

Influences of the end of injection and ambient temperature on biodiesel combustion

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ABSTRACT

Influence of the injection pressure and ambient temperature at the end of injection of biodiesel spray has been studied using Rapid Compression Machine (RCM). The experiments were conducted on a RCM for the premixed combustion with a single injection at 21% intake oxygen concentration. RCM is designed to simulate combustion phenomenon that observes the ignition, combustion process, and combustion characteristics under high injection pressure and variant ambient temperatures. Two types of biodiesel blend namely, B5 and B10 were tested in the RCM at the injection pressures of 80 MPa and 90 MPa. The ambient temperature of RCM was varied at 700 K to 1100 K. The result showed that higher ambient temperature produced shorter ignition. The initial combustion rate became low and the combustion duration became longer. Too short ignition delay resulted in decreased premixed combustion, which cannot provide enough time for air-fuel premixing. Under low ambient temperature, longer long ignition delay influenced the ignition that occurred late in the expansion stroke that caused incomplete combustion process, reduced power output, and poor fuel conversion efficiency. The emission showed that under the condition of higher ambient temperature, the product of CO, O₂, and HC became lower but resulted in the increase of NO_x level. Increased blends of biodiesel ratio were found to enhance the combustion process, resulted in decreased HC emissions. The improvement of combustion process is expected to be strongly influenced by oxygenated fuel in B10 biodiesel content.

Keywords: Rapid compression machine; biodiesel; ignition delay; emission; ambient temperature.

INTRODUCTION

The performance and exhaust emission characteristic of diesel engines depend on the parameter of injection various factors such as the quantity injected, injection timing, and injection pressure [1-3]. The function of fuel injection system in a direct injection diesel engine is to attain a high degree of atomisation for better penetration of fuel consecutively

to operate the full air charge, prop up the evaporation in a very short time, and reach higher combustion efficiency [4-8]. In general, fuel, ambient conditions, and the end of injection (EOI) transient determine the success or failure of combustion process in combustion chamber. The behaviour at the EOI is a complicated, unsteady process that includes chemical process and other inter-related phenomena. During EOI transient, the injector fuel flow decreases and more air is entrained into the jet from the surrounding air. The rate of air entrainment travels down through the increased jet. This increased air entrainment has significant effects on the evaporation of the liquid fuel after the EOI, with the liquid length receding from its steady position and also evaporation of the near-nozzle fuel due to increased entrainment near the nozzle [9]. The combustion process of air fuel mixture is the means of producing power and also forming pollutant emissions in diesel engines, and understanding and controlling the spray and combustion processes that are vital to making engines that are efficient and produce low levels of pollutant emissions [10]. The mixing process at EOI has specifically been linked to hydrocarbon emissions and soot emissions, with a slower decrease in fuel delivery reducing soot emissions [11, 12].

Diesel injection parameter effect on air fuel mixing on combustion process after the EOI was investigated in a constant-volume chamber over a range of ambient and injector conditions typical of a diesel engine. In this study, the influence of injection pressure and variant ambient temperature at EOI towards the ambient pressure and emission during combustion was investigated in the RCM. For instance, many studies have been conducted in the field of rapid compression machine. Some of them require continuation and improvement from the previous research. RCM needs to be set-up to simulate the occurrence of combustion process and analyse some of the many properties [13-19]. RCM is an excellent tool to clarify the effect of the injection pressure and ambient or compression temperature at EOI on exhaust emission [9, 20-22]. When there is a net heat released due to fuel evaporation and heating, the effect of injection pressure and temperature on the ignition process is investigated until early pressure rise. The interaction between fuel spray and surrounding gas is important for the combustion efficiency and exhaust emissions [23-29]. The objective of this study is to investigate the combustion process behaviour during the EOI period and operates under variant conditions using RCM. RCM used in the experiment is of a single cylinder, free moving piston, and direct injection of fuel and air. It is an essential instrument for the allowance of studying about the self-ignition of fuel and air mixture in an easier controlled condition than the standard compression ignition engine [30-32]. In addition, the constant volume chamber used on this machine is similar to each cylinder of an ordinary diesel engine [20, 33-38]. The injection pressure and variant ambient temperature research could obtain the nature of the burning fuel and air during combustion and how it affects ignition delay period and the emission produced. Furthermore, this machine can remove the complexity and confusion that often occurs in the test engine.

