VOL. 11, NO. 12, JUNE 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

THE INFLUENCES OF INJECTION PRESSURE AND AMBIENT TEMPERATURE ON IGNITION DELAY AND EMISSION

Norrizam Jaat, Amir Khalid, Azwan Sapit, Adibah Rhaodah, Mariam Basharie and Mas Fawzi
Automotive Research Group, Centre for Energy and Industrial Environment Studies, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
E-Mail: norrizam@uthm.edu.my

ABSTRACT

The purpose of this research is to investigate the effect of low injection pressure and variant ambient temperature towards the ignition delay period and emission. Three types of biodiesel blend which are B5, B10 and B15 were tested in the rapid compression machine (RCM) at low injection pressures of 80 MPa and 90 MPa. The ambient temperature of constant volume chamber (CVC) $T_{i,cvc}$, was varied at 70 °C and 80 °C while the ambient temperature of combustion chamber (CC), $T_{i,cc}$, was varied at 70 °C and 90 °C. The result shows that at specific ambient temperature combination of the CVC and CC, the higher value of ambient temperature combination produces shorter ignition. The initial combustion rate becomes low and the combustion duration became longer. This produces complete combustion process and good fuel conversion efficiency. Too short ignition delay results in decreased premixed combustion, which cannot provide enough energy for subsequent air-fuel mixing. While, with too long ignition delay, ignition occurs late in the expansion stroke that caused incomplete combustion process, reduced power output and poor fuel conversion efficiency. The emission shows that under the condition of higher ambient temperature, the product of CO, O_2, and HC becomes lower but results in increasing of NOx level. Increased blends of biodiesel ratio are found to enhance the combustion process, resulting in decreased HC emissions.

Keywords: rapid compression machine, injection pressure, temperature, ignition delay, emission.

INTRODUCTION

A rapid compression machine (RCM) is an excellent tool to clarify the effect of the air-fuel ratio, O_2 concentration, and compression temperature on ignition delay and NOx emissions, and study the effect of temperature on the auto-ignition of combustible mixtures because it provides a direct measure of the ignition delay (Adam 2007, Khalid 2013, Veltman 2009, Anand 2010). The 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 a more easy controlled condition than the standard compression ignition engine. In addition, the constant volume chamber used on this machine is similar to each cylinders of an ordinary diesel engine (Khalid 2009 and Khalid 2011). The low 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.

In this study the effect of injection pressure and variant ambient temperature towards the ignition delay period and emission during combustion was investigated in the RCM. There are many studies have been made in the field of rapid compression machine. Some of them require continuation and improvement from the previous research. The RCM needs to be set-up to simulate the occurrence of combustion process and analyzing some of the many properties (Khalid 2015, Mohamed 2014). By using different manipulative conditions on the experiment, the ignition delay responds by going shorter or longer and the product of emissions also could be analyzed at which specific substances of CO, O_2, HC and others decreases or increases.

Biodiesel is the completed blending of alternative fuel from animal fats or vegetable oils, with the pure fuel of crude palm oil called diesel fuel. It is safe, environmentally friendly, and also produces less air pollution than gasoline and diesel. These biodiesel functions as the alternative fuel for pure diesel fuel, as biodiesel have been approved by most vehicle manufacturers, diesel fuel are slowly declining from the source of oil wells (Kwon 1991, Amir 2013,). The mass difference of a diesel engine with a gasoline engine is the fuel injection process, and the injector itself (Yamaki *et al.* 1994).

In RCM, the injector is located at the opening side of the combustion. The injector must be designed to be able to withstand the large amount of temperature and pressure inside the combustion chamber.

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. It is during ignition delay that the reaction caused the production of NO_x. In RCM, there are needs to measure the emissions so as to lower the unwanted materials production from the emission. The delay period has been found to be different when diesel and 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 more undesirable quantity. This has been studied and tested by using the B5, B10, B15 and other blend of biodiesel (Kwon 1991).

VOL. 11, NO. 12, JUNE 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

The aim of this study is to investigate the influences of low injection pressure and variant ambient temperature on ignition delay and emissions. This study uses the rapid compression machine system, with three types of biodiesel grades of B5, B10 and B15. The conditions are by the use of low injection pressure of 80 MPa and 90 MPa, with variant ambient constant volume chamber (CVC) temperature of 70 °C and 80 °C, and variant ambient combustion chamber (CC) temperature of 70 °C and 90 °C.

