NO_x$).

### 1.4.1 Carbon Monoxide (CO)

Carbon monoxide is produced from partial oxidization of carbon containing compounds. When such a combustion process inside an internal combustion engine occurs without enough supply of oxygen, it will form carbon monoxide [13]. Tolga Topgul et al. [13] have conducted a study the effects of gasoline and gasoline-ethanol blends (E10, E20, E40 and E60) on engine performance and exhaust emission by using Hydra single cylinder, four-stroke, spark ignition engine. The tests were performed by varying compression ratios i.e. 8:1, 9:1 and 10:1 and ignition timing at constant speed of 2000 rpm at wide open throttle. They found that the blending fuels have reduced the carbon monoxide, CO emissions [14].

### 1.4.2 Carbon Dioxide ($CO_2$)

Carbon dioxide ($CO_2$) is one of the major gases in atmosphere. It is the principal product of carbon formed from the combustion of hydrocarbon fuels. High concentration of carbon dioxide leads to global warming. KB Siddegowda and J Venkatesh [9] had conducted an experiment to study the emission of ethanol gasoline blended fuel. Ethanol is blended with 10%, 20% and 30% by volume with gasoline. It was found that the blended fuel has reduced considerable amount of gas emission. The experimental results showed that the $CO_2$ emission increases notably as a result of complete combustion [9].

### 1.4.3 Smoke Opacity

Smoke opacity is a parameter for darkness of smokes due to the carbon content which blocks the light. Suraj Bhan Singh et al. [15], had performed a technical feasibility study of butanol-gasoline blends for powering medium-duty transportation spark ignition engine. From their work, it was observed that the opacity has increased with the increasing engine loads and speeds. At lower engine speeds, smoke from 50-75% butanol blends was higher than gasoline. At lower speed when the engine temperature is relatively low, the inferior vaporization and mixing of butanol in which has relatively high enthalpy, resulting inhomogeneity in mixture. Inhomogeneous combustion leads the smoke emitted increases [15].

## 2.0 EXPERIMENTAL PROCEDURE

This section describes briefly about the experimental layout (Figure 1) and procedures. The experiment has been carried out to investigate the engine performance and emissions with the blend ratios ranging from 0% to 30% with an increment of 10% at different ethanol-gasoline ratio. The engine is operated with variations of blend ratio at constant engine load and different engine speeds. The required engine load is obtained through the hydraulic dynamometer control. As comparative studies, the tests are also carried out using fossil gasoline fuel at the same engine test conditions.

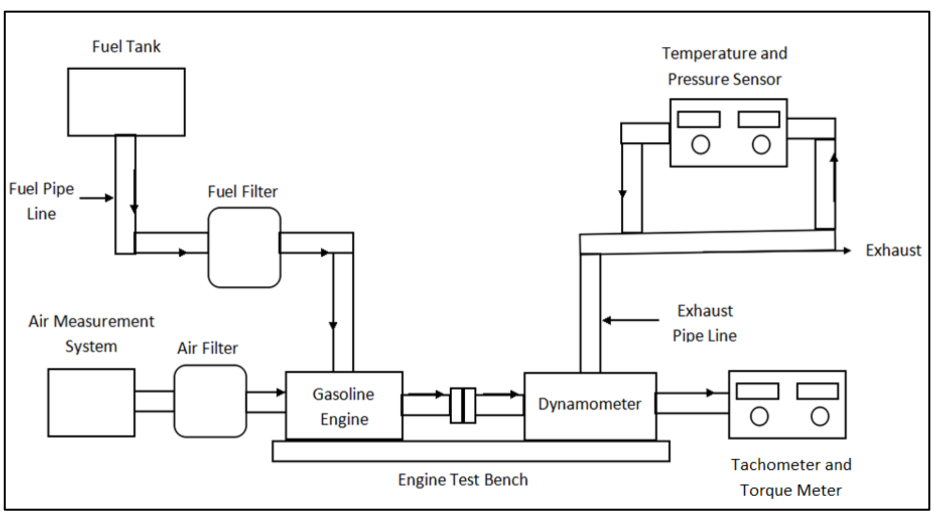



**Figure 1** Schematic diagram of engine setup

### 2.1 Engine Specifications

**Table 2** Engine specification

| | |
|---|---|
| Engine Type | Air-cooled 4-stroke |
| Bore x Stroke | 68mm X 45 mm |
| Displacement | 163 cm3 |
| Net Power Output* | 4.8 HP (3.6 kW) @ 3,600 rpm |
| Net Torque | 7.6 lb-ft (10.3 Nm) @ 2,500 rpm |
| Compression Ratio | 9.0 : 1 |

### 2.2 Engine Setup

The experiment is conducted using a single-cylinder, four stroke spark ignition engine. The engine is connected to an eddy dynamometer to control the engine load. Engine load is set constant throughout the experiment and the torque value will be recorded at different engine speeds. The exhaust pipe is connected to the exhaust measurement system in order to measure the emissions of engine due to the effects of ethanol blends. In fuel measurement system, it contains fuel tank and fuel pipe line. A scaled fuel tank is used to measure the volume of fuel consumed by the engine for one complete engine test cycle.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Brake Specific Fuel Consumption (BSFC)

Figure 2 shows the trend of brake specific fuel consumption (BSFC) from a spark ignition engine operating with variation of blend ratios at different engine speeds (2000 - 3000 rpm) and at constant load.

