IOP Conf. Series: Materials Science and Engineering **160** (2016) 012040 doi:10.1088/1757-899X/160/1/012040

Effect of High Injection Pressure of Algae and Jatropha Derived Biodiesel on Ignition Delay and Combustion Process

Nurdin Rahman [1,a] , Amir Khalid [1,b], Bukhari Manshoor[1] , Norrizam Jaat[1], Izzuddin Zaman[1] , Norshuhaila Sunar[2]

[1]Combustion Research Group (CRG), Centre for Energy and Industrial Environment Studies (CEIES), Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM)
[2] Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM)
E-mail : hd140042@siswa.uthm.edu.my[a], amirk@uthm.edu.my[b]

Abstract. This paper presents the investigation of the effect of high injection pressure on the ignition delay period and emission characteristics. Few experiments were conducted in a rapid compression machine (RCM). Four types of fuels were tested inside a RCM which are standard diesel (SD), Algae biodiesel (A2), Palm Oil biodiesel (B5, B10, and B15) and Jatropha biodiesel (J5, J10, J15). The experiments were conducted at high injection pressure of 130 MPa. The ambient temperature of constant volume chamber at the time of fuel injection was set at 850 K. The results indicate that the combined factors of specific of ambient temperature and higher injection pressure produces shorter ignition delay time. B5 has the shortest ignition delay with 1.5 ms. Biodiesel has the shorter ignition delay which is prolonged with increasing biodiesel content in the blends. In terms of emissions, Carbon dioxide (CO_2), Carbon monoxide (CO), hydrocarbon (HC) and smoke emissions decreased with all biodiesel–diesel blends. However, oxides of nitrogen (NOx) emission of the biodiesel was relatively higher than those of the diesel under all test conditions. In addition, the increase of blends in terms of biodiesel ratio was found to be significant in enhancing the combustion process.
Keywords: *Rapid Compression Machine, Ignition Delay, High Injection Pressure, Biodiesel*

1. Introduction

Nowadays, the price of gasoline and diesel has increased. One of the alternatives used to mitigate the issues is economic stability such as using biodiesel fuel. Biodiesel is a form of diesel fuel manufactured from animal fats or vegetable oils. It is safe, environmentally friendly, and also produces less air pollution than gasoline and diesel. Biodiesel can be used in pure form or blended with petroleum diesel [1-2]. The high viscosity of biodiesel is a problem to solve using swirl velocity, high injection and high pressure.

A rapid compression machine is an excellent tool to study the effect of the air-fuel ratio, O_2 concentration, and compression temperature on ignition delay and NO_x emissions, and to investigate the effect of temperature on the auto-ignition of combustible mixtures because it provides a direct measure of the ignition delay [3-5]. When there is a net heat release due to fuel

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

evaporation and heating, the effect of temperature on the ignition process being investigated until early pressure rise. Furthermore, this machine can remove the complexity and confusion that often occurs in the test engine. In the constant volume chamber, fuel combustion produces high temperatures and then high pressure gas development will occur [6-9].

During the combustion process, the period between the start of the injection and the first sign of ignition is called the ignition delay [10-12]. The ignition delay is very important for close control of the combustion process, also for the thermal performance and the gas emissions of the diesel engine. Ignition delay is major factor determining the rapid pressure rise in the initial burning stage and subsequent combustion. The ignition delay is not only directly affects the engine performance and combustion noise but also plays an important role in the formation of pollutants such as nitrogen dioxide and particulates [13-14].

The purpose of this paper is to investigate the effect of high injection pressure on the ignition delay period and emission characteristics. This experiment was performed in Rapid Compression Machine (RCM) with four types of fuels are standard diesel (SD), Algae biodiesel (A2), Palm Oil biodiesel (B5, B10, and B15) and Jatropha biodiesel (J5, J10, J15). The experiments were conducted at high injection pressure of 130 MPa.