EXPERIMENTAL SETUP

RCM is an experimental tool developed to study the mixture formation in the combustion chamber in the engine. It is a pneumatically driven device and reproduces a single combustion shot considering compression and partial expansion stroke. 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 ambient temperature of constant volume chamber on biodiesel 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 show 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 analyzer to observe the exhaust emissions and the in-chamber pressure data are acquired with piezoelectric pressure transducer. Fuel blends containing 5%, 10% and 15% of palm oil biodiesel in diesel oil were tested which called B5, B10 and B15.

The piston is pushed by the constant pressure of 19 bar, which is the pressure used for all of the experiments. The temperature of the constant volume chamber and the combustion chamber also is heated to requirement conditions. Temperature of CVC and CC under normal condition is recorded as room temperature and was heat up to 70 °C for both. Preparation and connection of all equipment such as piston, cylinder liner, combustion chamber, nitrogen gas, injector jigs and diaphragms. All connections are seal tightly to avoid leaking. Switch on the common rail and set up 80 MPa of pressure to the fuel injector that has been fixed at the opening of the combustion chamber. After few minutes, temperature both CVC and CC has reached its desired value. Next, switch on the controller, injector and EDU. The pressure and voltage graph is automatically recorded using PICO 3000 series and is transferred into the computer for visual.

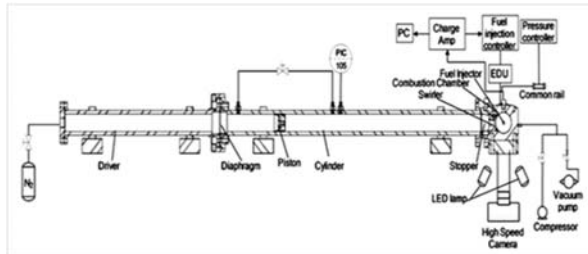

Figure-1. Schematic diagram of RCM.

RESULT AND DISCUSSIONS

The effect of injection pressure and ambient temperature on the ignition delay and emissions by using RCM were investigated. The biodiesel that have been testing are B5, B10 and B15.

The influence of ambient temperature on RCM pressure was firstly investigated. Figure-2 to Figure-4 illustrates the pressure change in the combustion chamber at various ambient temperature, T_a for all types of biodiesel and the injection pressure, P_{inj} is 80 MPa. These graphs were recorded by using the PICO software in the experiments. From the figures it is seen that the compression time decreases with the increase of ambient temperature T_a. It can be seen that combustion chamber pressure increases steeply a short while after the start of injection and that the timing of this rise is advanced with an increase in ambient temperature T_a.

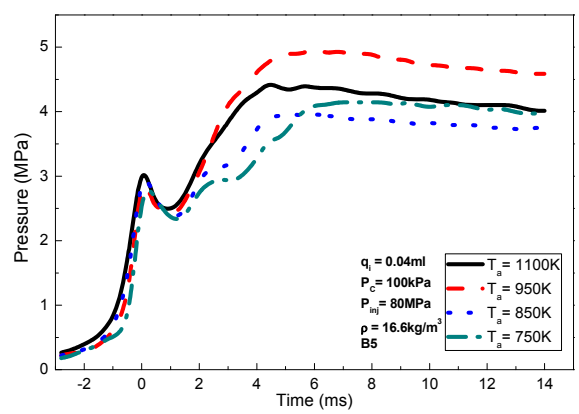

Figure-2. Effect of ambient temperature on B5 for P_{inj} = 80MPa.

VOL. 11, NO. 12, JUNE 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

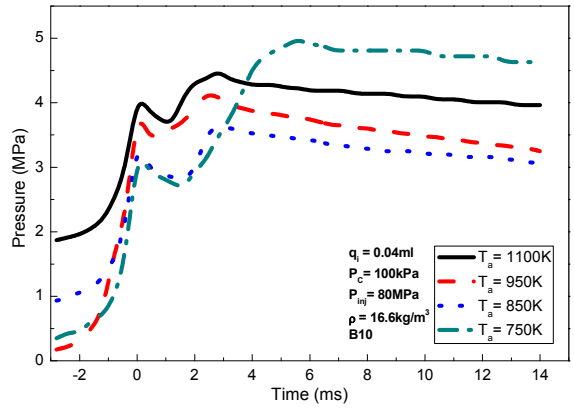

Figure-3. Effect of ambient temperature on B10 for P_{inj} = 80MPa.

