Engine Combustion Analysis using Wiebe Burn Rate Law

B. Tech Project Phase I
Final Report

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Certificate

Certified that the work presented in this report titled "**Engine Combustion Analysis using Wiebe Burn Rate Law**" is a bona fide work of Shubham Balasaheb Wakchaure (Roll No.131701026) carried out under my supervision in the Discipline of Mechanical Engineering, IIT Palakkad, as B. Tech project during August-November 2020

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Abstract

Analysis of engine combustion is necessary for many aspects of engine development, emission control, performance enhancement, etc. It also helps analysing how the energy release pattern during the combustion. 'Wiebe Function' is one of the widely used empirical correlation form to represent engine combustion. This function is from the engine experimental pressure histories used in the industry as well as by researchers for first order combustion analysis. The purpose of this project is to analyze the engine combustion for different fuels at various engine operating conditions. Wiebe burn rate gives an idea of rate of fuel burn throughout the combustion process in internal combustion engine. Wiebe burn rate is represented in terms of the mass burn or energy release fraction which varies over 0 to 1 from start of combustion to the end of combustion.

Different methods have been suggested in literature for finding the mass burn fraction. Of these, the Rassweiler-Withrow (RW) and the Apparent Energy Release methods are the two commonly used approaches. While Rassweiler-Withrow method uses the difference in firing and motoring pressure histories, the Apparent Energy Release method is based on the First Law Analysis of pressure data. In the latter method, cumulative heat release is determined and used to find out the burn fraction. Wiebe function includes two empirical parameters and the value of combustion duration. While the two parameters are obtained from best fit criterion to the mass burned fraction curves, the combustion duration is the time between the start and the end of combustion and is determined from logp - logv and energy release plots. The polytropic index is required for determining motoring pressures in RW method as well as in determining the apparent energy release from the First Law based analysis.

The variations of all the parameters like polytropic index, form factor, efficiency parameter, combustion duration determined in this analysis have been plotted against engine load and the test fuels for which experimental pressure time data were available. From the analysis it is observed that the polytropic index for the engine data at various loads slightly increases with load but becomes constant at higher load. However, the value of polytropic index for the diesel fuel is greater than Karanja and Palm biodiesels. Among two Wiebe parameters, the values of the efficiency factor 'a' is not significantly different for the three fuels but the form factor 'm' verified almost linearly with percent load.

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1.0 Introduction

Development of methods and tools to analyze the engine combustion helps in understanding the many aspects of engine. Engine pressure history is used as a primary data set to understand the engine combustion and later this data further processed to get other insights about the combustion. Energy conversion in the engine is described by the mass burnt fraction Wiebe burn rate law is used to identify the progress of combustion in much simpler manner. It includes the determination of the mass burnt fraction, polytropic index, start and end of combustion.

Various methods have been suggested in literature to determine the mass burnt fraction. Methods like Rassweiler-Withrow, Energy, Pressure ratio are some of the available methods for determining the mass burnt fraction [1-5]. Before determination of the mass burnt fraction, combustion pressure is extracted from the total pressure change using simple polytropic relations. Start and end of combustion are important factors while fitting the Wiebe curve. Energy and LogP-LogV methods have been implemented to determine the SOC and EOC [6]. Average of these values is further taken to remove variation in combustion duration due to these two methods.

The variations of all the parameters like polytropic index, form factor, efficiency parameter, combustion duration have been plotted against load for three different fuels viz. Diesel, Karanja Biodiesel and Palm Biodiesel for which the experimental pressure histories were available.

2.0 Literature Review

One of the approaches in engine combustion analysis is to obtain the mass burnt fraction as a function of crank angle. It is represented through an empirical relation known as the Wiebe equation fitted to the estimated mass burnt fraction (MFB) history during the period of combustion. This correlation has two empirical parameters viz. efficiency parameter ‘a’ and form factor ‘m’. There are a few methods suggested in literature for finding the mass burnt fraction [1-4]. Of these, the Rassweiler-Withrow (RW) and the Apparent Energy Release methods are the two commonly used approaches. It is reported that RW is the most effective in terms of calculation and accuracy. Mittal et al [1] computed the MBF using net pressure ratio method and shown good agreement with RW method at higher loads. Their method requires less data processing time and is easy to implement in real time applications particularly in engine control applications. RW method is an indirect method of determining the mass burnt fraction with the assumption of mass burnt over small crank duration is proportional to pressure rise over it [3]. But still the RW method gives the most acceptable results. It is easy to implement and computationally more efficient. SOC, EOC and polytropic index are important parameters while calculating the MBF but these parameters are very difficult to compute exactly [3]. Due to increasing demand of ECU controlled engines to reduce fuel economy and emissions, such combustion model helps in taking control decisions [3].