2. Experimental Set Up

The rapid compression machine (RCM) used in the experiment is of a single cylinder, free moving piston and single shot commonrail injection system. The piston is pushed by the constant pressure of 19 MPa, which is the pressure used for all of the experiments run. The temperature of the combustion chamber in the RCM is heated to requirement conditions. Temperature of combustion chamber under normal condition is recorded as room temperature and was heat up to 850 K. Preparation and connection of all equipment such as piston, cylinder liner, combustion chamber, nitrogen gas, injector jigs and diaphragms must be done before run the experiment. All connections are seal tightly by using gasket to avoid leaking. Switch on the common rail and supply requirement pressure to the fuel injector that has been fixed at the opening of the combustion chamber. After few minutes, temperature of combustion chamber has reached its desired value. Also, make sure to switch on the controller, injector and EDU.

The enclosed air inside the RCM is compressed to a high temperature and pressure in a rapid process, about 20 ms to 40 ms and the reaction is allowed to progress in the constant volume chamber at the end of the compression stroke. At the end of the stroke, the piston is required to stop instantaneously. The piston would have to stop and get locked in the final position of the top dead centre (TDC). The pressure and voltage graph is automatically recorded using PICO 3000 series and transferred to the computer for visual. The data obtained then been saved into specified folders based on the conditions used for the test run. For gaining the exhaust emissions, open the exhaust valve to release the emission and to release the pressure inside the combustion chamber. Disconnect all connection such polycarbonate, injector jig and cylinder liner. After all data have been received and saved, all the equipment need to clean up and prepare for next experiment. The experiment will be done and repeated with injection pressure of 130 MPa for 4 types of fuel such as standard diesel SD, Algae biodiesel A2 (2 vol%), Palm Oil biodiesel B5 (5 vol%), B10 (10 vol%), B15 (15 vol%) and Jatropha biodiesel J5 (5 vol%), J10 (10 vol%), J15 (15 vol%).

This research is aimed to analyze the ignition delay and emission under high injection pressure at ambient temperature conditions. The injection pressure used is 130 MPa while the temperature for combustion chamber was set at 850 K. The ignition delay period is gained at the pressure-time graph obtained at the end of experiment when the combustion process occurs. It takes several milliseconds for the combustion process in the combustion chamber to occur just as the injector injects fuel into the combustion chamber.

The emissions can be obtained after the combustion process in the rapid compression machine ends. The part where the taken of the emissions after combustion is crucial for later analyzing. The emissions are in the form of carbon dioxide (CO_2), carbon monoxide (CO), hydro carbon (HC) and the nitrogen oxide (NO_x). Table 1 shows the properties of test fuels and Table 2 shows the experimental conditions. Figure 1 has shown a schematic diagram of rapid compression machine (RCM) system.

Table 1 : Test Fuel Properties

Fuel Type	Properties	
	Density (g/m^3)	Kinematic Viscosity (Cp)
Standard diesel SD	0.8458	5.05
Algae biodiesel A2	0.8427	3.76
Palm Oil biodiesel B5	0.8370	3.01
Palm Oil biodiesel B10	0.8380	3.04
Palm Oil biodiesel B15	0.8480	3.11
Jatropha biodiesel J5	0.8163	4.55
Jatropha biodiesel J10	0.8173	4.62
Jatropha biodiesel J15	0.8183	4.72

Table 2 : Experimental Conditions

Fuel	Injector type	6 holes, Ø = 0.16 mm
	Fuel type	Standard Diesel SD , Algae Biodiesel A2, Palm Oil Biodiesel (B5, B10, B15) and Jatropha Biodiesel (J5, J10, J15)
	P_{inj} [MPa]	130
	Fuel quantity q_i [ml]	0.04
Ambient gas	Ambient Temperature T_i [K]	850
	Swirl velocity r_s [m/s]	19
	Air Density ρ [kg/m^3]	16.6
	O_2 [vol%]	21