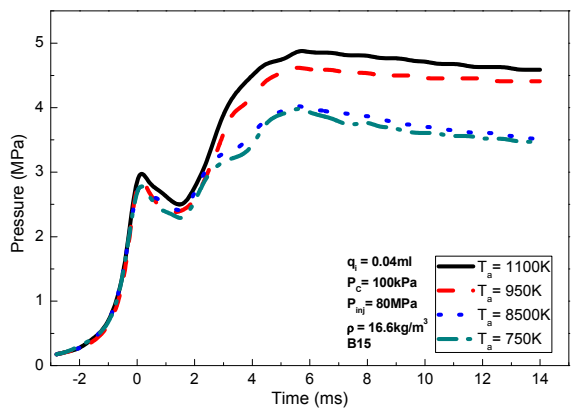

Figure-4. Effect of ambient temperature on B15 for P_{inj} = 80MPa.

This research is continuing by using the same types of biodiesel. Figure-5 to Figure-7 illustrates the relationship between combustion pressure, P_a and time after start of injection at various ambient temperatures and the injection pressure, P_{inj} 90 MPa on biodiesel B5, B10 and B15.

For B10 fuel, the chamber pressure profile showed a similar behavior to the biodiesel B15. In addition, as the ambient temperature is increased, the combustion chamber pressure also increased. It clearly shows that the high ambient temperature will affect the addition of chamber pressure.

The fuel vaporizes and mixes with the high temperatures and high pressure air in combustion chamber. The chamber pressure increases as combustion of the fuel-air mixture occurred. The mixture formation rate is controlled by the nature of the fuel injection system and the fuel spray characteristics and the combustion chamber geometry.

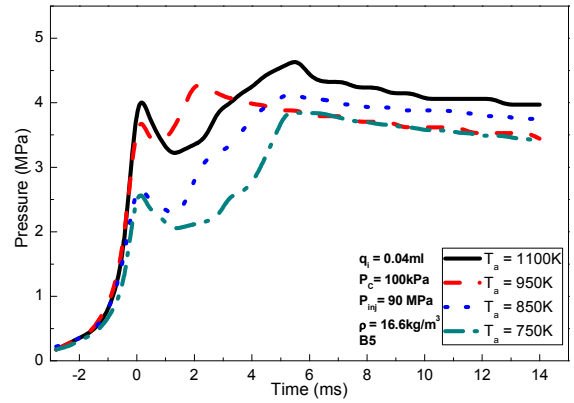

Figure-5. Effect of ambient temperature on B5 for P_{inj} = 90MPa.

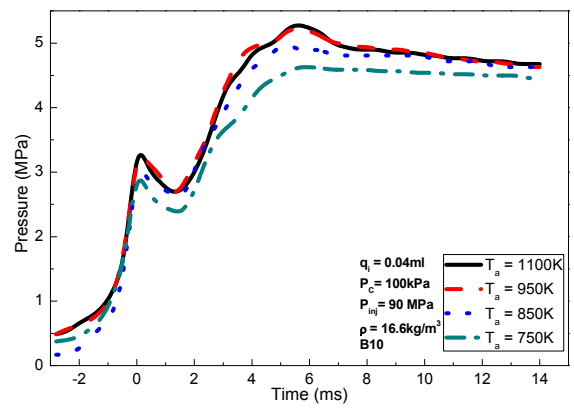

Figure-6. Effect of ambient temperature on B10 for P_{inj} = 90MPa.

