



Numerical Analysis of Combustion and Performance Characteristics of a Compression Ignition Engine Fuelled with Orange Peel Oil Based Biodiesel and its Blends under Varying Compression Ratio

Philip Adebayo and Samson Fasogbon

Department Mechanical Engineering, University of Ibadan, Ibadan, Nigeria
adebayophilip947@gmail.com (Philip Adebayo)

ABSTRACT

Fuel efficiency has been found to be affected by compression ratio in internal combustion engines. Information is however scanty on its effect on combustion and performance characteristics of Internal Combustion (IC) engines. This work therefore investigated combustion variables such as cylinder pressure, heat release fraction, ignition delay and heat transfer and performance characteristics such as brake power, volumetric efficiency and Brake Specific Fuel Consumption (BSFC) in compression ignition engine fuelled with orange peel oil based biodiesel and its blends under variable compression ratio. The research employed the use of Diesel-RK software in investigating the performance and combustion characteristics of a four stroke, single cylinder, water cooled, direct ignition, compression ignition engine fuelled with orange peel oil based biodiesel and its blends (B10, B20, B30, B40, B50, B60, B70, B80, B90) under varying compression ratios of 16, 17 and 18 at varying engine speed of 1500 rpm to 3500rpm. The result showed appreciable increase in cylinder pressure, heat release rate, brake power for orange peel oil based biodiesel and its blends at higher compression ratio and decrease in brake specific fuel consumption, ignition delay and volumetric efficiency. Consequently, it was concluded that orange peel oil based biodiesel and its blend could have better combustion and performance characteristics at higher compression ratio.

Key words: Internal combustion engine, compression ratio, combustion characteristics, performance characteristics, diesel-RK software, orange peel oil based biodiesel

INTRODUCTION

An internal combustion engine (ICE) is a heat engine where the combustion of a fuel occurs within the engine itself. ICE takes in air and mixes with a measured quantity of fuel which burn within the engine. This produces a high temperature and pressure gases containing high energy which apply direct force to some component of the engine. The force can be applied to pistons as in reciprocating engines which move the component over a distance, transforming chemical energy into useful mechanical energy. Typically, an ICE is fed with fossil fuels like natural gas or petroleum products such as Premium Methylated Spirit (PMS) also called Gasoline, Automotive Gas Oxide (AGO) also called diesel. There is increasing usage of renewable fuels like biodiesel for compression ignition engines and bioethanol or methanol for spark ignition engines.

The research and development in finding alternatives for fossil fuel has majorly been on fuel from renewable resources such as biofuel that are friendly to the environment. Fossil fuels when burnt release greenhouse gases like carbon dioxide to the atmosphere that raises the temperature and causes global warming. Apart from the global warming effect of fossil fuel, it has been reported that the availability of fossil fuel is decreasing and in few years to come, fossil fuel may not be readily available. Many people have adopted the use of biofuels in order to protect the environment from heating up. Biodiesel is considered as one of the most promising alternative fuels, which is available, viable, environmentally friendly that can be used as a substitute to Diesel fuel and enables a reduction of greenhouse gas emissions. In addition to reducing greenhouse effect, there is also a need to improve the performance and combustion characteristics of a compression ignition engine fuelled with biodiesel. There are a lot of studies in the literature that compared the result from a compression ignition engine fuelled with biodiesel from different source with Diesel. The optimum operating

parameters can be determined using experimental techniques which will be time consuming and expensive. Numerical investigation allows examining the effects of various parameters and reduced the need for experimental analysis of the engine. Numerical investigation involves the use of computer simulation for better understanding of the variables involved and also helps in optimizing the engine design for a particular application thereby reducing cost and time.

The research on the use of biodiesel for internal combustion engine especially compression ignition engine is on the increase. Biodiesel has been found to be the promising alternative fuel for combating problem of depletion of fossil fuel and global warming. Biodiesel source from Vegetable oil, rape seed oil, cotton seed oil, jatropha seed, orange peel oil as well as their blends, has been used to investigating the performance, combustion and emission parameters in a diesel engine with focus on improving the parameters such that biodiesel will be able to perform just like diesel fuel. Other alternate source especially from alcohol group such as ethanol and butanol has also been investigated in a diesel engine. Phate and Kulkarni [1] reviewed the experimental investigations of the suitability of orange peel oil as a blend with cotton seed oil as alternative fuel for diesel engine. It was reported that the performance carried out on various blends (orange peel and cotton seed oil) showed the same trend as the orange peel oil base biodiesel and consequently concluded that the usage of orange peel oil and cotton seed oil blend will be optimum compared to mineral diesel.

The impact of compression ratios on the combustion and performance parameters was clearly investigated in the study of Hariram, V. and Bharathwaaj, R. [2] over the entire loading conditions at various compression ratios. It was reported that maximum rate of pressure rise in the cylinder reduced with reduction of compression ratio and the Cumulative heat release was higher for higher loads at higher compression ratio. Increase of the compression ratio from 16 to 18 decreased the Break Specific Fuel Consumption while it increased the Break Thermal Efficiency. Senthil R. et al. [3] studied the influence of injection timing and compression ratio on performance, emission and combustion characteristics of annona methyl ester operated diesel engine. The compression ignition engine was run with 20% of annona methyl ester blend with diesel fuel and under different compression ratio (16.5, 17.5, 18.5, 19.5, and 20.5) and injection timings (24, 27, 30 and 33 before Top Dead Center (bTDC) in order to evaluate the combustion, performance and emission characteristics at 50% load. It was reported that 30°bTDC along with compression ratio of 19.5 gave better performance, combustion and lower emissions when compared with standard injection timing of 27°bTDC and compression ratio of 17.5. For all tested values, A20 (20% Annona methyl ester blend with diesel) was observed to provide the best result in terms of Break Thermal Efficiency (BTE), higher heat release rate. Hence, it was concluded that A20 can be efficiently used as an alternative biodiesel with injection timing of 30°bTDC along with compression ratio of 19.5 in tested engine.

Numerical tools helps in understanding better the design variables of an internal combustion engine and also helps in optimizing the engine design for a particular application which reduces the cost. It allows examining the effects of various parameters and minimizes the need for complex experimental analysis of the engine. Sanjay Patil, S. and Akarte, M. M. [4] studied the performance characteristics of CI engine fuelled with Biodiesel (palm oil methyl ester) and its blends by simulation using thermodynamics model programmed in MATLAB. They developed the model in such a way that it could be used for characterizing any hydro-carbon-fuelled engines (diesel, biodiesel or their blends.). They reported that increasing the compression ratio led to an increase in the peak pressure and the brake thermal efficiency; increased air-fuel ratio reduced the peak pressure and brake thermal efficiency as a result of closer approximation of the model. The model was validated with the experimental result of the engine fuelled with B0, B40, and B100. It was concluded that the model is safe for use for the prediction of performance characteristics of the compression ignition engine fuelled by any type of hydrocarbon fuel.

Ebaid A. [5] employed the use of diesel-RK software to study the prediction of Nox emission in a biofuel fuelled diesel engine and compared with a diesel engine fuelled with diesel fuel. He reported that higher compression ratio gave higher cylinder pressure, heat release rate as well as slower ignition delay. Hence, Nox emission was reported to increase due to higher pressure and temperature. El-Kassaby and Nemit-Allah [6] also studied the effect of varying compression ratio on a four-stroke, single cylinder, direct injection engine fuelled with waste oil produced biodiesel/diesel fuel. They were able to find out that the increased blend and compression ratio led to increase and decrease in the BSFC respectively. Also, it was reported that the brake thermal efficiency of diesel engine tested was reduced when substituting diesel by biodiesel in its blended form and the change of compression ratio from 14 to 18 resulted in increased brake thermal efficiency. In the work of Attri, V. K. *et al.*[7], the effect of varying compression ratio was also studied on the Performance and Emissions of Diesel on a Single Cylinder Four Stroke Variable Compression ratio (VCR) Engine, it was reported that the compression ignition engine at compression Ratio 17 gave the best result in performance in Brake specific fuel consumption, Brake Thermal efficiency and Exhaust gas temperature in comparison of other compression ratio used.

METHODOLOGY

In the present work, the combustion and performance characteristics of a single cylinder, four stroke, naturally aspirated and direct injection test engine of Kirloskar make was studied with Diesel-RK software at different blend ratio and compression ratio of 16, 17 and 18. The engine is water cooled with power rating of 3.5KW at 1500RPM. The specification of the engine used is summarized in table 1 while the physiochemical properties of fuel used is given by table 2.