The ignition delay of the diesel engine is generally the time interval between the start of the injection of the fuel and air into the combustion chamber and the piston's compression inside the combustion chamber [39-42]. It is during ignition delay that the reaction causes the production of NO_x . In RCM, there are needs to measure the emissions so as to lower the unwanted material production from the emission. The delay period has been found to be different when different types of biodiesel are used individually. By using RCM, the emissions can be investigated after the combustion takes place. The use of biodiesel may reduce the emissions on behalf of particulate matter (PM), but in NO_x regions, it will increase to a more undesirable quantity. At the end of combustion, ambient

temperature inside combustion chamber increases. At this temperature, oxidation of nitrogen takes place in the presence of oxygen inside the cylinder. NO_x level is higher for biodiesel mixtures than standard diesel fuel at the same engine torque. This can be explained due to the presence of extra oxygen in the molecules of biodiesel mixtures and additional oxygen responsible for extra NO_x emission [43]. This has been studied and tested by using the B5, B10, B15, and other blends of biodiesel [44-53].

METHODS AND MATERIALS

Experimental Set Up

The experiments were conducted in a RCM by direct injection diesel spray with a variant injection pressure and ambient temperature. RCM has been designed for the purpose of chemical kinetics studied at elevated pressures and temperatures. RCM performs a single compression act of the engine. The present RCM is designed as a versatile tool which includes the features of a well-defined core region, fast compression, ability to vary stroke and clearance, optical accessibility, and capability for special measurement. In this research, the influences of injection pressure and temperature of constant volume chamber on the end of injection spray were determined. The experimental apparatus is divided into four systems such as rapid compression machine, common rail system, data acquisition systems, and exhaust emission measurement systems. These experiments are conducted to develop an engine with better combustion by simulating the fuel injection in the RCM. Figure 1 shows a general schematic diagram of the device. A free-piston type rapid compression machine (RCM) was used to simulate diesel combustion in a constant volume over a wide range of ambient temperature and pressure conditions similar to actual diesel engines. In addition, systems were added with the exhausts analyser to observe the exhaust emissions and the in-chamber pressure data are acquired with piezoelectric pressure transducer. The physical and chemical properties of the fuels in this experiment are summarised in Table 1. Table 2 summarises operating parameters and fuel injection system including the specification of the nozzle that had been used in the experiment. Fuel blends containing 5% and 10% of palm oil biodiesel in diesel oil, which called B5 and B10 were tested.

The piston was driven by the constant ambient pressure of 4 MPa (16.6 kg/m³), which was the pressure used for all of the experiments. The temperature of the constant volume chamber and the combustion chamber also were heated to required conditions. all equipment such as piston, cylinder liner, combustion chamber, nitrogen gas, common rail system and diaphragms were prepared and connected. All connections were sealed tightly to avoid leaking during the experiment. The common rail was switched on and the requirement pressures were set up to the fuel injector that has been fixed at the opening of the combustion chamber. Also, it was needed to ensure the controller, injector, and electronic diesel control were switched on. Combustion pressure change inside combustion chamber was sensed by the piezo-electric pressure transducer sensor which the type of the sensor known as Kistler 601A fitted in combustion chamber head. Then, the signals were amplified with the sensitive charge from sensitive charger type Kistler 5018A before it was transmitted by data acquisition. PicoScope 3000 Series PC Oscilloscopes was used to measure voltages in the range -20 V to +20 V. Inputs were protected to ±100 V (±30 V for external trigger). PicoScope 3000 Series PC Oscilloscopes connected direct to the ground of a computer through the interconnecting cable provided to minimise interference. Pico was connected directly and data were transferred into the computer for data analysis. Gaseous emissions samples were immediately collected from

the combustion with the sampling plastic bags. Then, the sample gases were measured with emission analyser. There were many types of the emissions analyser due to the accuracy of the sample result required the different of the emissions species such as NO_x, CO, O₂ and HC.