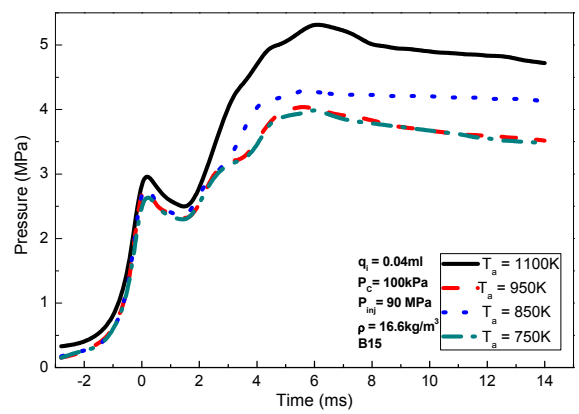

Figure-7. Effect of ambient temperature on B15 for P_{inj} = 90MPa.

The comparison of the chamber pressure with respect to the time obtained for B5, B10 and B15 fuels at injection pressures of 90 MPa is shown in Figure-8. It

observed that the B15 fuel had a slightly longer ignition delay and nearly identical chamber pressure characteristics. The initial combustion rates for all types of biodiesel were nearly identical. The B5 fuel had a slightly shorter delay and also had a slightly higher maximum combustion rate during the premixed stage of combustion.

The peak in chamber pressure of the B15 fuel was lower than those of B10 fuel. The peak in chamber pressure mainly depends on the initial ambient air in the first stage, which is influenced by the fuel taking part in the air-fuel mixing phase. The peak in chamber pressure of the B5 and B15 fuel was lower due to deterioration in the preparation of the air-fuel mixture as a result of poor atomization characteristics, which is induced by its higher density and viscosity as well as surface tension.

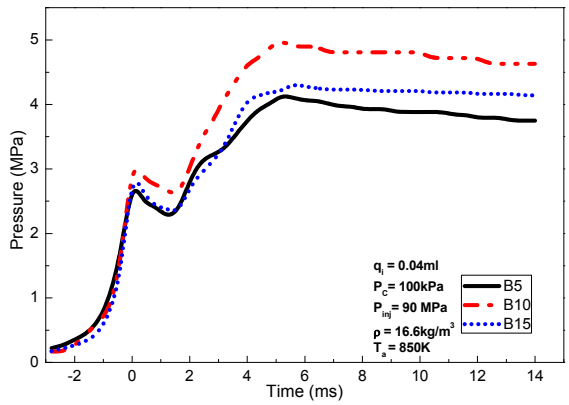

Figure-8. Comparison between B5, B10 and B15.

Ignition delay data for a wide range of air ambient temperature in combustion chamber are shown in Figure-9 to Figure-11. The data are plotted as chamber pressure P_a against ignition delay time at various ambient temperatures during the delay period for each types of biodiesel. The ignition delay is defined as the time between the start of injection and the minimum of the pressure versus time which was used to predict the start of combustion. The data cover a range of temperatures from 850 K to 1100 K with resulting ignition delay times varying from 0 ms to 2.5 ms.

The peak of the chamber pressure was increased when 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.

From the figures, it can be seen that the combustion had a slightly higher pressure at a lower ambient temperature. This is due to at lower ambient temperature resulted in a longer ignition delay, causing more premixed combustion in the chamber and consequently increased the chamber pressure. Heat loss through the chamber wall conduction and flame radiation at low ambient temperature also contribute to increase the pressure.

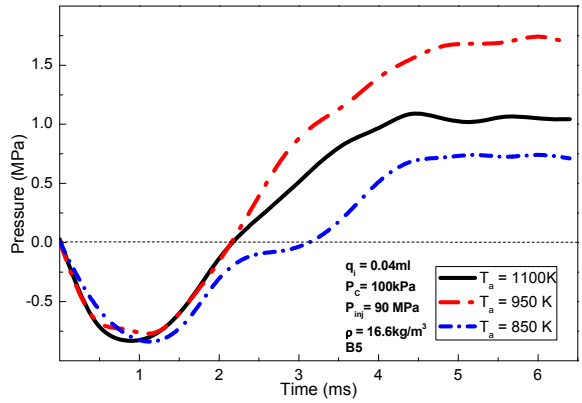

Figure-9. Effect of ambient temperature on ignition delay for B5.