Table-1 Specifications of the Engine

Engine	Four stroke, single cylinder, water cooled, direct injection diesel engine
Rated power	3.5 KW
Speed	1500 rpm
Bore	87.5 mm
Stroke	110 mm
Compression ratio	16-18
Injection timing	23°C
Injector pressure	200 bar
Swept volume	661cc
Number of nozzle	3
Connecting rod	230mm

Table -2 Physical properties of Fuel

Properties	Diesel	Orange Peel Oil based Biodiesel
Density (kg/m ³)	830	886
Viscosity (Pa.s)	3.6	1.9
Flash point (°c)	45	84
Calorific Value (MJ/Kg)	42.5	38.4
Cetane number	48	54.4

The Diesel-RK software is a professional thermodynamic full-cycle engine simulation software. The parameters of fuel in the cylinder of an engine are defined by step by step solution of the system of differential equations of conservation of energy, mass and equation of state for open thermodynamic systems. The inputs to the software were the engine specification as defined in table 1 and fuel properties as described by table 2. The properties of the various blend used in this work were gotten by interpolating between the properties of the two known fuel based on the observation by most researchers that fuel properties of blends varies linearly. The combustion parameters studied by the Diesel-RK software are cylinder pressure, heat release rate, ignition delay, heat release fraction while the performance parameters studied include Brake specific Fuel consumption, (BSFC), Brake Power and volumetric efficiency at a speed range of 1500 to 3500 rpm.

THEORETICAL BASIS

The software assumed an open system which involves mass flow and the governing equations are defined by equation (1) to equation (19) taken from [8] to [11]. To conserve mass in the system, rate of change of total mass is equal to the sum of mass flow into and out of the system. Mathematically, conservation of mass can be written as

$$\frac{dm}{dt} = \sum_j \dot{m}_j \quad (1)$$

$\frac{dm}{dt}$ is the rate of change of mass with time; \dot{m}_j is the mass flow rate of species

Conservation of energy: the generalized equation for an open system can be written as

$$\frac{dU}{dt} = \frac{dQ}{dt} - p \frac{dV}{dt} + \sum_j \dot{m}_j h_j \quad (2)$$

$\frac{dU}{dt}$ is the rate of change of Internal energy with time; $\frac{dQ}{dt}$ is the rate of change of total heat transfer to the system with time;

$p \frac{dV}{dt}$ is the work transfer rate out of the system; P is the cylinder pressure; $\frac{dV}{dt}$ is the rate of change of volume with time;

$\sum_j \dot{m}_j h_j$ is the enthalpy flux.

$$\frac{dQ}{dt} = \frac{dQ_{ch}}{dt} - \frac{dQ_{ht}}{dt} \quad (3)$$

The rate of total heat transfer is the difference between the rate of heat generated by the fuel due to combustion and the rate of heat transferred to the cylinder wall due to in cylinder gases.

$$\frac{dU}{dt} = MC_v \frac{dT}{dt} \quad (4)$$

Equation (4) defines the internal energy generated in the system. The rate of change of internal energy is a function of in cylinder instantaneous mass (M), Specific heat of gases at constant volume (C_v) and temperature (T)

Substituting (3) and (4) into (2)

$$MC_v \frac{dT}{dt} = \frac{dQ_{ch}}{dt} - \frac{dQ_{ht}}{dt} - p \frac{dV}{dt} + \sum_j \dot{m}_j h_j \quad (5)$$

The above equation can also be written as a differential equation varying with the crank angle.

$$M C_v \frac{dT}{d\theta} = \frac{dQ_{ch}}{d\theta} - \frac{dQ_{ht}}{d\theta} - p \frac{dV}{d\theta} + \sum_j \frac{dm_j}{d\theta} h_j \quad (6)$$

The above equation can be solved using methods to get cylinder pressure and temperature. The last term in the equation is often assumed to be negligible.

The heat transfer rate which is often calculated in terms of mass of burnt gas; it is given by wiebe function as

$$x_b(\theta) = 1 - \exp \left[-a \left(\frac{\theta - \theta_o}{\Delta\theta} \right)^{m+1} \right] \quad (7)$$

Where x_b is the mass of burnt gas; a is the parameter which characterizes the completeness of combustion and is given as $a=6.908$; m characterizes the rate of combustion; θ_o is the crank angle at which combustion starts and $\Delta\theta$ is the total crank angle for the period of the combustion.

The rate of change of combustion of fuel with respect to the crank angle can be taken as

$$\frac{dQ_{ch}}{d\theta} = m_f Q_{LHV} \eta_c \frac{dx_b}{d\theta} \quad (8)$$

Where m_f is the mass of the fuel; Q_{LHV} is the lower heating value of the fuel; η_c is the combustion efficiency and $\frac{dx_b}{d\theta}$ is the rate of change of mass of fuel burnt with crank angle.

The rate of change of the Volume with crank angle is given as

$$V(\theta) = V_c \left[1 + \frac{1}{2}(\varepsilon - 1)(R + 1 - \cos \theta) - (R^2 - \sin^2 \theta)^{1/2} \right] \quad (9)$$

Where V_c is the swept volume, ε is the compression ratio given as

$$\varepsilon = \frac{V_s + V_c}{V_c} \quad (10)$$

R is the ratio of connecting rod length to crank radius i.e $R = \frac{l}{a}$

Diesel Rk software employs Woschni heat transfer model for modeling heat transfer rate. Rate of heat transfer with respect to the crank angle is given as

$$\frac{dQ_{ht}}{d\theta} = h_c A(\theta) (T_g - T_w) \left[\frac{1}{\omega} \right] \quad (11)$$

$A(\theta)$ is the combustion chamber surface area at any crank position and it is given as

$$A(\theta) = A_{ch} + A_p + \frac{\pi B S}{2} [R + 1 - \cos \theta - (R^2 - \sin^2 \theta)^{1/2}] \quad (12)$$

Where A_{ch} is the cylinder head surface area, A_p is the piston crown area given as $A_p = \frac{\pi B^2}{4}$

R is the ratio of connecting rod length to crank radius and B is the bore and S is the stroke length.

T_g is the gas temperature in the cylinder; T_w is the temperature of the cylinder wall and ω is the speed of crankshaft in rad/s. The convective heat transfer (h_c) is given by Woschni model as

$$h_c = 3.26 D^{-0.2} p^{0.8} T_g^{-0.55} w^{0.8} \quad (13)$$

D is the cylinder diameter (Bore), p is the cylinder pressure, T_g is the gas temperature in the cylinder and w is the velocity of the burned gas and is given as

$$w(\theta) = 2.28 \bar{S}_p + C_1 \frac{V_d T_{gr}}{P_r V_r} (P(\theta) - P_m) \quad (14)$$

V_d , P_r , V_r and T_{gr} are displaced volume, working fluid pressure, volume and temperature at some reference state at closing of inlet valve. P_m is the pressure motored cylinder pressure (pressure value in cranking). For compression process, constant $C_1 = 0$, while for combustion and expansion processes, $C_1 = 0.00324$.

\bar{S}_p is the mean piston speed given as

$$\bar{S}_p = \frac{2NS}{60} \quad (15)$$

Where S is the engine stroke and N is the speed of rotation of the crankshaft.

Ignition delay Model: ignition delay is defined as the time or crank angle interval between the start of injection and start of combustion. The ignition delay model used in this work is that of modified Tolstov's model and it is given as

$$t_{iT} = 3.8 * 10^{-6} (1 - 1.6 * 10^{-4} n) \left[\frac{T}{P} \right]^m \exp \left[\frac{E_a}{8.3127 T} \right] C_c C_T \quad (16)$$

Where t_{iT} is the ignition delay period; C_T is the correction factor accounting for the temperature growth rate during the ignition delay period; C_c is the correction factor accounting for the concentration of combustion products during the ignition delay period; m depends on the current cylinder pressure and is given as $m = \text{MAX}(0.5, (0.64 - 0.035p))$; E_a is the activation energy in the ignition process; n is the engine speed in RPM; T and P are the current cylinder temperature (K) and pressure (MPa) respectively

The parameters that are used in Diesel RK software to determine the performance of the engine include: brake power, brake specific fuel consumption, volumetric efficiency, brake torque and brake effective mean pressure. In this study, much concentration was given to brake power, brake specific fuel consumption and volumetric efficiency.