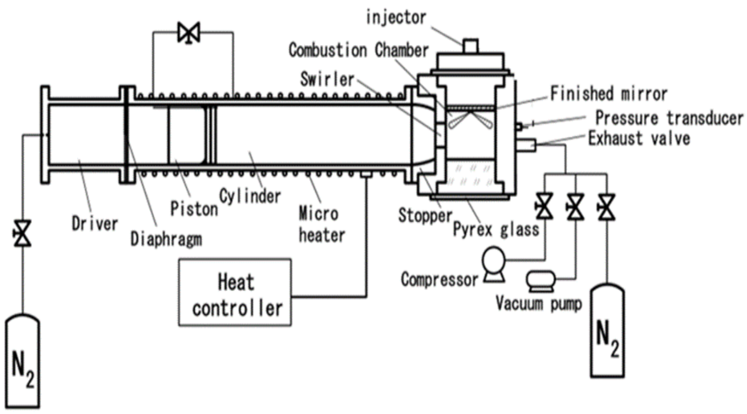

Figure 1: Schematic diagram of RCM

3. Result And Discussions

The Effect of High Injection Pressure on Ignition Delay

The effect of high injection pressure on ignition delay in combustion chamber of rapid compression machine (RCM) was investigated. Figure 2 shows the comparison of combustion process graph of standard diesel SD, algae biodiesel A2, palm oil biodiesel B5, B10 and B15 at ambient temperature, T_i of 850 K with the injection pressure, P_{inj} at 130 MPa. It was observed that the standard diesel SD had a slightly longer ignition delay with 2.40 ms compared to algae biodiesel A2 palm oil biodiesel B10 and B15 with ignition delay 2.10 ms, 2.20 ms and 2.30 ms, while palm oil biodiesel B5 has the shortest ignition delay with 1.50 ms.

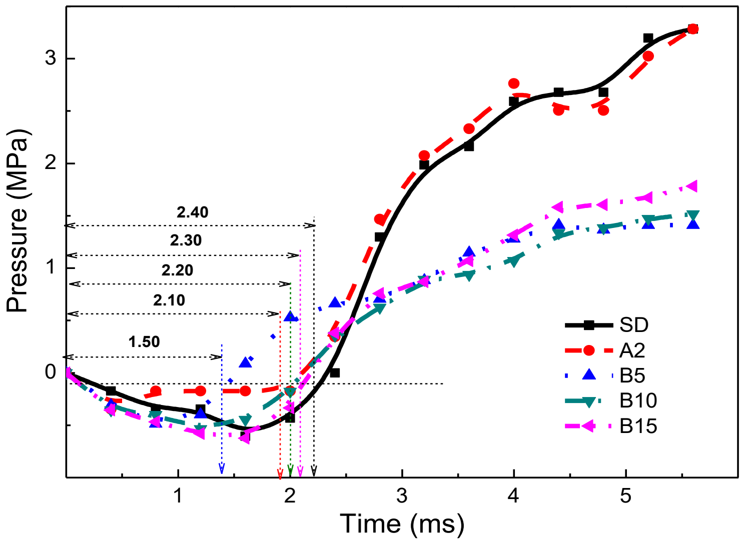

Figure 2: The effect of high injection pressure on ignition delay for variants fuel (SD, A2, B5, B10 and B15).

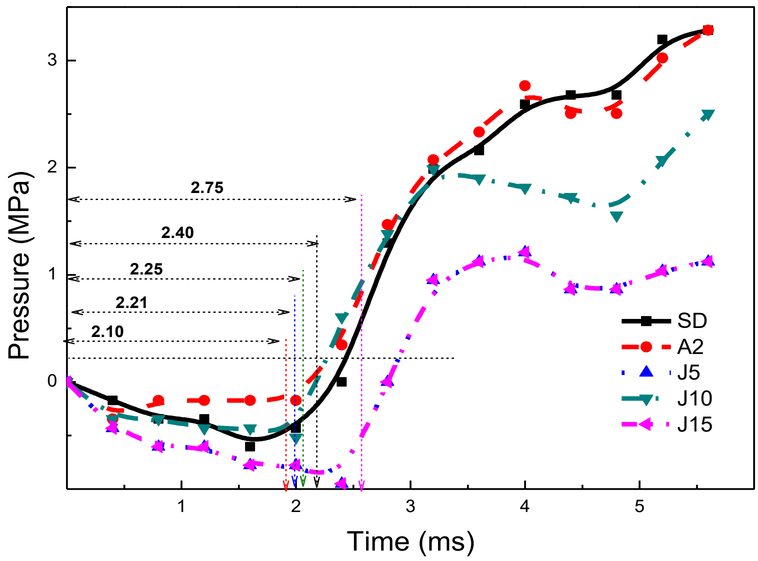

Figure 3: The effect of high injection pressure on ignition delay for variants fuel (SD, A2, J5, J10 and J15).