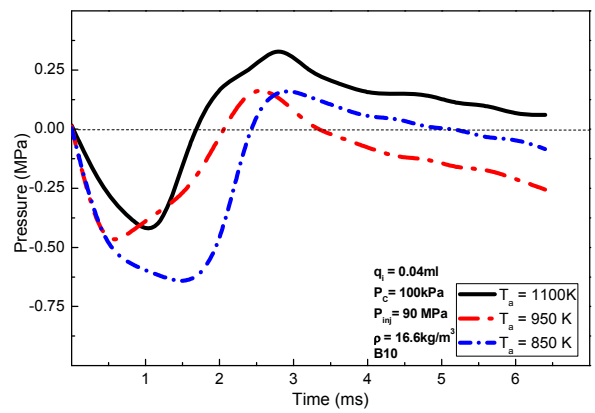

Figure-10. Effect of ambient temperature on ignition delay for B10.

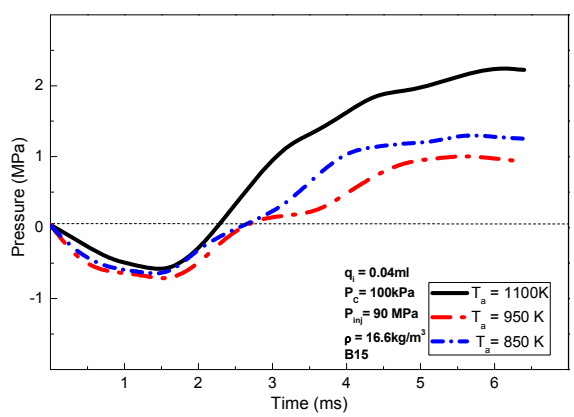

Figure-11. Effect of ambient temperature on ignition delay for B15.

Figure-12 shows the comparison of the ignition delay with respect to the initial ambient temperature with different fuels B5, B10 and B15. The increase of initial

ambient air resulted in the reduction of ignition delay regardless of fuel type used. From the figure, it can be seen that the ignition delay shorten as the ambient temperature increased. This is because higher initial ambient temperature improved fuel atomization and enhanced evaporation of fuel droplets and mixing process.

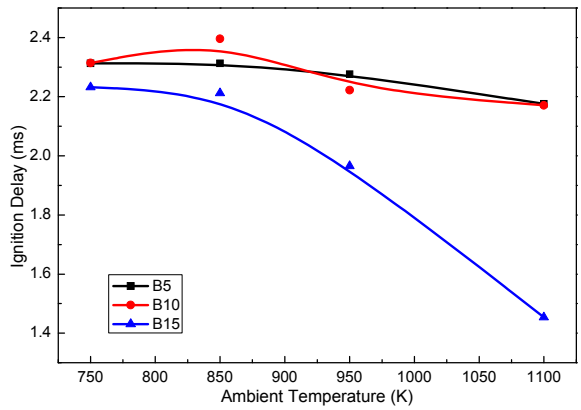

Figure-12. Influence of ambient temperature on ignition delay.

Figure-13 and Figure-14 shows the influence of ambient temperature on emissions. It is observed that smoke opacity of fuels were lower at high ambient temperature, but increased at higher ambient temperature because more fuel is injected at higher temperature so less oxygen will be available for the reaction. smoke decreases with high oxygen content in the biodiesel that contributes to complete fuel oxidation even in locally rich zones, so the oxygen within the fuel decreases the tendency of a fuel to produce soot.

NOx emissions are depending on the volumetric efficiency, ignition delay and temperature arising from high activation energy. The increase in the NO_x emissions were 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 NOx emissions (Al and Bhatti 2014). It will decrease as the ambient temperature increase because of shorter ignition delay inside combustion chamber. The NOx emission increasing as the injection pressure increases. Higher blends will result in higher NOx emission such as B10 and B15.

Unburned hydrocarbon, HC is an important parameter for determining the emission behavior of the engine. B10 and B15 gives lower HC 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. The emissions increased as ambient temperature increase is due to the temperature inside combustion chamber will increase under higher ambient pressure, thus prevent condensation of HC in sampling line.

