Effects of Biofuel and Variant Ambient Pressure on Flame Development and Emissions of Gasoline Engine.

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Abstract. There are many technologies about exhaust emissions reduction for wide variety of spark ignition (SI) engine have been considered as the improvement throughout the combustion process. The stricter on legislation of emission and demands of lower fuel consumption needs to be priority in order to satisfy the demand of emission quality. Besides, alternative fuel such as methanol-gasoline blends is used as working fluid in this study due to its higher octane number and self-sustain concept which capable to contribute positive effect to the combustion process. The purpose of this study is to investigate the effects of methanol-gasoline fuel with different blending ratio and variant ambient pressures on flame development and emission for gasoline engine. An experimental study is carried out towards to the flame development of methanol-gasoline fuel in a constant volume chamber. Schlieren optical visualization technique is a visual process that used when high sensitivity is required to photograph the flow of fluids of varying density used for captured the combustion images in the constant volume chamber and analysed through image processing technique. Apart from that, the result showed combustion burn rate increased when the percentage of methanol content in gasoline increased. Thus, high percentage of methanol-gasoline blends gave greater flame development area. Moreover, the emissions of CO, NOX and HC are performed a reduction when the percentage of methanol content in gasoline is increased. Contrarily, the emission of Carbon dioxide, CO_2 is increased due to the combustion process is enhanced.

1.0 Introduction

The demand for energy and stringent pollution regulations has ever-increasing due to the result of population growth and technological development [1]. Nowadays, biofuels have attracted the attention of policy makers, researchers and industrial as a renewable, biodegradable, and non-toxic means of increasing energy source diversification [2]. Biofuels can be classified into conventional biofuel and advanced biofuel. The conventional biofuel such as sugar and starch-based ethanol, oil crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion. Meanwhile, the advanced biofuel generally involved cellulose-based ethanol, biomass-toliquids-diesel and bio-synthetic gas [3-4]. The cost of biofuel can be lower in the region of states whose economy is greatly depends on agriculture, due to the production of biofuel mostly from agricultural crops. The simplest utilization of biofuels used for spark ignition (SI) engines is to blend moderate amount of biofuels with gasoline [5].

However, methanol is known as methyl alcohol, which is also a type of bio-fuel that can be used as pure or blended fuel in the gasoline or internal combustion engine. Methanol is a promising and ideal alternative fuel for spark ignition engines [6]. Besides, methanol has higher octane number, oxygen ratio, flammability limit, and low carbon to hydrogen ratio compared to the gasoline which allowed engine increases the compression ratios for improving fuel economy. Apart from that, flame propagation of methanol with laminar flow speed is about twice faster than gasoline flame propagation speed [7].

Ambient pressure is one of the parameter or factor that affects the combustion of internal combustion engine. Ambient pressure can be define as the pressure of the surrounding medium, such as a gas or liquid, which comes into contact with the object. Within the atmosphere, the ambient pressure decreases with height above ground and by measuring ambient atmospheric pressure, a pilot may determine height. Near the ground, a change of ambient pressure of 1 millibar is taken to represent a change of height of 9 metres. The ambient pressure in water with a free surface is a combination of the hydrostatic pressure due to the weight of the water column and the atmospheric pressure on the free surface. This increases approximately linearly with depth. Since water is much denser than air, much greater changes in ambient pressure can be experienced under water. Each 10 metres of depth adds another bar to the ambient pressure [8].

In the internal combustion engine, the combustion process can be divided into three specific broad regions which are ignition and flame development, flame propagation and flame termination [9-10]. The first phase of combustion is development of flame, the consumption of A/F mixture is only 5%. Meanwhile, the second phase is propagation of flame that dominated about 80vol% to 90vol% of the A/F mixture. In this stage, a significant pressure increased, which allow the force to produce work in the stroke of expansion. The final stage is the flame termination, which is the consumption of A/F mixture at only 5%. During this stage, the pressure dropped quickly and combustion achieved complete [11].