Figure 3 shows the comparison of combustion process graph of standard diesel SD, algae biodiesel A2 and jatropha biodiesel J5, J10 and J15 at ambient temperature, T_i of 70^0C and the injection pressure, P_{inj} at 130 MPa. The initial combustion rates for all types of biodiesel were nearly identical. It was observed that the algae biodiesel A2 and jatropha biodiesel J10 had a slightly shorter ignition delay compare with standard diesel SD with 2.10 ms and 2.25 ms. But jatropha biodiesel J5 and J15 had a slightly longer ignition delay with 2.73 ms and 2.75 ms. From the Figure 2 and Figure 3, it can be seen that the combustion had a slightly higher pressure in the combustion chamber. This is shown that at high injection pressure, biodiesel has produced shorter ignition delay compared to standard diesel SD. Furthermore, higher injection pressures generate faster combustion rates and this tends to vaporize the fuel spray so quickly that the fuels cannot penetrate deeply into the combustion chamber.

The Effect of High Injection Pressure on Emission

Figure 4 shows that standard diesel SD has carbon dioxide (CO_2) substances readings 3.48 %. Algae biodiesel A2, jatropha biodiesel J5 and palm oil B5 have slightly same figure with 4.06%, 3.92% and 4.11% of CO_2. Meanwhile, jatropha biodiesel J10, J15, palm oil B10 and B15 have low of CO_2 content with 2.41%, 2.33%, 2.47% and 2.38% of CO_2. This figure has shown that at high injection pressure high blended biodiesel produced less CO_2 compare with low blended biodiesel.

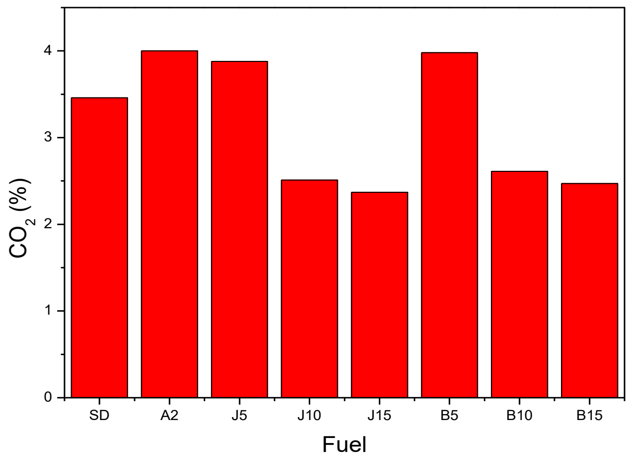

Figure 4: The effect of high injection pressure on CO_2 emission for variants fuel (SD, A2, B5, B10, B15, J5, J10 and J15).

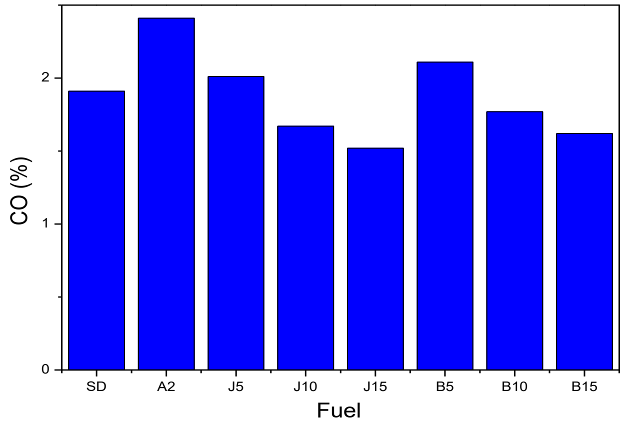

Figure 5: The effect of high injection pressure on CO emission for variants fuel (SD, A2, B5, B10, B15, J5, J10 and J15).

Figure 5 shows the standard diesel SD has carbon monoxide (CO) substances readings with 1.89 %. Algae biodiesel A2 has the highest CO with 2.45%. Jatropha biodiesel J5, J10 and biodiesel B5, B10, B15 have slightly same figure with 1.91%, 1.61%, 2.01%, 1.78% and 1.67% of CO. Meanwhile, Jatropha biodiesel J15 has the lowest of CO content with 1.52%.Carbon monoxide (CO) emissions occur due to the incomplete combustion of fuel. High blended biodiesel were found to emit significantly lower CO concentration compared with low blended biodiesel over high 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.