Brake power (P_b) is the product of Engine torque (T) and rotational speed (ω)

$$P_b = T\omega \quad (17)$$

Brake Specific Fuel Consumption is the fuel flow rate (\dot{m}_f) per unit power output. It measures the efficiency of an engine in using fuel supplied to produce work.

$$SFC = \frac{\dot{m}_f}{P} \quad (18)$$

Volumetric efficiency (n_v) is the ratio of the quantity of air and fuel that enters the cylinder during induction to the actual capacity of the cylinder under static condition. It is used to measure the effectiveness of the induction process.

$$n_v = \frac{nm_a}{p_a V_c N} \quad (19)$$

n is the number of revolution of crankshaft per cycle; m_a is the mass of air induced into the system per cycle; p_a is the air density; V_c is the piston displaced volume per cylinder; N is the engine speed

RESULTS AND DISCUSSION

Diesel-RK software has been used for investigating the combustion and performance characteristics of a compression ignition engine fuelled with orange peel oil based biodiesel and its blends. Blend of B10, B20, B30, B40, B50, B60, B70, B80, B90 as well as pure biodiesel (B100) and diesel has been used in this work. The result generated is presented inform of a graph with the cylinder pressure, heat release rate and heat release fraction plotted against crank angle while ignition delay, brake power, brake specific fuel consumption and volumetric efficiency are plotted against varying engine speed between the range of 1500-3500 rpm.

Cylinder Pressure

Fig 1, 2 and 3 shows the variation of cylinder pressure against the crank angle for compression ratio of 16, 17 and 18 respectively. A similar trend of variation of cylinder pressure with the crank angle was observed for pure orange peel oil based biodiesel and its blends as well as for diesel fuel. Also, the peak cylinder pressure can be seen to be increasing with increasing compression ratio for all tested fuel. Peak cylinder pressure increased by 8.44%, 7.36%, 7.41%, 7.75%, 7.91%, 7.78%, 8.05%, 8.05%, 8.17%, 8.15% and 7.94% for diesel, B10, B20, B30, B40, B50, B60, B70, B80, B90 and pure biodiesel (B100) respectively as the compression ratio increased from 16 to 17 while for an increment of compression ratio from 16 to 18, an increment of 14.39%, 15%, 15.15, 15.54%, 15.55%, 15.86%, 16.08%, 16.37%, 16.87%, 16.67% and 16.43%. It can be seen that biodiesel and its blends can perform better at higher compression ratio as a result of better and rapid combustion.

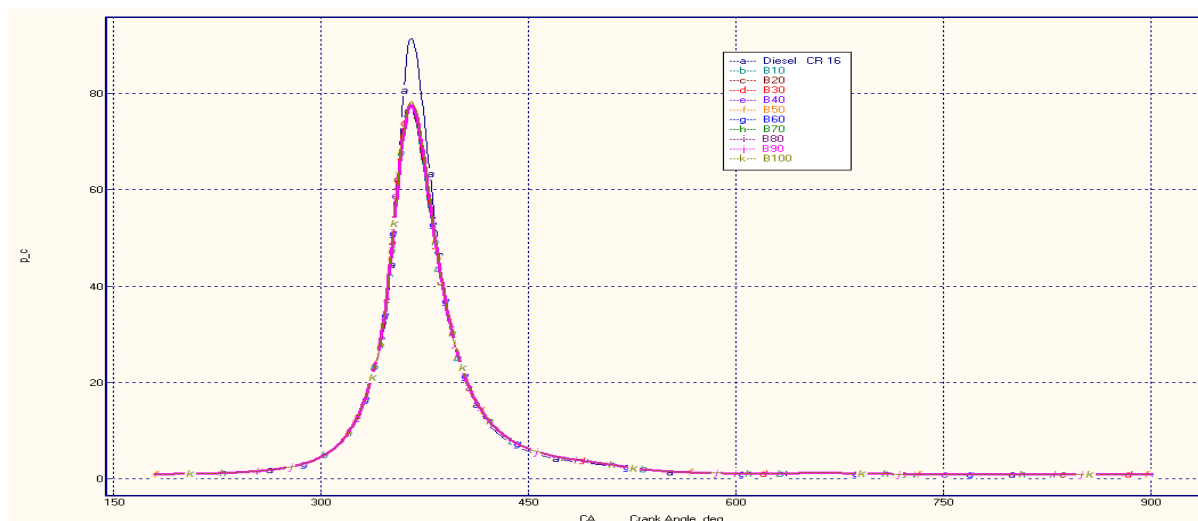


Fig. 1 Cylinder Pressure against crank angle at a compression ratio of 16

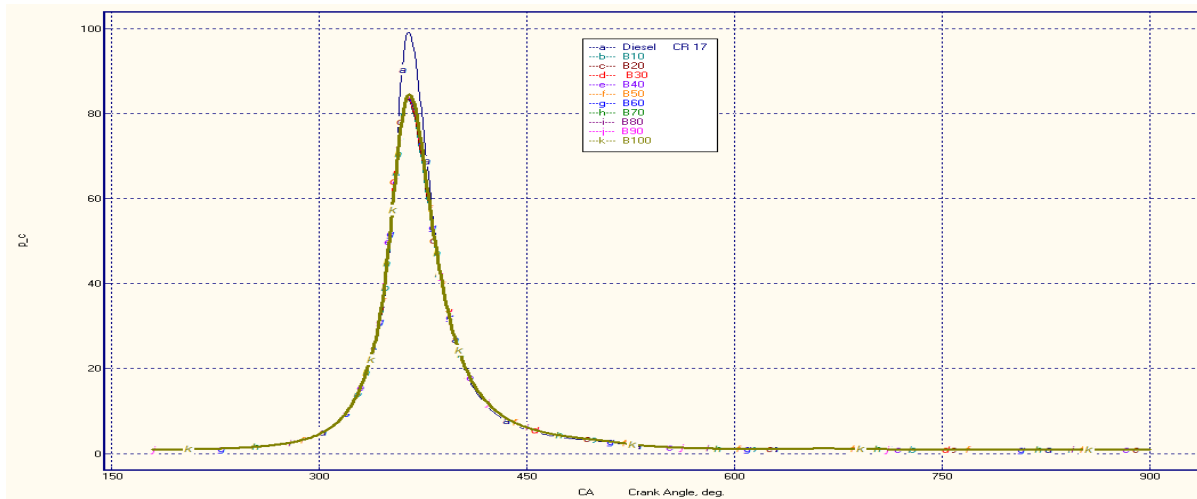


Fig. 2 Cylinder Pressure against crank angle at a compression ratio of 17

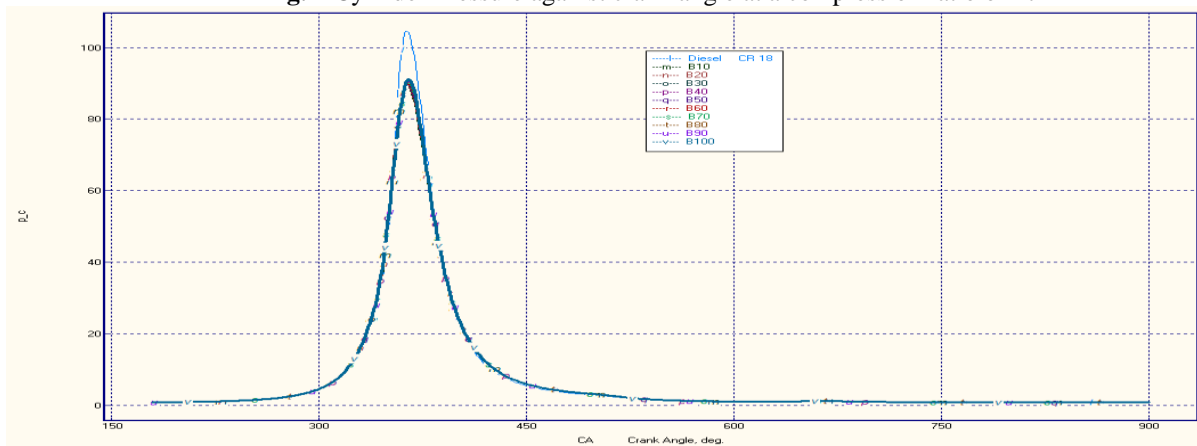


Fig. 3 Cylinder Pressure against crank angle at a compression ratio of 18

Heat Release Rate

The effect of compression ratio on the heat transfer rate of biodiesel, diesel and its blend is presented in fig 4, 5 and 6. Heat release rate is analyzed based on the variation of the cylinder at an engine speed of 1500 rpm. The maximum heat release rate was observed to be higher for all biodiesel blends at higher compression ratio. For all investigated compression ratios, it was also observed that the heat release rate of biodiesel and its blends are lower compared to that of diesel as a result of lower energy content of biodiesel and its blends