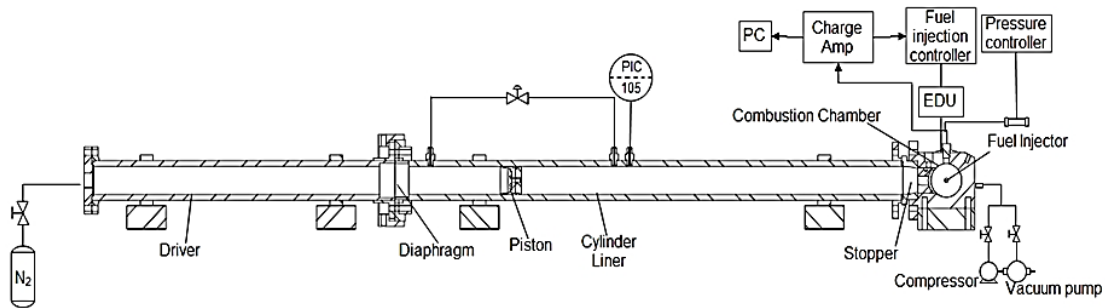


Figure 1. Schematic diagram of RCM.

Table 1. Fuel Properties

Fuel type	Properties		
	Density (g/m ³)	Kinematic viscosity (Cp)	Water content (ppm)
B5	0.837	3.0	120.1
B10	0.838	2.9	158.6

Table 2. Experimental specification

Parameters		Values
Fuel type	Injection type	6 holes, $\phi = 0.16$ mm
	Fuel type	B5, B10
	P _{inj} (MPa)	80, 90
	q _i (ml)	0.04
Ambient gas	T _a (°K)	750-1100
	r _s (m/s)	19.0
	ρ (kg/m ³)	16.6
	O ₂ (vol%)	21.0

RESULT AND DISCUSSION

The effect of injection pressure and ambient temperature at the end of injection on the ignition delay and emissions by using RCM were investigated. The biodiesel tested were B5 and B10. The influence of ambient temperature on RCM pressure was firstly investigated. Figure 2 to Figure 5 illustrate the in-cylinder pressure change in the combustion chamber at various ambient temperatures, T_i = 700 K to 1100 K for B5 and B10 with the injection pressure, P_{inj} is 80 MPa and 90 MPa. From the figures, the compression time decreased with the increase of air temperature T_i. It can be seen that combustion chamber pressure increased steeply a short while after the start of injection and that the timing of this rise was advanced with an increase in ambient temperature T_i. The pressure at EOI between biodiesel B5 and B10 blend fuel showed a similar behaviour. As shown in the graph, it clearly showed that the combustion chamber pressure at EOI increases as the ambient temperature rose. This result proves that high ambient

temperature affected the pressure after the start of combustion that influenced the combustion process. In fact, higher initial ambient temperature improved fuel atomisation and air-fuel mixing process. According to the investigation [30], the combustion chamber pressure distributed larger amount of fuel-air premixing thus predominantly influenced the good spray atomisation and improvement of combustible mixture.

As the temperature and pressure increased, a great variation in the spray structure was observed. It promoted mixture formation and distributed larger amount of fuel between sprays, thus creating good spray atomisation and exhibiting a greater amount of fuel-air premixing prepared for combustion. Increment of the ambient temperature promoted the evaporation process or on the other hand, the evaporation process is elevated by higher ambient temperature [41]. Increase in the ambient temperature caused the rate of fuel evaporation to increase. Fuel droplets with small diameter tend to evaporate easily while those with greater diameter take a much longer time to evaporate [35].

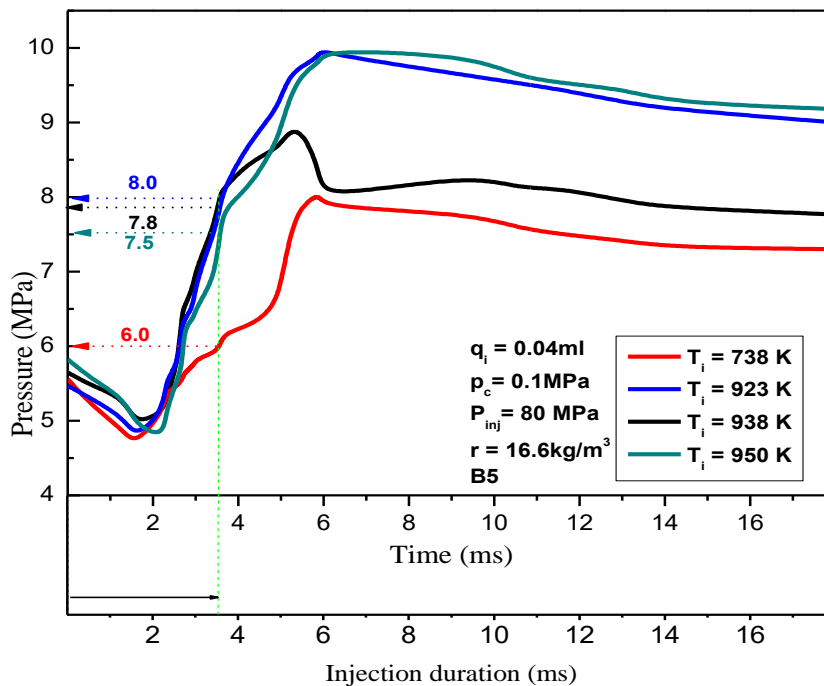


Figure 2. Effect of pressure at EOI under variant ambient temperature and $P_{inj} = 80$ MPa of B5 fuel.