In these empirical methods, the determination of certain parameters like polytropic index, combustion duration, Wiebe parameters (form factor and efficiency parameter) is central. Approximation method like slope of LogP-LogV method are used for computing the polytropic index. These points are calculated mathematically using tangent method so the high accuracy cannot be maintained. For determining start (SOC) and end (EOC) of combustion, the energy method is widely used [5-6].

3.0 Project Objectives

The objective of this project is to carry out engine combustion analysis using an empirical approach of Wiebe correlation based on the estimated mass burnt fraction history derived from the experimental pressure time histories. For this purpose, it is required

1) To determine the compression and expansion index for different operating conditions.
2) To determine the start (SOC) and end (EOC) of combustion using RW and energy methods at different operating conditions.
3) To obtain the mass burnt fraction (MBF) history during the period of combustion using Rassweiler-Withrow (RW) and Apparent Energy methods and compare their results
4) To investigate the effect of the engine load and fuel type on Wiebe parameters.

4.0 Methodology

The methodology adopted for the engine combustion analysis using Wiebe's burn rate law is described here.

4.1 Basis and Assumptions

The available experimental pressure histories at different engine load operations at fixed speed for three different fuels viz. diesel, Karanja biodiesel and Palm biodiesel are analyzed with the following simplified assumptions:

i. Gas mixture is an ideal gas.
ii. Cylinder content and its thermodynamics properties are same throughout the cylinder.
iii. Heat release from the combustion process occurs uniformly throughout the cylinder.
iv. Heat transfer to the wall is implied in use of actual polytropic index and hence no direct estimate of the heat transfer is required.
v. Mass loss such as from cervices is neglected in the first law analysis method.
vi. Combustion is modeled as the release of energy and mass burnt fraction is estimated from there.

4.2 Determination of mass burnt fraction

A) Rassweiler-Withrow Method

Rassweiler-Withrow method determines the mass burnt fraction by calculating the ratio of the difference between the measured pressure and the polytropic pressure to the total fuel energy [3]. This method considers pressure rise over a small interval of crank angle as proportional to the mass burnt between that interval. In this method, the fuel mass burnt fraction (MBF) is a parameter representing the chemical energy of fuel released during combustion. For any crank angle interval $\Delta\theta$ the total pressure rise Δp is made up of pressure rise due to cylinder volume change (Δp_v) and pressure rise due to combustion (Δp_c). Thus,

$$\Delta p = \Delta p_v + \Delta p_c \qquad (1)$$

The pressure change due to volume can be obtained using the polytropic relation

$$pV^n = \text{Constant} \qquad (2)$$

where n is polytropic index which can be deduced from the actual pressure histories.

Normalized mass burnt fraction with respect to crank angle (x_b) is the ratio of the fuel mass burnt (m_b) to the total fuel mass supplied (m_{total}) in a cycle. It represents the amount of energy released during combustion and varies between 0 to 1. The mass burnt fraction can then be represented by a well-known mass burnt fraction formulation known as Wiebe's function

$$x_b = \left\{1 - \exp\left[-a\left(\frac{\theta - \theta_0}{\Delta\theta}\right)^{m+1}\right]\right\} \qquad (3)$$

where a and m are empirical parameters described as efficiency parameter and form factor respectively. θ is crank angle, θo is the crank angle at the start of combustion and Δθ is the combustion duration.