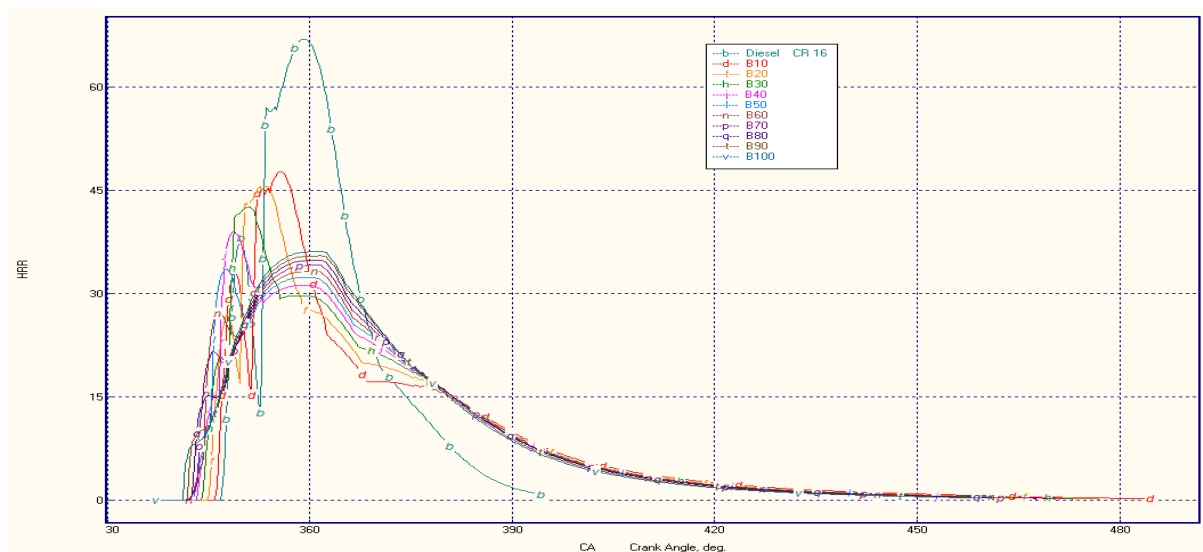


Fig. 4 Heat Release rate against crank angle at the compression ratio of 16

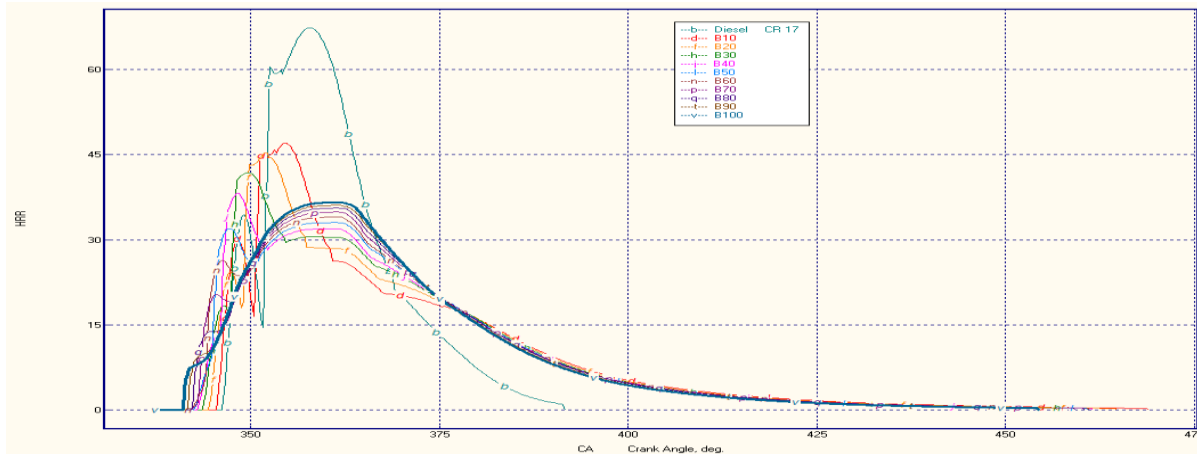


Fig. 5 Heat release Rate against crank angle at a compression ratio of 17

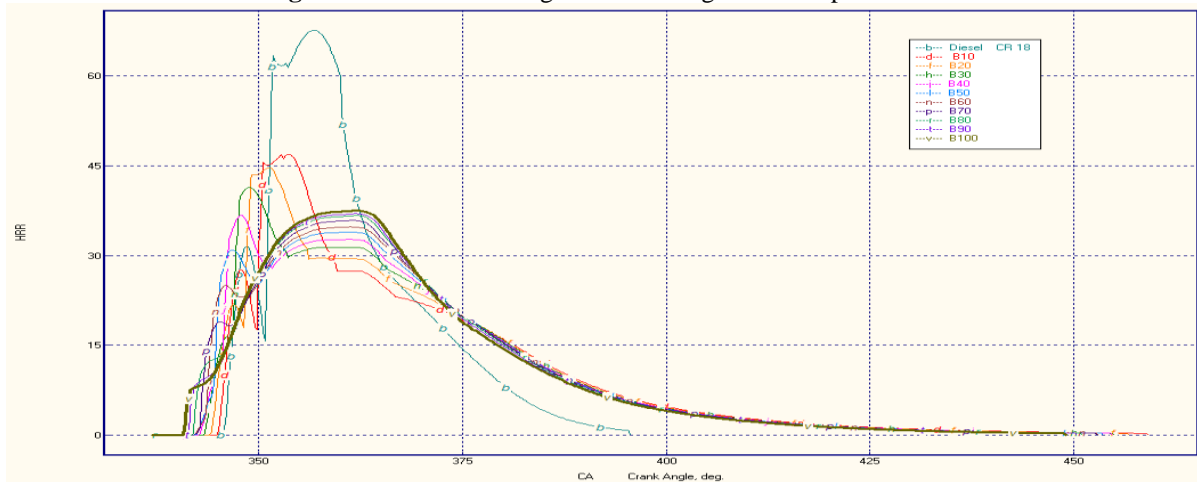


Fig. 6 Heat Release rate against crank angle at a compression ratio of 18

Ignition Delay Period

Ignition delay period is the difference between the start of injection and start of combustion. Fig 7, 8, 9 shows the variation of ignition delay with engine speed for all tested fuel at compression 16, 17 and 18. It was observed that the ignition delay decreases for higher compression ratio. This can be attributed to higher temperature and pressure developed in the cylinder at higher compression ratio that makes combustion to start early. Pure biodiesel (B100) was seen to have the lowest ignition delay period for all investigated compression ratio. A reduction of about 5.91% was noticed for pure biodiesel Ignition delay period as the compression ratio increases from 16 to 17 while a decrement of 9.58% was observed upon increment of compression ratio from 16 to 18. B10 was observed to have the highest ignition delay for all tested blends for all compression ratios and suffers a decrease of 6.24% as compression ratio changes from 16 to 17 while a reduction of 11.48% was observed upon increment of compression ratio from 17 to 18. The ignition delay period of diesel remain higher compared to that of pure biodiesel and its blends for all investigated compression ratio.