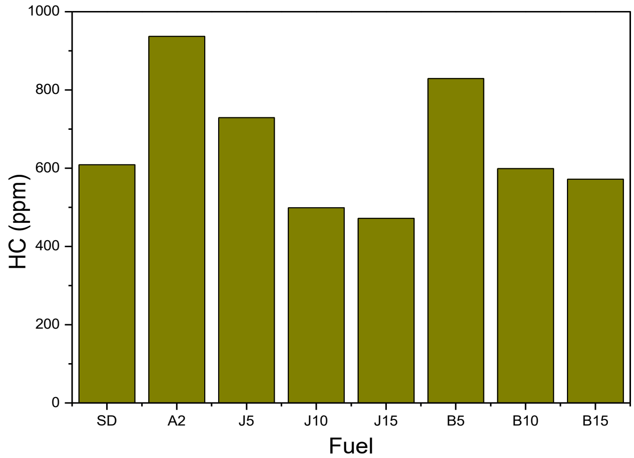

Figure 6: The effect of high injection pressure on HC emission for variants fuel (SD, A2, B5, B10, B15, J5, J10 and J15).

Figure 6 also shows that at high injection pressure, standard diesel SD has hydrocarbon (HC) substances readings with 602 ppm. Algae biodiesel A2, Jatropha biodiesel J5 and palm oil biodiesel B5 have higher HC compared with standard diesel SD with 932 ppm, 699 ppm and 786 ppm. Meanwhile, Jatropha biodiesel J10, J15 and palm oil biodiesel B10, B15 has lower of HC content compared with standard diesel SD with 442 ppm, 422 ppm, 586 ppm and 569 ppm. HC is an important parameter for determining the emission behavior of the engine. High blended biodiesel gives lower HC emission as compared to low blended biodiesel. This is due to 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.

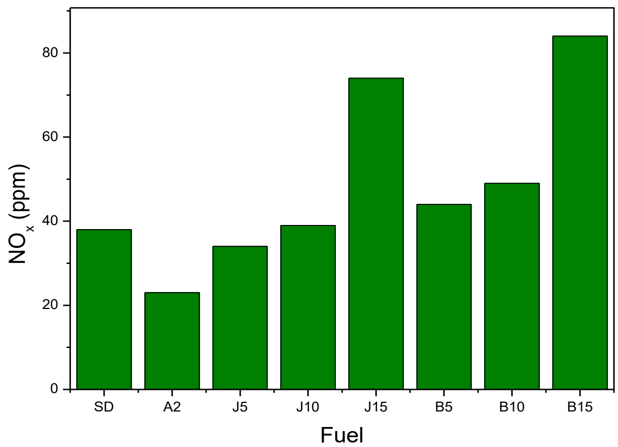

Figure 7: The effect of high injection pressure on NOx emission for variants fuel (SD, A2, B5, B10, B15, J5, J10 and J15).

For injection pressure P_{inj} 130 MPa, standard diesel SD has nitrogen oxides (NO_x) substances readings with 39 ppm as shown in Figure 7. Algae biodiesel A2 and jatropha biodiesel J2 have low NOx compared with standard diesel SD with 22 ppm and 32 ppm. Meanwhile, jatropha J10, J15 and palm oil biodiesel B5, B10, B15 have high of NO_x content with 40 ppm, 73 ppm, 42 ppm, 46 ppm and 82 ppm. It is shown that high blended biodiesel produced higher NO_x content at high injection pressure compared with low blended biodiesel. NO_x 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 NO_x emissions [12]. It will decrease as the ambient temperature increase because of shorter ignition delay inside combustion chamber. The NO_x emission increasing as the injection pressure increases. Higher blends will result in higher NO_x.

Conclusion

A rapid compression machine has been used to investigate the influence of high injection pressures on ignition delay and combustion process. The ignition delay have been taken at various types of fuels. Biodiesel fuel used were standard diesel SD, Algae biodiesel A2, Palm Oil biodiesel (B5, B10, B15) and Jatropha biodiesel (J5, J10, J15).