Injection pressure and duration are important in a diesel engine. Higher injection pressure resulted in better dispersion as well as greater penetration of the fuel into all locations in the chamber where its presence is desired. The peak in chamber pressure at EOI of the B10 fuel was higher than B5 fuel. The peak in chamber pressure mainly depends on the initial ambient temperature in the first stage, which is influenced by the fuel taking part in the air-fuel mixing phase. The peak of the chamber pressure increased as the ambient temperature increased, and the ignition delay was lengthened. The reason is that as ignition delay lengthened, more homogeneous air-fuel mixture was formed in the ignition delay and combusted in premixed phase which led to higher peak in chamber pressure [54].

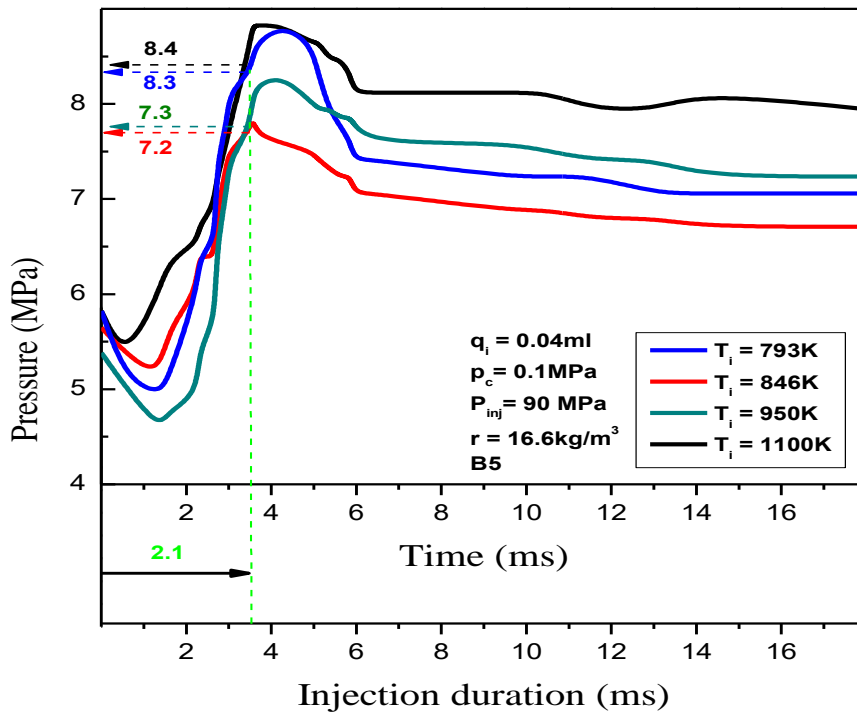


Figure 3. Effect of pressure at EOI under variant ambient temperature and $P_{inj} = 90$ MPa of B5 fuel.