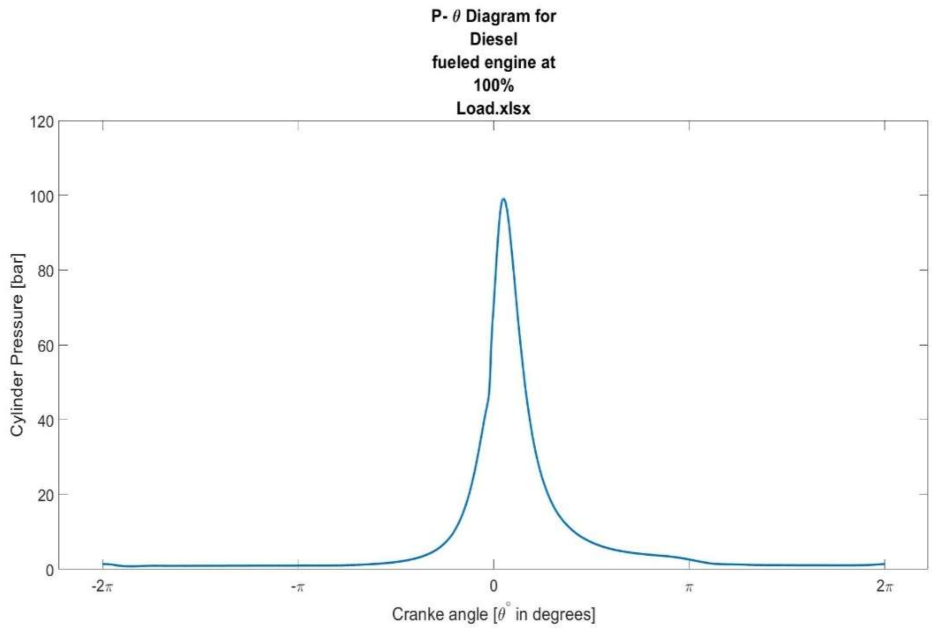

Figure 1:Engine pressure history for diesel fuel at 100 % load condition

General mathematical procedure of Rassweiler-Withrow (RW) method

$$\Delta p = p_{j+1} - p_j \qquad (4)$$

$$\Delta p = \Delta p_v + \Delta p_c \qquad (5)$$

During the interval $\Delta\theta = \theta_{j+1} - \theta_j$ is assumed to be made of pressure rise due to combustion and pressure rise due to volume change

$$\Delta p_v(j) = p_{j+1,v} - p_j = p_j\left(\left(\frac{V_j}{V_{j+1}}\right)^n - 1\right) \qquad (6)$$

Using all the above relations we get

$$\Delta p_c(j) = p_{j+1} - p_j\left(\frac{v_j}{v_{j+1}}\right)^n \qquad (7)$$

Now assuming the mass of charge burn in the interval Δθ is proportional to the pressure rise during that interval, therefore MFB at the end of kth interval can be calculated as the [3]

$$\frac{m_{bk}}{m_{btotal}} = \frac{\sum_0^k \Delta p_c}{\sum_0^N \Delta p_c} \quad (8)$$

where N = total number of the crank angle intervals

B) Apparent Energy release method

Heat release analysis is done using first law of thermodynamics. System under consideration is the in-cylinder fuel and air mixture. It is represented by the dotted line the figure 2.

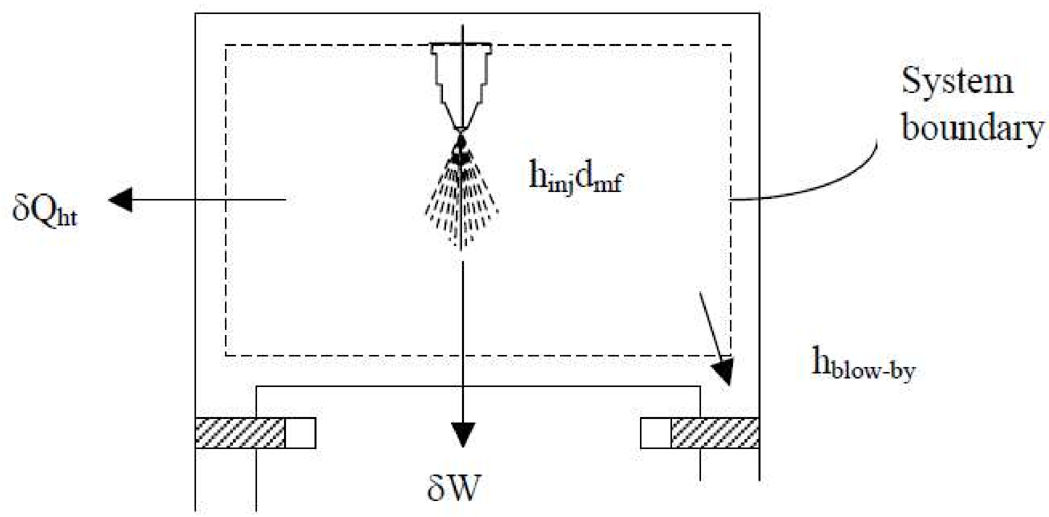

Figure 2:Engine thermodynamical system

$$dU = \delta Q - \delta W \quad (9)$$

where dU is the change in internal energy,δQ is the heat added to the system,δW is the work done by the system.

$$dU = mC_v dT \quad (10)$$

After applying the ideal gas equation, we will get

$$\delta Q = \frac{C_v}{R} d(pV) + pdV \quad (11)$$

Differentiating the above equation w.r.t crank angle (θ)

$$\frac{\delta Q}{d\theta} = \frac{C_v}{R} * \frac{d(pV)}{d\theta} + p(\theta)\frac{dV}{d\theta} \quad (12)$$

Above equation can be integrated to get the cumulative heat release

$$Q(\theta) = \frac{C_v}{R}[p(\theta)V(\theta) - p(\theta_0)V(\theta_0)] + \int_{\theta_0}^{\theta} p(\theta)\frac{dV}{d\theta}d\theta \quad (13)$$

Using the equation $C_v = \frac{R}{\gamma-1}$ and converting the integration into the finite sum for discrete values of pressure and volume

$$Q_i = \frac{1}{\gamma - 1}[p_i V_i - p_0 V_0)] + \sum_{j=0}^{i} p_j (\Delta V)_j \qquad (14)$$

Using the above equation heat release at each crank angle be calculated which is further used to calculate the mass burnt fraction

$$MBF_i = \frac{\sum_{k=0}^{k=i} Q_k}{\sum_{k=0}^{k=N} Q_k} \qquad (15)$$

where i is the ith mass burnt fraction and N is the total number of crank angle intervals.