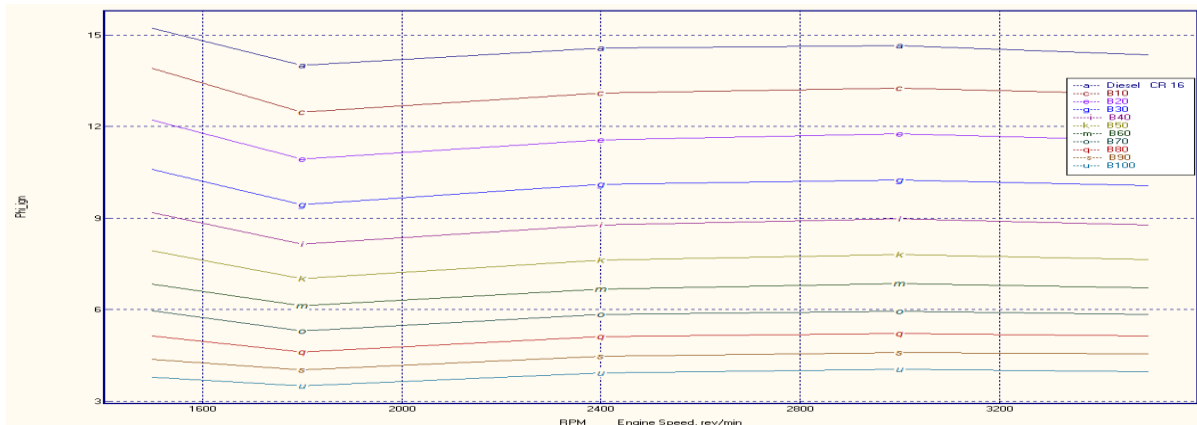


Fig. 7 Ignition delay against Engine Speed at a compression ratio of 16

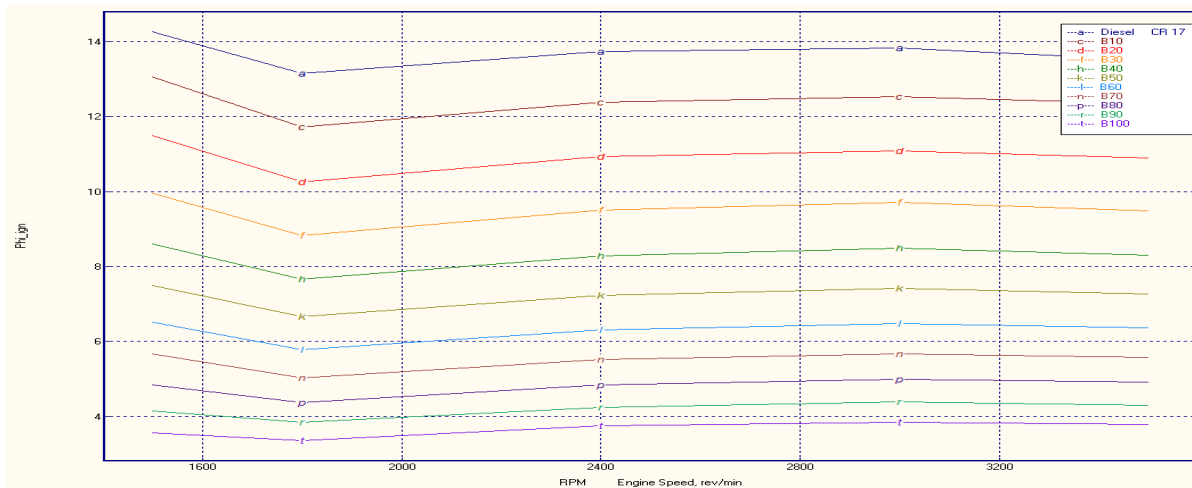


Fig. 8 Ignition delay against engine speed at a compression ratio of 17

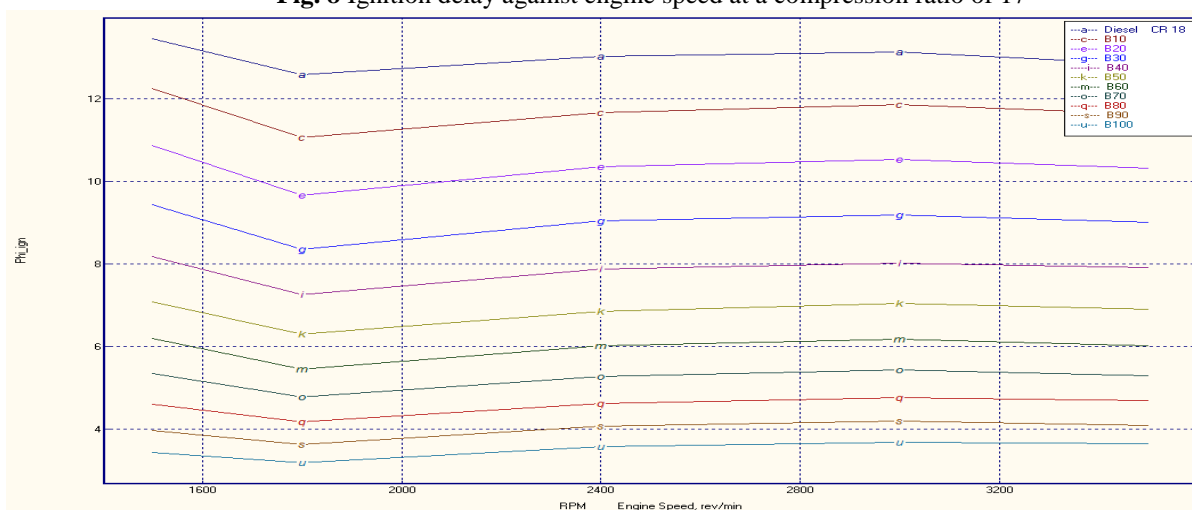


Fig. 9 Ignition delay against engine speed at a compression ratio of 18

Heat Release Fraction

The effect of compression ratio on orange peel oil based biodiesel and its blends can be seen as shown in fig 10, 11, 12. Heat release fraction depends on the start of combustion and the duration of combustion of a fuel in the cylinder. Start of combustion can be determined from the change of slope from the graph and it has been observed that combustion start earlier for increasing compression ratio for all tested fuel which further decreases combustion duration. This can be attributed to decrease in the ignition delay period for higher compression ratio. B10 was observed to have the highest combustion duration as it can be seen that B10 has a prolonged burning rate compared to other tested fuel for all investigated compression ratio. Prolonged burning rate of biodiesel fuel and its blend could be as a result of slow combustion experienced by the fuel.