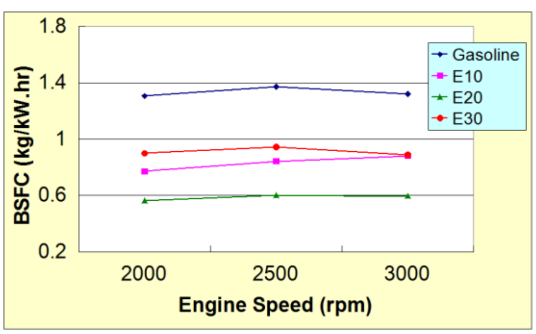



**Figure 2** BSFC against engine speed (rpm) at constant torque 2 N.m

In overall, the trend of BSFC shows gradually increased when the engine speed increases. In Figure 2, it shows that the E20 produces lowest BSFC compared with other blend ratios and gasoline fuel for all engine test conditions, meaning that the E20 has provided improvement on fuel consumption compared to unleaded gasoline. This can be said that the high energy content and oxygen intensity [9] in the E20 fuel blend, could produce a better combustion compared to gasoline and other fuel blends. When the engine speed increases (2500-3000 rpm), the value of BSFC showed no significant increase due to higher combustion temperature resulting in complete combustion for all blends.

### 3.2 Exhaust Temperature

Figure 3 shows that with increasing engine speed resulted in higher exhaust temperature. The higher engine speed produces higher temperatures due to the more fuel being injected for increasing the speed; therefore, more heat is generated in the combustion chamber. The increasing power produced from the combustion process resulting in increasing heat exhausted from the engine. Thus, it increases the temperature of exhaust.

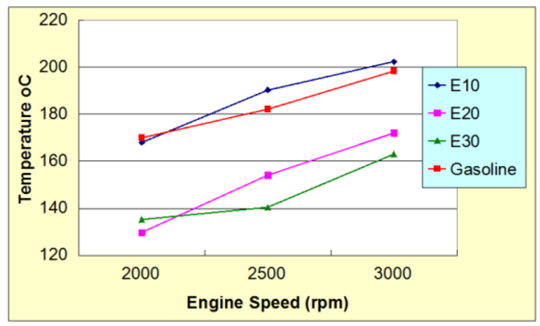



**Figure 3** Variations of exhaust temperature against engine speed (rpm) at constant torque 2 N.m.

Besides that, the duration of combustion in combustion chamber and energy content in fuel are the major factors to the high value of exhaust temperature. Referring to the investigation done by B.M. Masum et al. [10], the addition of alcohol to gasoline will reduces exhaust temperature compare to base gasoline which is due to the lower energy content of alcohol. Meanwhile, other researchers [11, 12] made clear that higher octane number of alcohol start earlier on the in-cylinder combustion which will assists in utilizing more heat of combustion and decrease exhaust temperature than gasoline. Overall results show that, the E20 has improved the exhaust temperature compared with other blends and gasoline.

### 3.3 Exhaust Emissions

#### *3.3.1 Carbon monoxide (CO)*

Figure 4 shows the trend of carbon monoxide (CO) emissions from a spark ignition engine operating with variation of blend ratios at different engine speeds (2000 - 3000 rpm) and at constant load. Overall, the trend of CO emissions show gradually decreased when the engine speed increases. This indicates that when the engine speed increases, the combustion process would become more complete, thus completing oxidation of CO to $CO_2$.

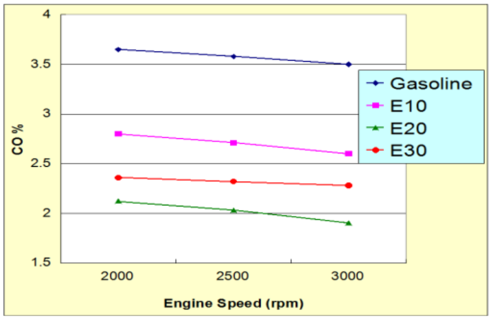



**Figure 4** Carbon Monoxide (CO) emissions for several blend ratios operating at different engine speeds and constant load.

In Figure 4 also shows that the trend of CO emissions decrease with the increased blend ratio for almost all engine test conditions, which is believed due to a more complete combustion, occurred. The E20 has the lowest percentage of carbon monoxide emission. The CO emissions are greatly dependent on the air-fuel ratio. At higher blend ratio, the fuel droplet size is particularly fine due to higher evaporation rate. This allows more air entrainment during the injection process, promoting a fast combustible mixture formation.

### *3.3.2 Carbon Dioxide ($CO_2$)*

Figure 5 shows the trend of carbon dioxide ($CO_2$) emissions from a spark ignition engine operating with variation of blend ratios at different engine speeds (2000 - 3000 rpm) and at constant load. Overall, the trend shows that the $CO_2$ emissions gradually increased when the engine speed increases. This indicates that when the engine speed increases, the combustion process would become more complete, thus completing the oxidation of CO to $CO_2$ [16].