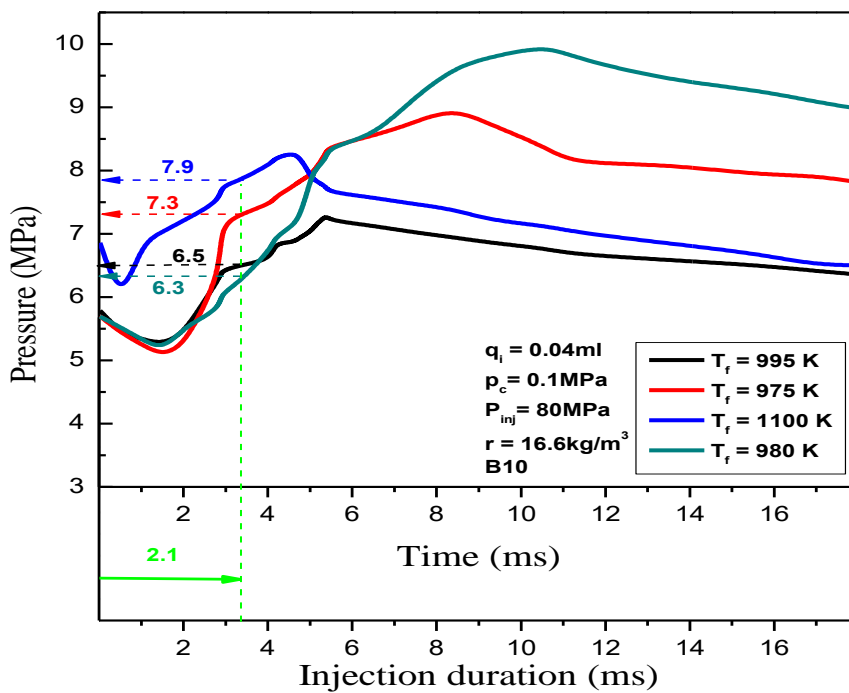


Figure 4. Effect of pressure at EOI under variant ambient temperature and $P_{inj} = 80$ MPa of B10 fuel.

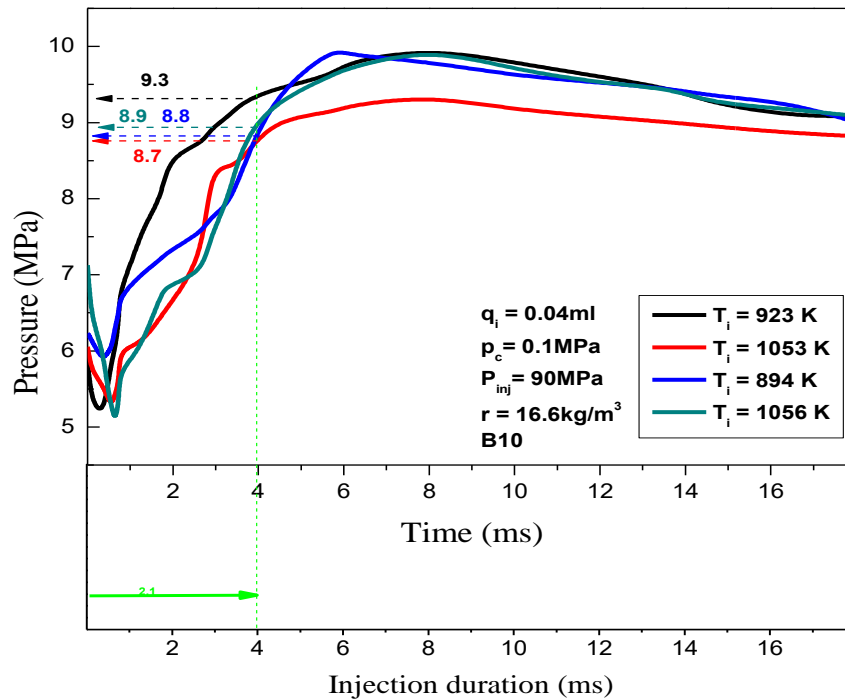


Figure 5. Effect of pressure at EOI under variant ambient temperature and $P_{inj} = 90$ MPa of B10 fuel.

From Figure 4 and 5, the combustion had a slightly higher pressure at a lower ambient temperature. This is due to lower ambient temperature that resulted in a longer ignition delay, causing more premixed combustion in the chamber and consequently increased the chamber pressure at EOI [18]. Heat loss through the chamber wall conduction and flame radiation at low ambient temperature also contributed to increase the pressure [32]. The influence of ambient temperature on exhaust emissions is illustrated in Figure 6. It was observed that the NO_x emission increased as the ambient temperature increased. Higher blends resulted in higher NO_x emission such as B10. The dependence of NO_x emission is volumetric efficiency, ignition delay, and temperature arisen from the start of injection. The increase in the NO_x emissions was due to the oxygen content, since the fuel oxygen provided additional oxygen for NO_x formation and also the difference in the compressibility of the tested fuels can cause early injection timing and produce higher NO_x emissions [40]. It decreased as the ambient temperature increased because of the shorter ignition delay inside combustion chamber [41]. NO_x emission depends on the volumetric efficiency, ignition delay, and temperature arising from high activation energy. The increase in the NO_x emissions was associated with the oxygen content of the methyl ester, since the fuel oxygen provided additional oxygen for NO_x formation and also the difference in the compressibility of the tested fuels can cause early injection timing and produce higher NO_x emissions [45]. It will decrease as the ambient temperature increased because of shorter ignition delay inside combustion chamber. The NO_x emission increased as the injection pressure increases. Higher blends resulted in higher NO_x emission such as B10 [42]. Besides NO_x , unburned hydrocarbon, UHC is also a critical exhaust for the emission behaviour of the diesel engine. Based on the figure, B10 blend fuel had lower UHC emission as compared to B5. This is because of better