Some researches indicated that the engine fuelled with methanol-gasoline blends could efficiently reduce the emission of hydrocarbon and carbon monoxide [12]. This type of biofuel (methanol) has a high compression ratio and heat of vaporization which capable to cool the entering air into engine. Thus, the volumetric efficiency and power output are increased. However, this biofuel also has negative side effect which is lower in latent heating value [13].
Furthermore, methanol-gasoline mixture has potential to reduce the emissions such as nitrogen oxide (NO_X), hydrocarbon (HC), carbon monoxide (CO) and carbon dioxide (CO_2). Therefore, a study is conducted to investigate the effects of biofuel with different blends ratio and variant ambient pressure specially focus on flame development and exhaust emission of gasoline engine. The scope of this research is to study the flame development during combustion process with 0vol.%, 5vol.%, 10vol.% and 15vol.% of methanol blend with gasoline fuel. Besides, different ambient pressure (0.10 MPa, 0.15 MPa and 0.20 MPa) also been investigated. Moreover, the experimental method used to evaluate the detail of mixture formation process is schlieren optical visualization method. The basic principle of this technique is to combine the optical projection of an object with an indication of its light deflection [14-16].

2.0 Experimental Setup

Fuel properties - Gasoline fuel (M0) is used to carry out the initial experiment as the reference line data. Afterward, the methanol-gasoline blends (5, 10 and 15 vol.% of methanol in gasoline) were prepared and tested under the same experimental procedure as M0. Table 1 showed the properties of working fluids used in this study. The parameters such as density, lower heating value, Reid vapour pressure, motor octane number, research octane number, anti-knock and oxygen content in fuels were presented in the Table 1.

Table 1: Properties of methanol and gasoline

Item	Accuracy	Gasoline (M0)	M5	M10	M15
Density (g/cm^3)	0.001	0.7682	0.7715	0.7737	0.775
LHV (kJ/kg)	1	43313	42610	41815	41597
RVP (kPa)	0.1	59.2	83.1	83.3	83
MON	0.1	81.6	83.8	84.4	84.6
RON	0.1	85.3	87.3	88	88.2
Anti-Knock	-	83.45	85.55	86.2	86.4
Oxygen (g/cm^3)	-	0	1.98	3.97	5.96

Constant Volume Chamber - The constant volume chamber is fabricated based on the concept of spark ignition engine. Figure 1 shows the constant volume chamber and also called as combustion chamber. The mild steel material is used to fabricate combustion chamber with specific dimension of 160mm x 160mm x 160mm and a 75mm bore. At each face of the chamber is sealed with polycarbonate disc shaped quartz viewing window 25mm thick. Moreover, Table 2 illustrates the specification of combustion chamber.

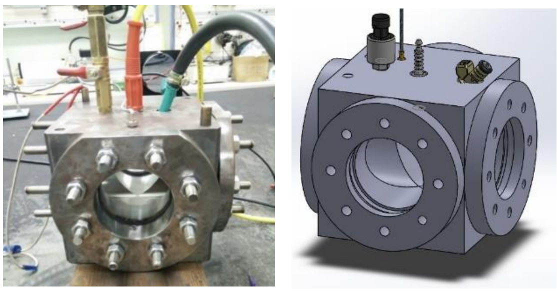


Figure 1: Constant Volume Chamber

Table 2: Specification of combustion

Constant Volume Chamber	
Material	Mild Steel
Volume	400 cc
Dimension	160 mm x 160 mm x 160 mm
Bore	75 mm

Schlieren Optical Setup - In this study, the method used to evaluate the detail of mixture formation process is schlieren optical visualization method. The basic principle of this technique is to combine the optical projection of an object with an indication of its light deflection [12]. Nevertheless, this method can be conducted by high speed camera and it is a visual process that used photograph to analysis. August Toepler [16], a German physicist in 1864 were developed this technology to study supersonic motion which widely used in aeronautical engineering to snap photograph of air flow around objects. Schlieren photography method was also used to observe the fluid evaporation and mixture formation in engine [15]. Figure 2 shows the schematic diagram of Schlieren optical visualization technique.