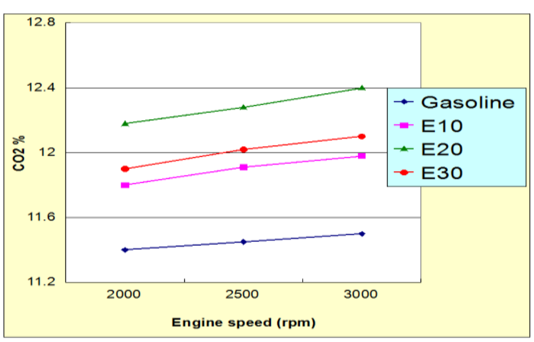



**Figure 5** Carbon dioxide ($CO_2$) emissions for several blend ratios operating at different engine speeds and at constant load.

In Figure 5 also shows that the E20 has the highest percentage of carbon dioxide emission compared with the other blends and gasoline fuel due to the high intensity of oxygen in the blended fuel. This level of oxygen in the blended fuel could promote a better combustion process. According to Mustafa Kemal Balki et al. [5], the high oxygen ratio in alcohols could improve the combustion efficiency and caused higher $CO_2$ emissions.

Due to more complete combustion with sufficient oxygen and ignition timing, the carbon residue tends to combine with oxygen to form carbon dioxide. Unlike with the incomplete combustion with less oxygen content, the carbon residue tends to combine with oxygen to form carbon monoxide and release oxygen gases.

### *3.3.3 Smoke Opacity*

Figure 6 shows the trend of smoke opacity emissions from a spark ignition engine operating with variation of blend ratios at different engine speeds (2000 - 3000 rpm) and at constant load. Overall, the results show that the trend of smoke opacity is sharply decreased when the engine speed increases. It indicates that when the engine speed increases, the combustion process would become more complete to burn the fossil fuel.

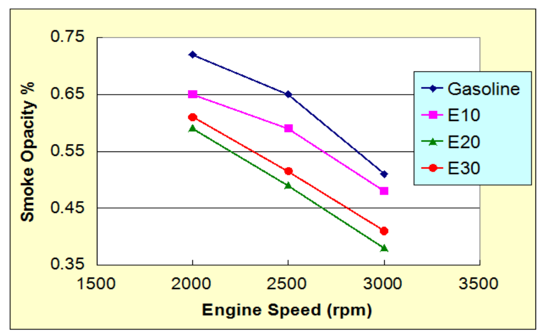



**Figure 6** Smoke opacity for several blend ratios operating at different engine speeds and constant load.

Figure 6 also shows that the smoke opacity emissions decrease with the increased blend ratio for almost all engine test conditions, due to more complete combustion occurred. The ethanol-gasoline blend has improved the smoke opacity. The engine operates with E20 has the lowest percentage of smoke opacity with the improvement of 28.6 % compared with gasoline fuel. This indicates that, the higher blend ratio can be beneficial due to better fuel evaporation rate leading to improve combustion behavior. In contrast, fossil fuel emits higher levels of smoke opacity due to lower evaporation rate resulted in poor mixing process, this could lead to less complete combustion. Less complete combustion emit higher smoke due to rich zones inside the flame reaction and insufficient amount of oxygen available during a combustion process [17].

## 4.0 CONCLUSION

This research investigates the effects of ethanol fuel blends on engine performance and exhaust emissions. The engine was tested with variations of engine speed and constant load fueled with different blend ratio of ethanol-gasoline fuel (E0, E10, E20, E30) to obtain the fuel consumption, exhaust temperature and exhaust emissions. Results recorded from the research can be concluded as below:

1. Fuel consumption of ethanol fuel blends have been improved with the results shown that the E20 gave the best value of BSFC for all engine test conditions with improvement up to 41.5 % compared with fossil gasoline fuel.
2. Ethanol fuel blends have better combustion efficiency compared with gasoline fuel due to higher oxygen intensity. Thus, it promotes better combustion process and resulting in lower exhaust temperature.
3. Emissions of carbon dioxide ($CO_2$) for the ethanol-gasoline fuel blends are higher than gasoline fuel. Meanwhile, the emission of carbon monoxide (CO) is lower for the fuel blends compared to the fossil gasoline due to better combustion process.
4. Smoke opacity is improved by using ethanol-gasoline fuel blends with the E20 has the lowest smoke opacity with improvement of 28.6 % compared with fossil gasoline fuel due to the enhancement of air-fuel mixture which decreasing the formation of soot.

The overall results show that the engine operating with higher blend ratio of alcohol produced improved engine performance and exhaust emissions. It can therefore be assumed that the additional of ethanol to fossil gasoline fuel can be considered as an alternative strategy in order to control exhaust emissions and performance simultaneously. In fact, ethanol-gasoline fuel blends can be further improved with additions of higher alcohol fuels such as isopropanol and iso-butanol. With the additions of higher alcohol fuels, resulted in improvements on boiling point, vapor pressure, energy density and knock resistance that can be considered as a future alternative fuel.

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