combustion of biodiesel inside the combustion chamber due to the availability of oxygen atom in percentage of biodiesel content [55]. The emissions increased as ambient temperature increased is due to the increasing temperature inside combustion chamber under higher ambient pressure, thus preventing condensation of HC in sampling line. Carbon Monoxide, CO emissions occur due to the incomplete combustion of fuel. B10 is found to emit significantly lower CO concentration compared with that B5 fuel over the injection pressure [56]. When the percentage of blend of biodiesel increases, CO emission decreases. The excess amount of oxygen content of biodiesel results in complete combustion of the fuel and supplies the necessary oxygen to convert CO to CO₂. The reduction for smoke emission may be attributed to its oxygen content and small particle diameter of the injected fuel at high injection pressure, thus more oxygen content produces more C to CO, then decreases the smoke emission while increasing the CO emission when ambient pressure increases.

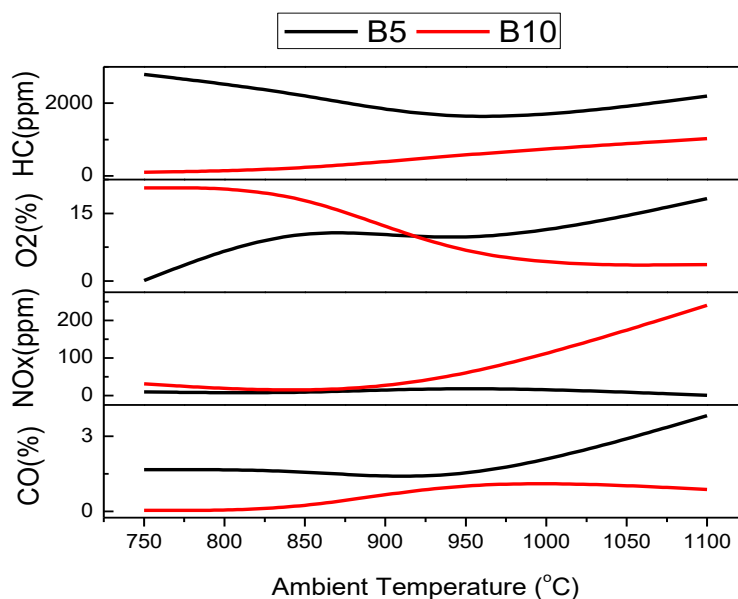


Figure 6. Influence of emission under variant ambient temperature.

CONCLUSIONS

The effect of injection pressure and ambient temperature at EOI on ignition delay and emission was investigated in a rapid compression machine fuelled with different B5 and B10 biodiesel. Emissions including CO, HC, O₂, and NO_x were measured at various injection pressures and ambient temperatures. The major findings of this study are summarised as follows:

- i) At low injection pressure, the ignition delay becomes short and ignition occurs near the nozzle, the initial combustion rate becomes low and the combustion duration became longer. This will produce complete combustion process and good fuel conversion efficiency.
- ii) Short ignition delay results in decreased premixed combustion, which cannot provide enough energy for subsequent air-fuel mixing. Meanwhile, with long ignition delay, ignition occurs late in the expansion stroke that will cause incomplete combustion process, reduced power output, and poor fuel conversion efficiency.

- iii) Experimental ignition delay for the fuels was shortened under increasing initial ambient temperature conditions. Ignition delay for B10 fuel was shorter compared to B5 fuel. The reduction in the ignition delay at high temperature indicated a decrease in the rate of pressure, which resulted from a decrease in the viscosity of the fuel due to high temperature. In addition, increasing of fuel density shortens the ignition delay.
- iv) Higher blending ratio from B5 to B10 increases the oxygen content which makes the combustion more complete, thus, promoting reduction of emissions specifically for CO, O₂, and HC. Nevertheless, the NO_x emission increases.

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