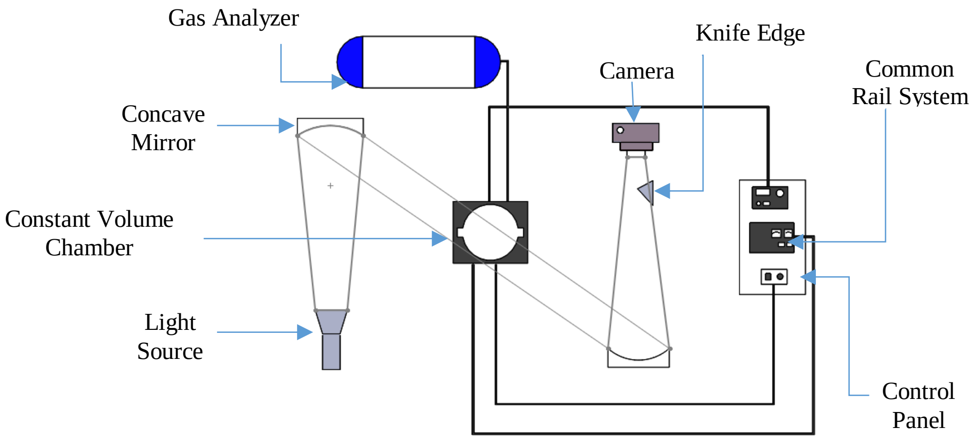


Figure 2: Schematic diagram of Schlieren optical visualization technique

Schlieren photography method was employed compared to direct shadowgraph photography to observe the flame development in combustion chamber after ignition. This is because Schlieren method is a visual process that used when high sensitivity is required to photograph the flow of fluids of varying density compared to direct shadowgraph method which only create the shadows of refractive index of fluid density on the screen creating an image. The colour image of flame development was captured by high speed camera, Nikon 1 J1 with lens of Nikon f-3.8 AF-S, 30-110 mm. Meanwhile, the resolution of image is 480 by 480 pixel with focal length 60mm at maximum frame per second of 1200 fps and 750 fps for video mode with 640 x 240 pixel.

2.4 Experimental Specification

The investigation of flame development and emissions with different concentrations of methanol blends with gasoline like 5vol% (M5), 10vol% (M10), 15vol% (M15) and gasoline (RON 95) were conducted at different ambient pressures of 0.10 MPa, 0.15 MPa and 0.20 MPa. The ambient pressure also refer to the initial pressure of constant volume chamber, before undergo combustion process. The experiments have been conducted at same base conditions as shown in Table 3.

Table 3: Experimental Specification

Experimental Specification	
Ambient Temperature, T_i	328 K
Ambient Pressure, P_i	0.10 MPa, 0.15 MPa, 0.20 MPa.
Injection Pressure	0.3 MPa
Fuel quantity	0.15 ml
Equivalence ratio, ϕ	1.1
Fuel Injector Type	OE Toyota, Green Composite Plastic
Fuel Nozzle	12-hole Disc
Nozzle Hole Diameter	50 micron
Flow Rates (observed)	330cc/min at 3.0 BAR - 43.5 PSI

Flame development and combustion characteristics are playing an important role to the application of combustion specifically on methanol-gasoline blend in the gasoline engine. However, performance, combustion quality and emission characteristics are based on the physical and chemical properties to indicate the quality of combustion in gasoline engine.

2.5 Image Analysis Method

In this study, image processing method is applied through ImageJ software to analyze the captured images. This software uses an integrated program for visualizing, analyzing, transforming and presenting data purposes. The image processing analysis became easier due to the ability of programming coding in this software is able to measure the area of combustion from the image inserted as shown in Figure 3.

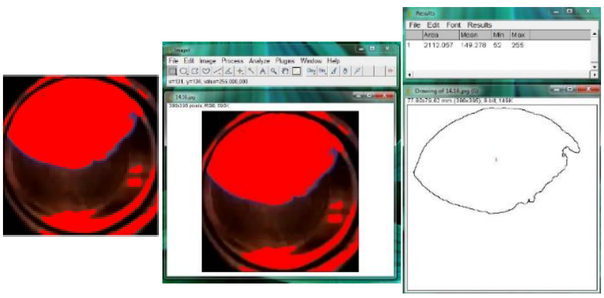


Figure 3: Flame development area analysis by using Image J software

3.0 Experimental Result

Variant experiments were performed with different blend ratio of methanol-gasoline fuels and different ambient pressures in a constant volume chamber. Ambient temperature of 328 K and injection pressure of 0.3 MPa are the fixed conditions throughout whole experiment. First of all, the result of 0.10 MPa ambient pressures on flame development area is studied. Moreover, Table 4, Table 5 and Table 6 show the results of flame development for different ambient pressures such as 0.10 MPa, 0.15 MPa and 0.20 MPa with variant types of methanol-gasoline blends fuel.