Carbon Monoxide, CO emissions occur due to the incomplete combustion of fuel. B10 and B15 are found to emit significantly lower CO concentration compared with that B5 fuel over both injection pressure. 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 CO_2. The reduction for smoke emission may attributed to its oxygen content and small particle diameter of the injected fuel at high injection pressure, thus more oxygen content will produce more C to CO, then decrease the smoke emission while increase the CO emission when ambient pressure increases.

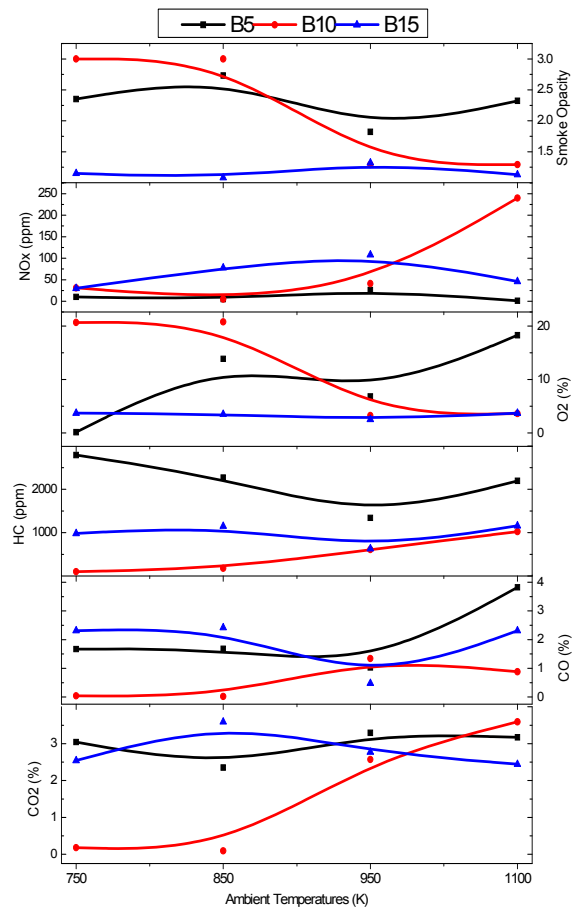

Figure-13. Effects of ambient temperature on emissions using B5, B10 and B10 under P_{inj} 80MPa.

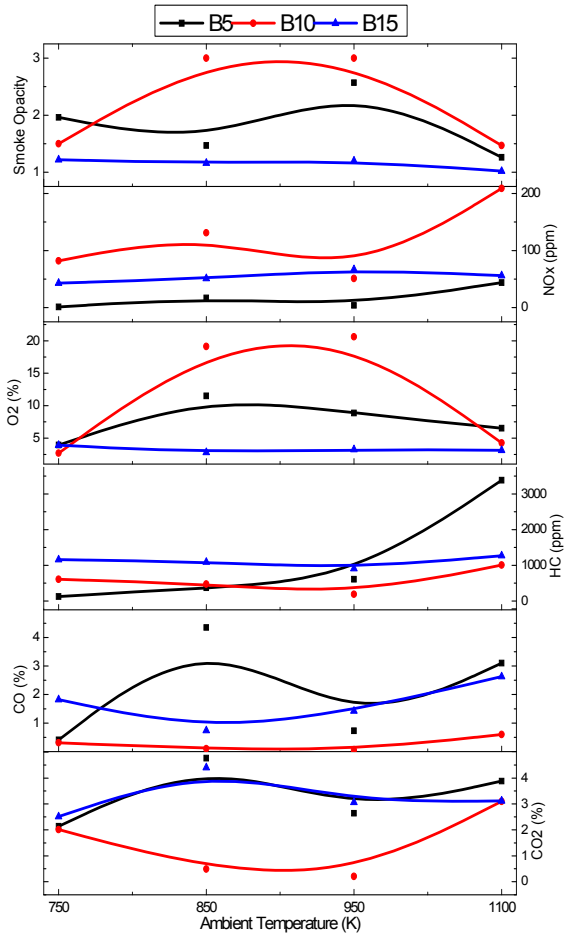

Figure-14. Effects of ambient temperature on emissions using B5, B10 and B10 under P_{inj} 90MPa.