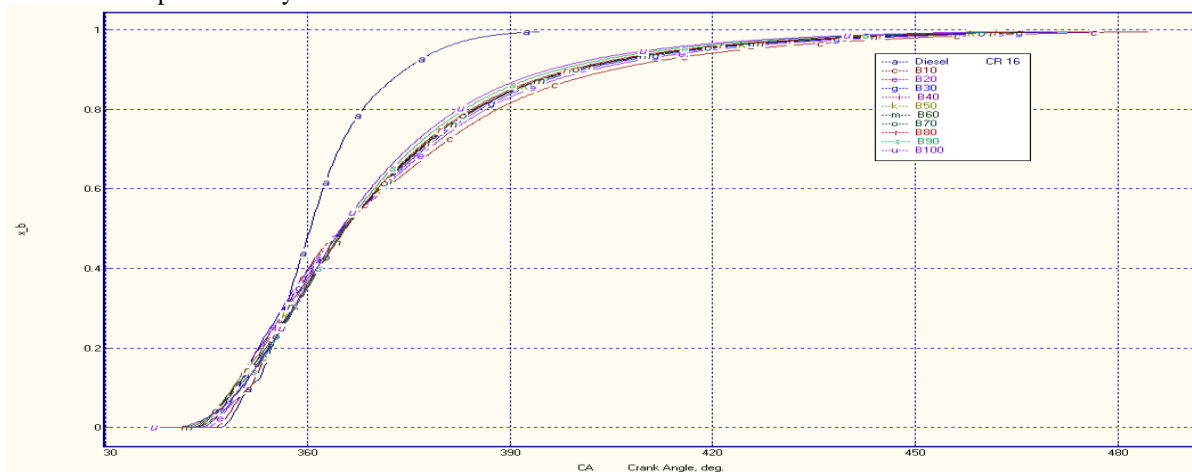


Fig. 10 Heat release fraction against crank angle at a compression ratio of 16

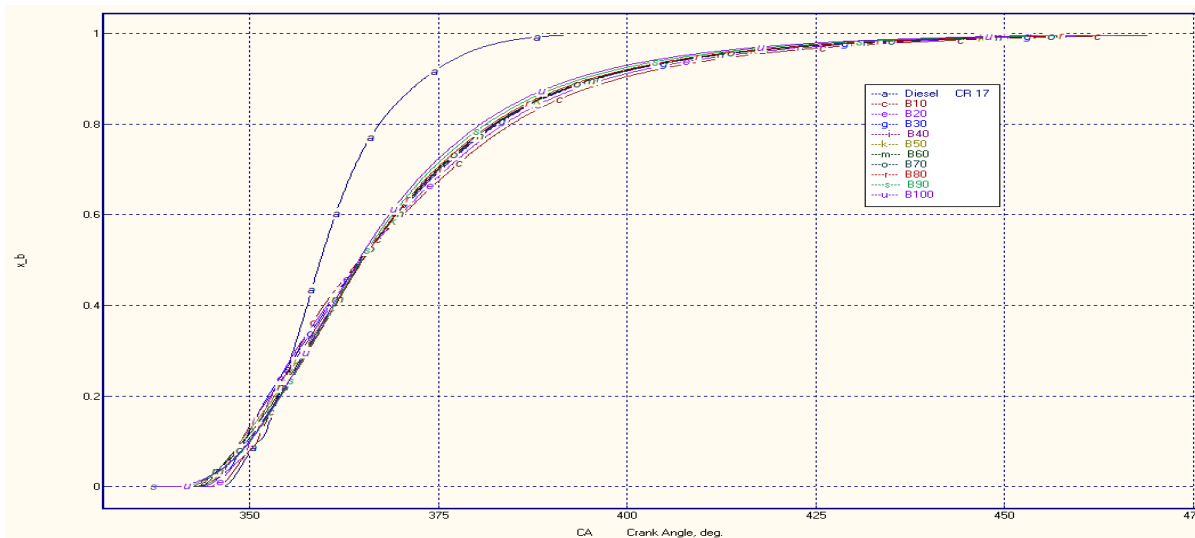


Fig. 11 Heat Release Fraction against crank angle at a compression ratio of 17

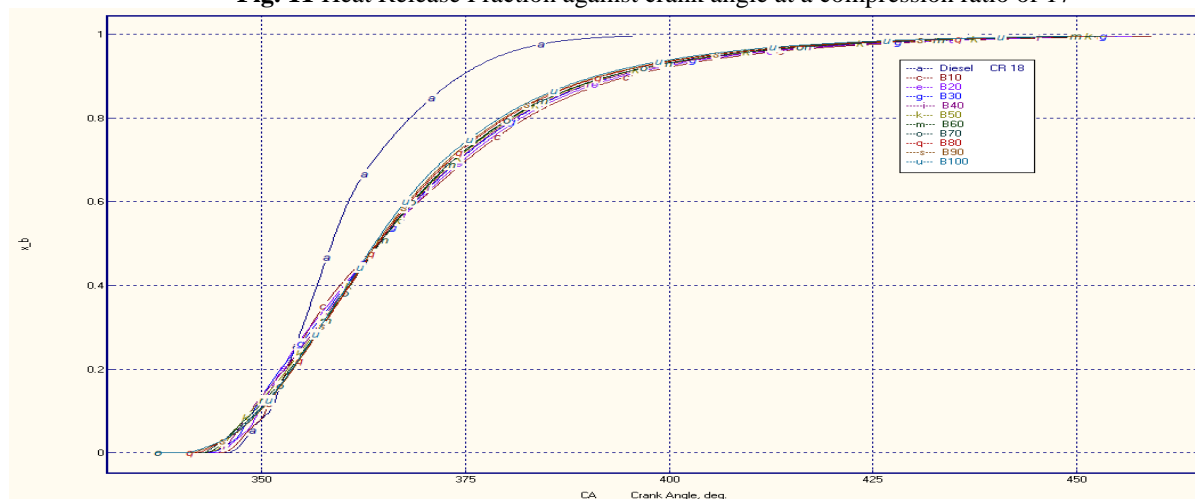


Fig. 12 Heat Release Fraction against crank angle at a compression ratio of 18

Brake Power

Fig 13, 14 and 15 shows the variation of brake power with engine speed for a compression ratio of 16, 17 and 18 respectively. Higher brake power was observed for higher compression ratio and the brake power increases with increasing compression ratio for orange peel oil based biodiesel and its blends. The higher break power observed is expected to complement the pressure increase at higher compression ratio. It was also noticed that brake power for diesel is higher than pure orange peel oil based biodiesel and its blends at lower and higher engine speed for all compression ratio investigated as a result of rapid and improved combustion of diesel.

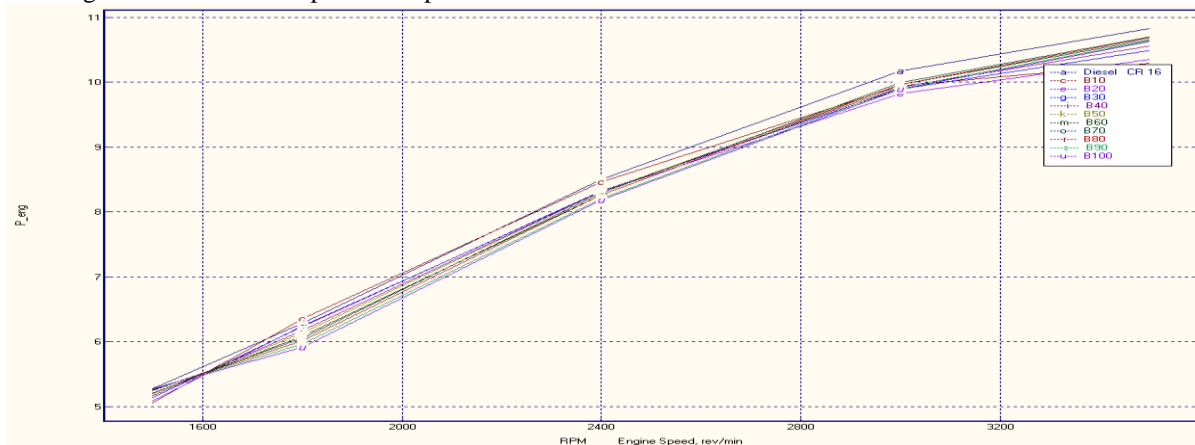


Fig. 13 Brake Power against engine speed at a compression ratio of 16

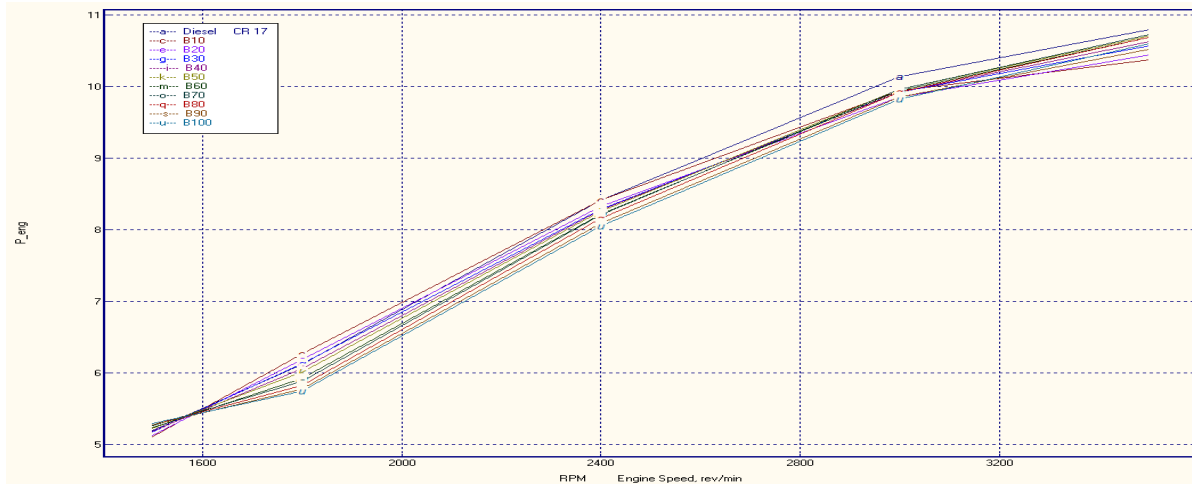


Fig. 14 Brake power against engine speed at a compression ratio of 17

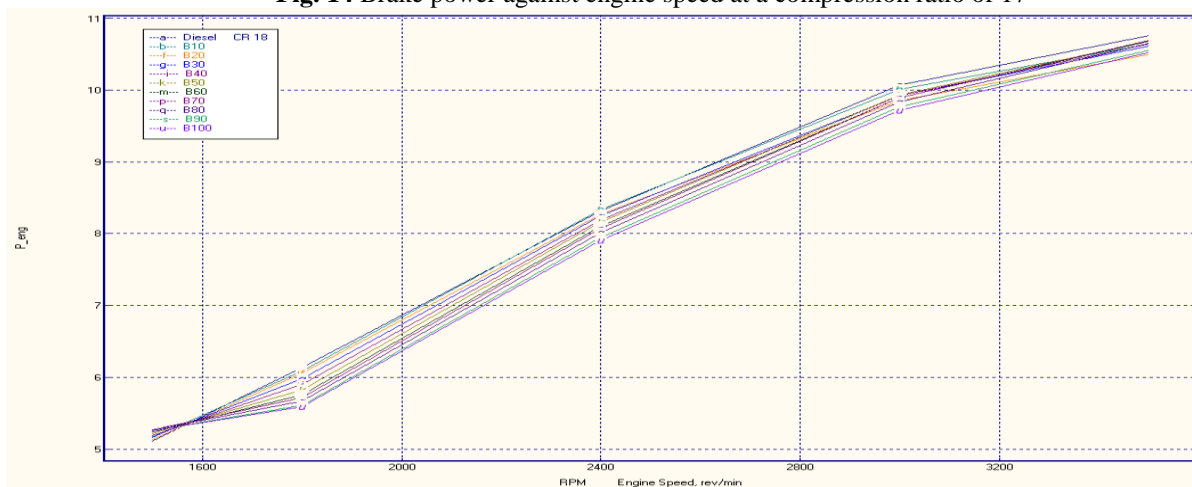


Fig. 15 Brake power against engine speed at a compression ratio of 18

Break Specific Fuel Consumption

Brake specific fuel consumption is an important performance parameter of an engine. It can be seen from fig 16, 17, 18 that the brake specific fuel consumption decreases with increasing compression ratio for orange peel oil based biodiesel and its blends. The brake specific fuel consumption remains higher for biodiesel blends this can be attributed to their lower calorific. Also, improved combustion at higher compression ratio can be the reason for the decrease in the brake specific fuel consumption. On increasing the compression ratio from 16 to 17, a decrease of 1.29%, 1.02%, 0.89% for blend B10, B20 and B30 was observed at low engine speed while 1.65%, 1.23%, 1.1% decrease was observed for compression ratio 18.