The Effects of Ambient Pressure and Fuel Blends on Flame Development of Combustion Process. This section illustrates the improvement of air-fuel mixture formation under the condition of variant ambient pressure and methanol-gasoline blend ratio. As shown in Table 4, the increasing of ambient pressure caused high density in constant volume chamber, thus resulted greater flame development area of the combustion process. This study used two parameters to develop the flame development, variant ambient pressure and different percentage of methanol blends in gasoline fuel.

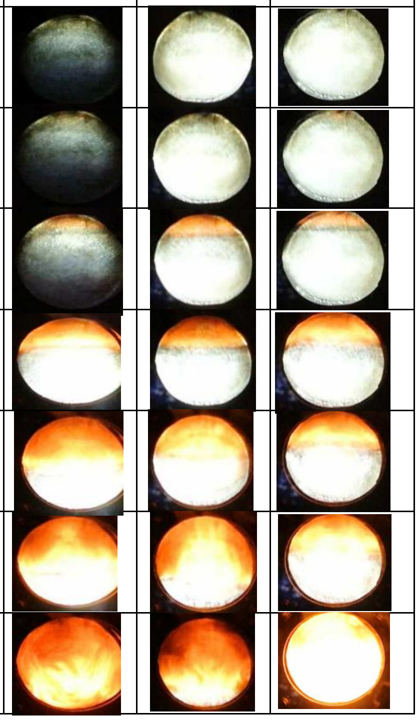
Ambient pressure is rose from 0.10 MPa to 0.20 MPa with the same injector specification. Furthermore, Figure 4 illustrates the flame distribution in the constant volume chamber. The flame distribution pattern of ambient pressure 0.20 MPa is constantly distributed at each burn rate compared to the flame distribution pattern of ambient pressure 0.15 MPa.

Table 4: Flame development for ambient pressure of RON 95.

Time (ms)	Ambient Pressure		
	0.10 MPa	0.15 MPa	0.20 MPa
0			
28.8			
57.5			
86.3			
115.1			
143.9			
172.6			

Table 5: Flame development for ambient pressure of M5.

Time (ms)	Ambient Pressure		
	0.10 MPa	0.15 MPa	0.20 MPa
0			
28.8			
57.5			
86.3			
115.1			
143.9			
172.6			



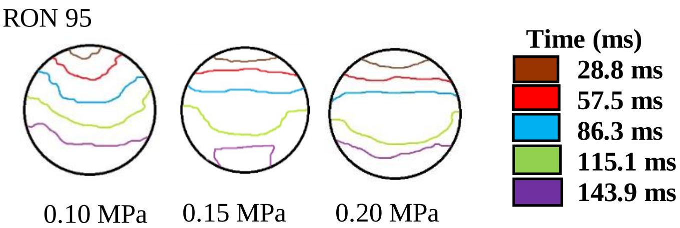


Figure 4: Flame development pattern for RON 95

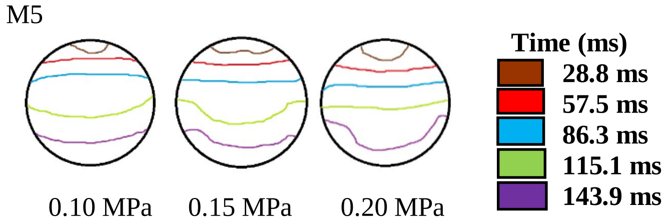


Figure 5: Flame development pattern for M5

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According to the Schlieren photograph image of 5vol.% (M5) fuel type, the increment of ambient pressure caused the flame development area to increase. Thus, the increasing of ambient pressure also gives impact to the burn rate of combustion. The flame distribution pattern of fuel M5 as similar as fuel RON 95 where the flame distribution pattern are constantly distributed for ambient pressure 0.20 MPa compared to the flame distribution pattern at ambient pressure 0.15 MPa as shown in Figure 5.

Apart from that, the performance for fuel M10 is also similar as RON 95 and M5, which is the flame development area increased as the ambient pressure increased, as shown in Table 6. However, the pattern of flame distribution performed oppositely to RON 95 and M5. The flame pattern of M10 is constantly distributed at ambient pressure of 0.10 MPa compared to the flame distribution pattern for 0.15 MPa and 0.20 MPa as illustrated in Figure 6. Table 7 shows the Schlieren photograph image for fuel M15. The result shows the area of flame development increased as the ambient pressure increased in the constant volume chamber. Besides, the distribution of flame for ambient pressure 0.20 MPa is constantly distributed compared to the 0.15 MPa and 0.10 MPa.