Results at high injection pressure at 130 MPa, the ignition delay becomes short. This is because ignition occurs near the injector nozzle, thus the initial combustion rate becomes low and the combustion duration became longer. This will produce complete combustion process, more fuel vaporization and good fuel conversion efficiency. Short ignition delay results in decreased premixed combustion, which cannot provide enough energy for subsequent air-fuel mixing. The ignition delay difference between the biodiesel blended becomes less apparent with increasing of density of the fuels. The combustion has a higher pressure at higher ambient temperature.

Biodiesel fuel reduces the exhaust emission at high injection pressure such as CO_2, CO, and HC but increases the NOx emission due to shorter ignition delay. This is because short ignition delay increased premixed combustion, which provides 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. Higher blending ratio increases the oxygen content which makes the combustion more complete, thus, promotes reduction of emissions specifically for CO_2, CO, and HC but nevertheless, the NOx emission increases.

Acknowledgements

The authors also would like to thank the Ministry of Higher Education, Malaysia for supporting this research under Fundamental Research Grant Scheme (FRGS)(Vot 1466).

References

[1] Wilbur, A. A. (1974) "*Ignition Studies-The Determination of Auto Ignition Temperatures of Hydrocarbon Fuels."* Naval Research Laboratory, Washington DC.

[2] Somnuek Jaroonjitsathian, Nirod Akarapanjavit, Somchai Siang Sa-norh, Ratanavalee In-ochanon, Arunratt Wuttimongkolchai and Chonchada Tipdecho "*Evaluation of 5 to 20% Biodiesel Blend on Heavy-duty Common-rail Diesel Engine".* PTT Research and Technology Institute, PTT Public Company Limited (Thailand).

[3] 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

[4] Khalid, A., Yatsufusa, T., Miyamoto, T., Kawakami, J., Kidoguchi, Y., "Analysis of relation between mixture formation during ignition delay period and burning process in diesel combustion", SAE Technical Papers, 2009, SAE International.

[5] Mittal. G., "*A Rapid Compression Machine* – Design, Characterization, and Auto Ignition Investigations" Department Of Mechanical and Aerospace Engineering, Case Western Reserve University. 2006
[6] Lyn,W and Valdmanis " *The Effect of Physical Factors on Ignition Delay*" 1968.
[7] M. P. B. Musculus, T. Lachaux, L. M. Pickett, and C. a Idicheria, "Hydrocarbon Emissions in Low-Temperature- Combustion Diesel Engines," vol. 2007, no. 724, pp. 776–790, 2007.
[8] S. Kook, L. M. Pickett, and M. P. B. Musculus, "*Influence of Diesel Injection Parameters on End-of-Injection Liquid Length Recession*," SAE Int. J. Engines, vol. 2, no. 1, pp. 1194–1210, 2009.
[9] Kuti, O.A., Zhua, J., Nishidaa,K., Wang, X., Huang, Z. "*Characterization of spray and combustion processes of biodiesel fuel injected by diesel engine common rail system*". 104, 838 – 846, 2013.
[10] 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
[11] Phan, Anthony, (2009) "*Development of a Rate of Injection Bench and Constant Volume Combustion Chamber for Diesel Spray Diagnostics*", Graduate Theses and Dissertations. Paper 10691.
[12] A. Khalid, N. Jaat, A. Sapit, A. Razali, B. Manshoor, I. Zaman and A.A. Abdullah, "Performance And Emissions Characteristics Of Crude Jatropha Oil Biodiesel Blends In A Diesel Engine", International Journal of Automotive and Mechanical Engineering (IJAME) ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 11, pp. 2447-2457, January-June 2015, DOI: http://dx.doi.org/10.15282/ijame.11.2015.25.0206.
[13] Dhandapani Kannan, Md. Nurun Nabi and Johan Einar Hustad. (2009). "*Influence of Ethanol Blend Addition on Compression Ignition Engine Performance and Emissions Operated with Diesel and Jatropha Methyl Ester*". Norwegian University of Science and Technology.
[14] Bhatti, S K, Al, Mohamed F "*Experimental and Computational Investigations for Combustion , Performance and Emission Parameters of a Diesel Engine Fueled with Soybean Biodiesel-Diesel Blends*" Energy Procedia, Volume 52, Page 421-430, 2014