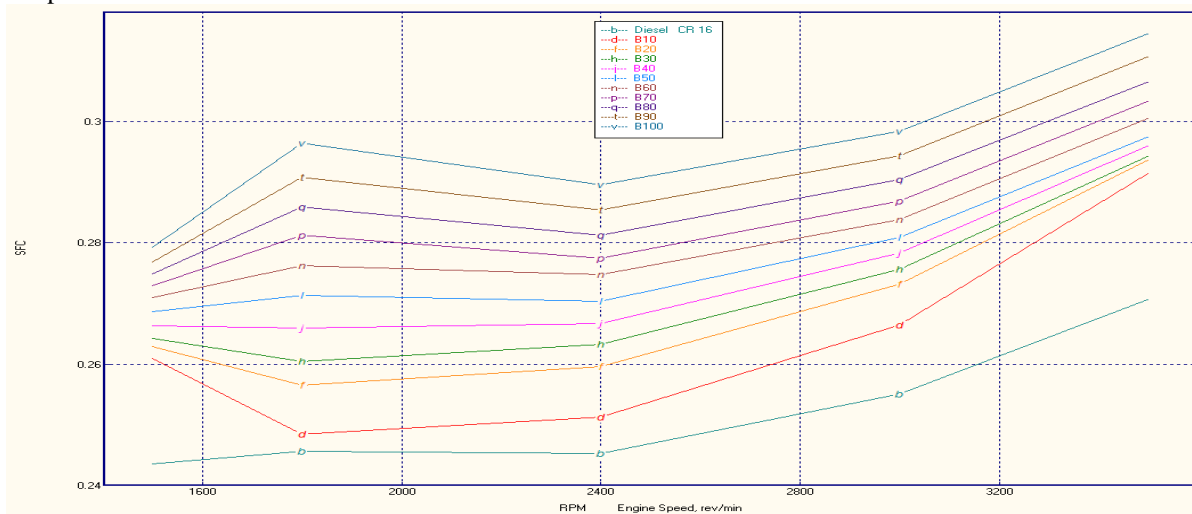


Fig. 16 Brake Specific Fuel Consumption against engine speed at a compression ratio of 16

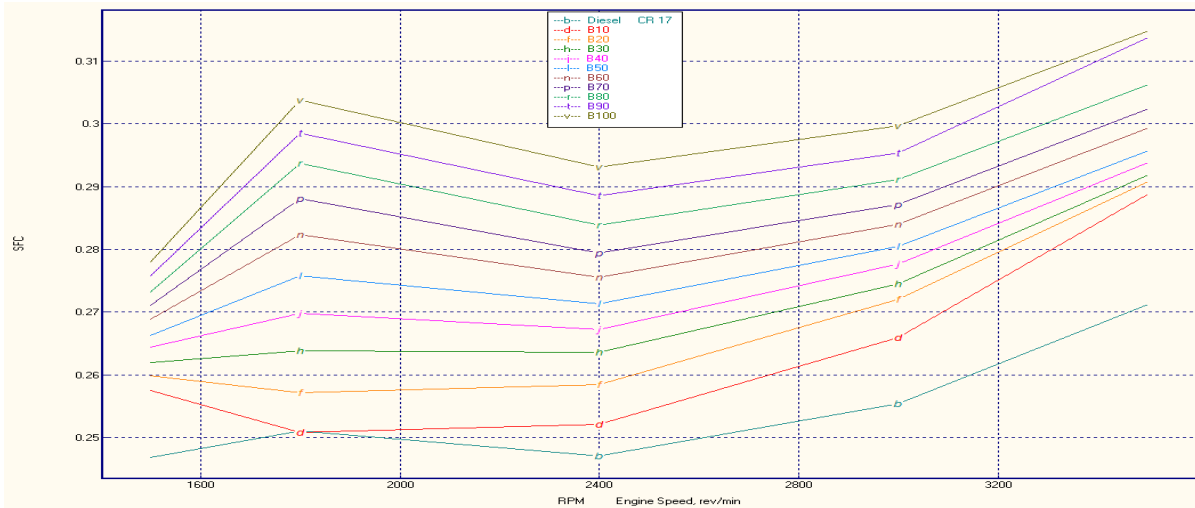


Fig. 17 Brake Specific Fuel Consumption against engine speed at a compression ratio of 17

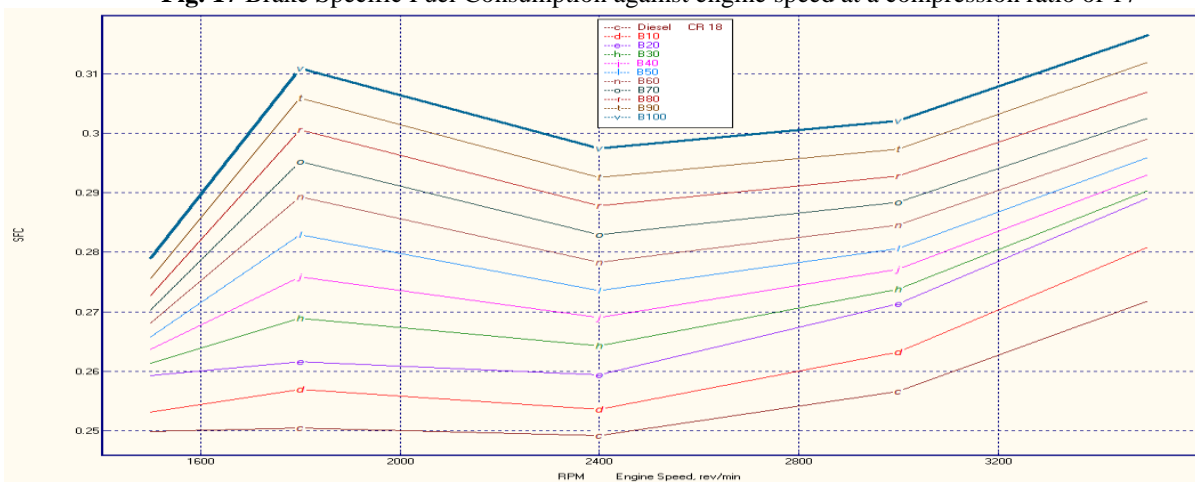


Fig. 18 Brake Specific Fuel Consumption against engine speed at a compression ratio of 18

Volumetric efficiency

The effect of volumetric efficiency variation with engine speed is shown in fig 19, 20, 21 at a compression ratio of 16, 17 and 18. At lower and higher engine speed, biodiesel and its blend can be seen to be higher than that of neat diesel for all compression ratio investigated. Also, at engine speed of 2400 rpm, the volumetric efficiency was observed to be at the maximum for all tested fuel at all investigated compression ratio and then the volumetric efficiency reduces for higher speed. The reason for lower volumetric efficiency at the maximum engine speed can be as a result of difference between the cylinder and atmospheric pressure during the intake process.