Table 6: Flame development for ambient pressure of M10

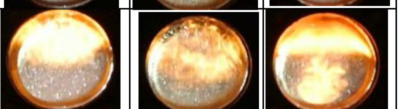
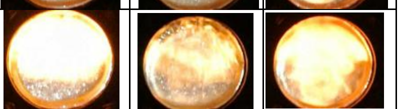
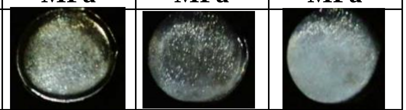
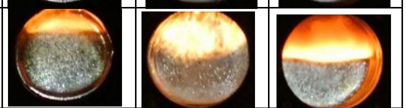
Time (ms)	**Ambient Pressure**		
	0.10 MPa	**0.15 MPa**	**0.20 MPa**
0			
28.8			
57.5			
86.3			
115.1			
143.9			
172.6			

Table 7: Flame development for ambient pressure of M15

Time (ms)	**Ambient Pressure**		
	0.10 MPa	**0.15 MPa**	**0.20 MPa**
0			
28.8			
57.5			
86.3			
115.1			
143.9			
172.6			

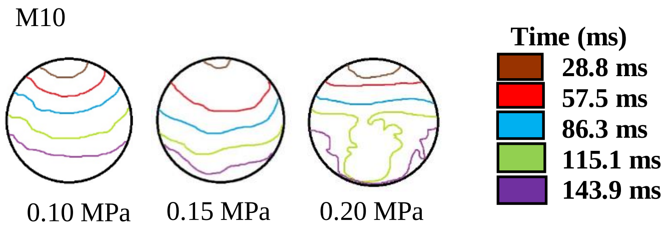


Figure 6: Flame development pattern for M10

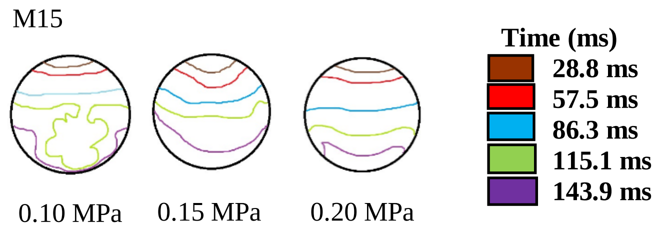


Figure 7: Flame development pattern for M15

As mentioned above, only 5%.vol and 15%.vol methanol blend ratios are compared due to the indistinguishable influence on combustion performance. As shown in this research, the combustion rate of M15 is larger than that of M5 when operated. From the experiment, M15 is more advanced than that of M5 because methanol produces more complete combustion due to the more oxygen content and leaner fuel air mixture leading to more energy input from fuel chemical reactions. Moreover, the flame pattern and flame development are analysed by the image processing method. Nevertheless, it is concluded that higher ambient pressure has the capability to increase the burn rate of combustion for fuel M15.

The analysis data from Figure 8 indicates the comparison between flame development areas of variant types of fuel for different ambient pressures. The experimental result shows that the increasing of methanol percentage content in gasoline fuel affected the enlargement of flame development area. Besides, the ambient pressure also influenced the enlargement of flame development area. As observed from the Figure 8, the highest flame development area is under fuel M15 and ambient pressure of 0.20 MPa with 4821.9 pixels/ mm^2 at time 172.6 ms. Therefore, the higher ambient pressure, the larger is the flame development area.