CONCLUSIONS

The effect of injection pressure and ambient temperature on ignition delay and emission was investigated in a rapid compresion machine fuelled with different B5, B10 and B15 biodiesel. The following conclusions are drawn from this study:

a. The rapid compression machine is developed for fundamental studies of diesel combustion. Although the mechanism is very simple, the performance and the reliability is verified to be sufficient.
b. 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.
c. Short ignition delay results in decreased premixed combustion, which cannot provide enough energy for subsequent air-fuel mixing. While, 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.
d. Experimental ignition delay for the fuels were shortened under increasing initial ambient temperature conditions. Ignition delay for B10 and B15 fuel were shorter compared to B5 fuel.
e. The ignition delay difference between the all fuels becomes less apparent with increasing of ambient temperature. The combustion has a higher pressure at lower ambient temperature.The B5 fuel has a higher normalized peak pressure indicating a higher potential thermal efficiency.
f. 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.
g. Higher blending ratio from B5 to B15 increases the oxygen content which makes the combustion more complete, thus, promotes reduction of emissions specifically for CO, O_2, and HC but nevertheless, the NOx emission increases.

REFERENCES

Adam, Abdullah, Naoki Inukai, Yoshiyuki Kidoguchi, Kei Miwa, and Seiji Miyashiro. 2007. “A Study on Droplets Evaporation at Diesel Spray Boundary During Ignition Delay Period.” SAE Technical Papers 2007-01-1893.

Khalid, A., Tamaldin, N., Jaat, M., Ali, M.F.M., Manshoor, B., Zaman, I., “Impacts of Biodiesel Storage Duration on Fuel Properties and Emissions”, Procedia Engineering, Volume 68, 2013, Pages 225-230, Elsevier Ltd, DOI: 10.1016/j.proeng.2013.12.172.

Veltman, M.K., P.K. Karra, and S.-C. Kong, "Effects of Biodiesel Blends on Emissions in Low Temperature Diesel Combustion". SAE Technical Papers 2009-01-0485, 2009.

Anand, R., *et al*., "Performance Emission and Combustion Characteristics of a Diesel Engine Fueled with Biodiesel Produced from Waste Cooking Oil".SAE Technical Papers 2010-01-0478, 2010.

Khalid, A., Hayashi, K., Kidoguchi, Y., Yatsufusa, T., “Effect of air entrainment and oxygen concentration on endothermic and heat recovery process of diesel ignition”, SAE Technical Papers, 2011, Society of Automotive Engineers of Japan, Inc. and SAE International, DOI: 10.4271/2011-01-1834.

Khalid, Amir, Tomoaki Yatsufusa, Takayuki Miyamoto, Jun Kawakami, and Yoshiyuki Kidoguchi. 2009. “Analysis of Relation between Mixture Formation during Ignition Delay Period and Burning Process in Diesel Combustion.” SAE Technical Papers 2009-32-0019 / 20097018.

Khalid, A., Jaat, N., Sapit, A., Razali, A., Manshoor, B., Zaman, I., Abdullah, A.A., Performance and emissions characteristics of crude jatropha oil biodiesel blends in a diesel engine, International Journal of Automotive and Mechanical Engineering, Volume 11, Issue 1, Pages 2447-2457, 2015. DOI: 10.15282/ijame.11.2015.25.0206.

Al, Mohamed F, and S K Bhatti. 2014. "Experimental and Computational Investigations for Combustion, Performance and Emission Parameters of a Diesel Engine Fueled with Soybean Biodiesel-Diesel Blends." Energy Procedia 52: 421-30.

Kwon, Soon-ik. 1991. "Ignition Delay of a Diesel Spray Injected into a Residual Gas Mixture." SAE Technical Papers No 911841.

Khalid, A., "Effect of Ambient Temperature and Oxygen Concentration on Ignition and Combustion Process of Diesel Spray", Asian Journal of Scientific Research, Volume 6, Issue 3, 2013, Pages 434-444, Asian Network for Scientific Information, DOI: 10.3923/ajsr.2013.434-444.

Yamaki, Yoshihisa, Kazutoshi Mori, Hiroshi Kamikubo, Susumu Kohketsu, Kohji Mori, and Tetsuro Kato. 1994. "Application of Common Rail Fuel Injection System to a Heavy Duty Diesel Engine." SAE Technical Papers No 942294, no. 412.