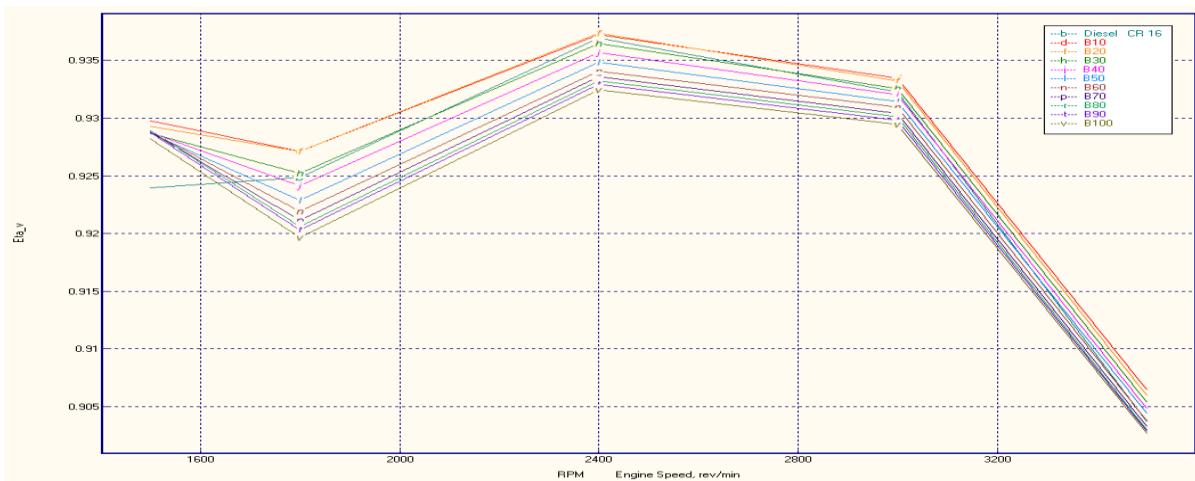


Fig. 19 Volumetric efficiency against engine speed at a compression ratio of 16

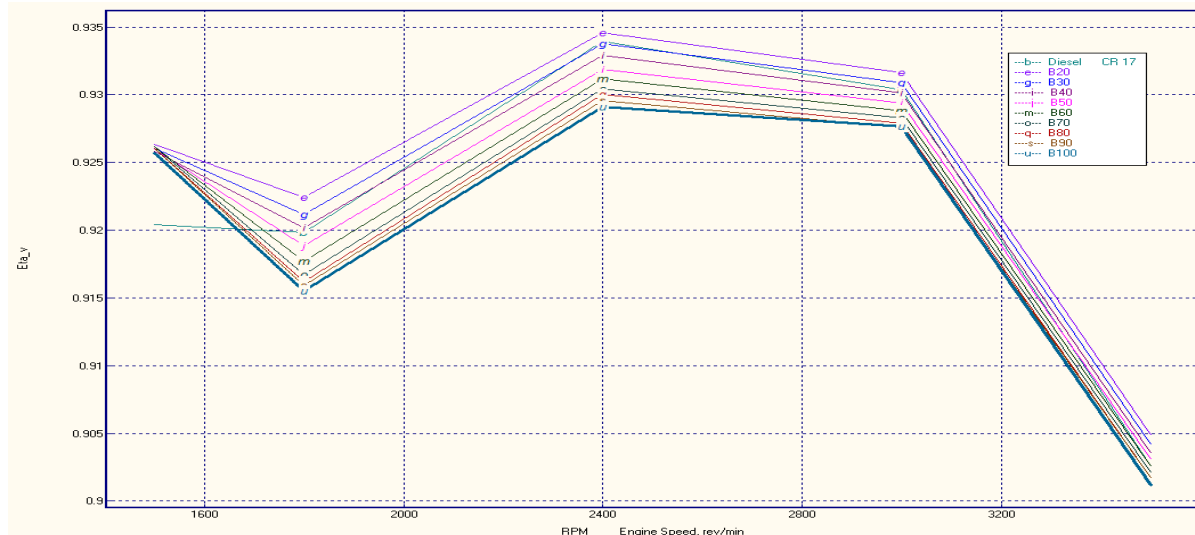


Fig. 20 Volumetric efficiency against engine speed at a compression ratio of 17

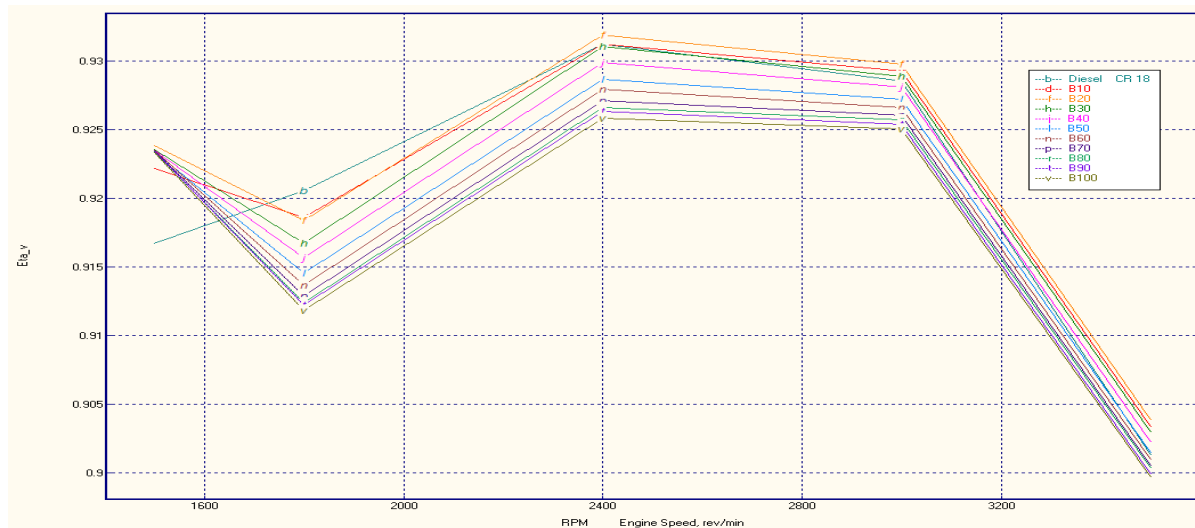


Fig. 21 Volumetric efficiency against engine speed at a compression ratio of 18

CONCLUSIONS

The combustion and performance characteristic of a compression ignition engine fuelled with orange peel oil based biodiesel has been investigated and the following conclusion drawn:

- (i) For all blends tested, B10 provides best result in terms of BSFC, higher heat release rate and cylinder pressure for all investigated compression ratio. Therefore, B10 can be used as an alternative biodiesel preferably at a compression ratio of 18 for rapid and better combustion.
- (ii) Ignition delay was lower for orange peel oil based biodiesel and its blends at all investigated compression ratio. A reduction in the ignition delay was observed at higher compression ratio for all tested fuel.
- (iii) In general, increasing the compression ratio had more benefit to orange peel oil based biodiesel and its blends in terms of their combustion and performance characteristics.

REFERENCES

- [1]. Phate and Kulkarni (2014) “ Experimental Investigation of the Suitability of Orange Peel Oil as a Blend with Cotton Seed Oil as Alternate Fuel for Diesel Engines : A Review ”, 3(4), pp. 67–70.
- [2]. Hariram, V. and Bharathwaaj, R. (2016) ‘Application of zero-dimensional thermodynamic model for predicting combustion parameters of CI engine fuelled with biodiesel-diesel blends’, *Alexandria Engineering Journal*. Faculty of Engineering, Alexandria University, 55(4), pp. 3345–3354. doi: 10.1016/j.aej.2016.08.021.
- [3]. Senthil, R., Silambarasan, R. and Ravichandiran, N. (2015) ‘Influence of injection timing and compression ratio on performance, emission and combustion characteristics of Annona methyl ester operated diesel engine’, *Alexandria Engineering Journal*. Faculty of Engineering, Alexandria University, 54(3), pp. 295–302. doi:

- 10.1016/j.aej.2015.05.008.
- [4]. Patil, S. and Akarte, M. M. (2012) 'Performance Characteristics of CI Engine Fuelled with Biodiesel and its Blends by Simulation', 3(4), pp. 1–6.
- [5]. Ebaid, A., Mater, M. and Mustafa, E. A. (2017), 'Prediction of NO_x emission from turbocharged biofuel engine', M.SC thesis (August).
- [6]. El-Kassaby, M. and Nemit-Allah, M. A. (2013) 'Studying the effect of compression ratio on an engine fueled with waste oil produced biodiesel/diesel fuel', *Alexandria Engineering Journal*, 52(1), pp. 1–11. doi: 10.1016/j.aej.2012.11.007.
- [7]. Attri, V. K. *et al.* (2015) 'Effect of Compression Ratio on Performance and Emissions of Diesel on a Single Cylinder Four Stroke VCR Engine', *International Journal of Emerging Technology and Advanced Engineering*, 5(1), pp. 94–102. doi: 10.1016/j.ijhydene.2015.07.051.
- [8]. J.B. Heywood, "Internal combustion engines fundamentals", McGraw Hill Series in Mechanical Engineering.
- [9]. Kuleshov, A. S. (2010) 'Self-Ignition delay Prediction in PCCI direct injection diesel engines using multi-zone spray combustion model and detailed chemistry'.
- [10]. Paul, G., Datta, A. and Mandal, B. K. (2014) 'An experimental and numerical investigation of the performance, combustion and emission characteristics of a diesel engine fueled with jatropha biodiesel', *Energy Procedia*. Elsevier B.V., 54, pp. 455–467. doi: 10.1016/j.egypro.2014.07.288.
- [11]. Sakhrieh, A. *et al.* (2010) 'Computational thermodynamic analysis of compression ignition engine', *International Communications in Heat and Mass Transfer*. Elsevier Ltd, 37(3), pp. 299–303. doi: 10.1016/j.icheatmasstransfer.2009.11.002.63–870.