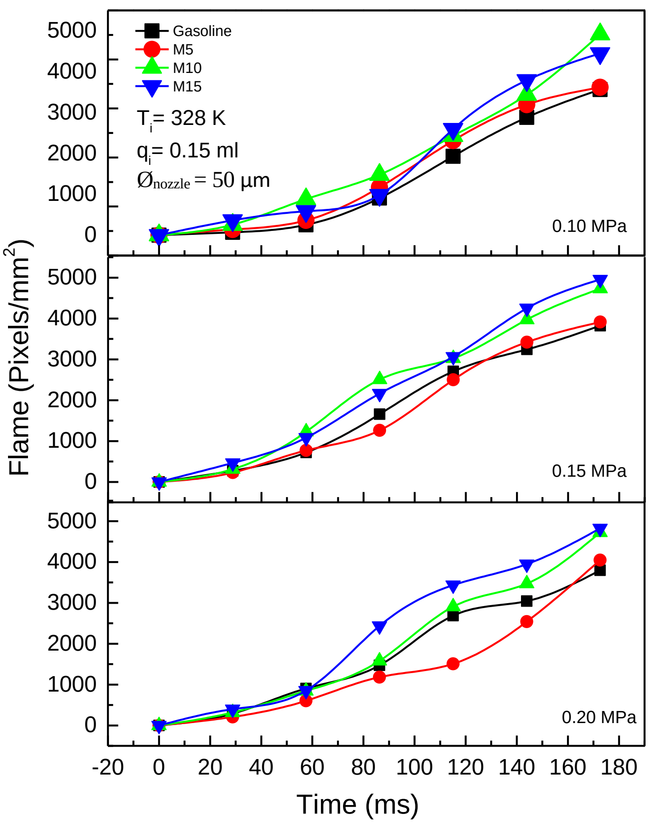


Figure 8: Graph of flame development area against time for ambient pressure

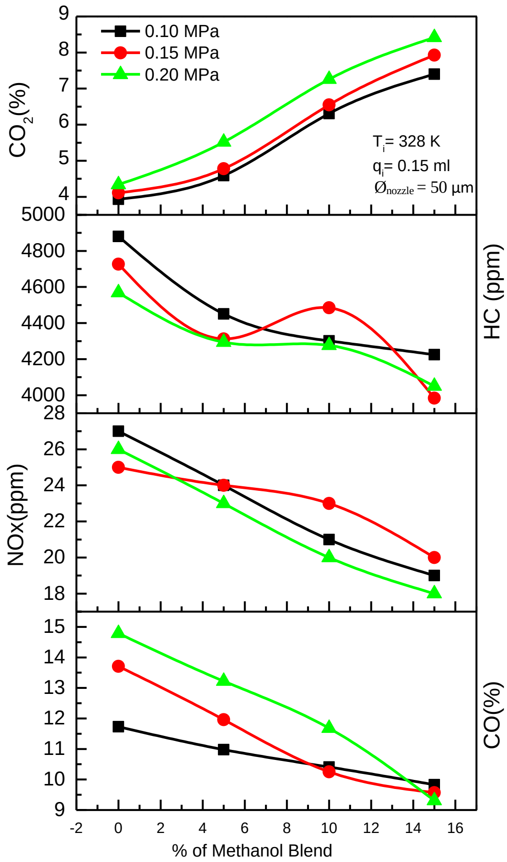


Figure 9: Effects of methanol blend on exhaust emissions

The Effect of Fuel Blend on Exhaust Emission of Spark Ignition Engine.

Exhaust emission is still an issue for the internal combustion engine nowadays. Therefore, the exhaust emission produced from combustion for each type of fuels were investigated through automobile exhaust gas analyzer. Figure 9 illustrates the pollutant emissions of methanol-gasoline fuel blends after combusted in constant volume chamber. The investigation showed that the small amount of methanol added in gasoline fuel could reduce the emissions of NO_X due to higher heat vaporization of methanol compared to the gasoline. Higher heat vaporization generated contributed to the decline of combustion temperature. Moreover, the increasing of methanol concentration reduced the CO and HC emissions as observed from the Figure 9. The HC emission is reduced due to high oxygen content in ethanol which causing the reaction move towards to the complete combustion. Meanwhile, the CO_2 emissions increased due to improvement of combustion process

4.0 Conclusion

As conclusion, this research was conducted with the Schlieren optical visualization technique to obtain the flame development area and exhaust emissions for each type of fuels (RON 95, M5, M10, and M15) with different ambient pressures (0.10 MPa, 0.15 MPa and 0.20 MPa). As a result, the experimental investigation showed different parameters developed different results as listed below:

i. The used of bio-methanol as alternative fuel in pure gasoline can improve the exhaust emission produced by spark ignition engine.
ii. The increasing of methanol percentage content in gasoline fuel could increase the burn rate of combustion.
iii. The increasing in ambient pressure contributes the increment of flame development area for each type of fuels. However, the rose in ambient pressure reduced the emission of Carbon Monoxide, Hydrocarbon and Nitrogen Oxide.
iv. The increasing of methanol percentage content blends with gasoline reduced the emission of CO, HC and NO_X but increased the CO_2 due to combustion process improvement.

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