4.3 Determination of combustion duration

A) Energy method

From the calculated energy release data start of combustion is taken at point of 5% of maximum energy is release and end of combustion is taken at 95% of maximum energy release point. This 5% Q_{max} and 95 % Q_{max} values are interpolated on the heat release-crank angle plot to get the SOC and EOC values [6].

Fig shows the interpolation of values calculated using this method.

$$\theta_{start} = \text{Crank angle at } 5\% \text{ Qmax} \qquad (16)$$

$$\theta_{end} = \text{Crank angle at } 95\% \text{ Qmax} \qquad (17)$$

After finding the SOC and EOC duration of the combustion can be found by taking the difference of two

$$\Delta\theta_{comb} = \theta_{end} - \theta_{start} \qquad (18)$$

Fig3 gives the graphical representation of this method.

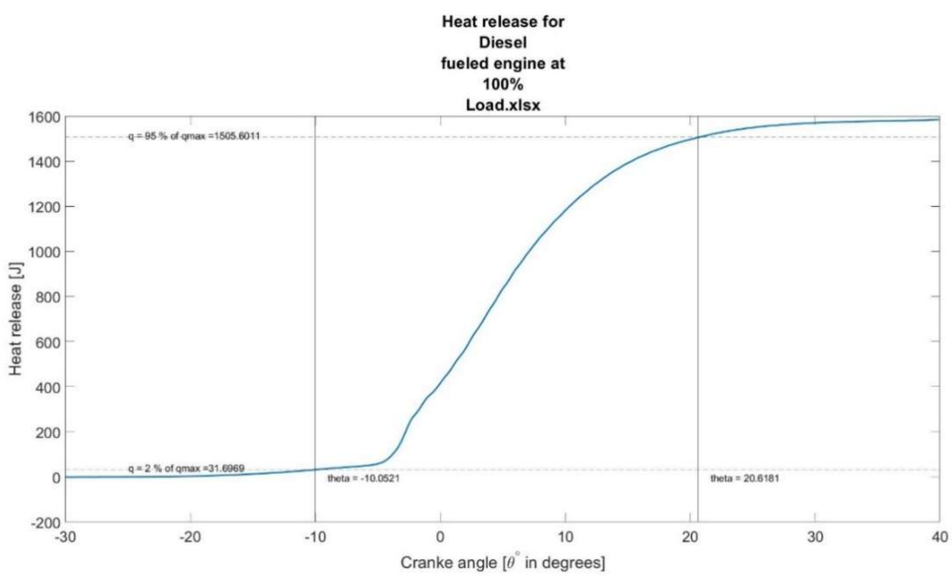

Figure 3:Heat release for diesel at 100 % load condition

B) LogP-LogV method

When P-V data is plotted on logarithmic scale during the compression and expansion stroke it gives the straight line with constant slope within some interval. As during the compression and expansion it follows $PV^n = C$ for some n and C values

On log-log plot this equation will look like

$$LogP + nLogV = LogC \quad (19)$$

$$LogP = -n.LogV + LogC \quad (20)$$

$$y = mx + c \quad (21)$$

Within compression and expansion stroke the slope of the plot will be approximately constant. So, the change of slope in those intervals will be zero. As from start of compression change in slope will be zero but after some point the changes in the slope will be significant and again after some point slope change will becomes zero (during expansion stroke)

So, start of combustion is the point on compression stroke line from where the slope changes are significant and end of combustion is the point on expansion line from where the changes in start to become zero. As there are the fluctuations in the pressure data so the practically the slope cannot be zero and greater than some particular value therefore some tolerance value is given to check whether slope is within the range or not.

$$\theta_{start} = \text{CA at first occurance of abs}(\Delta m_c) > \epsilon_1 \quad (20)$$

$$\theta_{end} = \text{CA at first occurance of abs}(\Delta m_e) < \epsilon_2 \quad (21)$$

$$\text{where } \epsilon_1 \text{ and } \epsilon_2 \text{are very small value of order } 0.001 - 0.01$$

$$m_c \text{and } m_e \text{ represents the slope of compression and expansion line on}$$

$$\text{logP} - \text{logV diagram}, \Delta m_c \text{and } \Delta m_e \text{represents the change in slope}$$

Fig.4 gives an idea about the variation of slope with respect to the crank angle so by setting some tolerance values SOC and EOC can be found graphically.

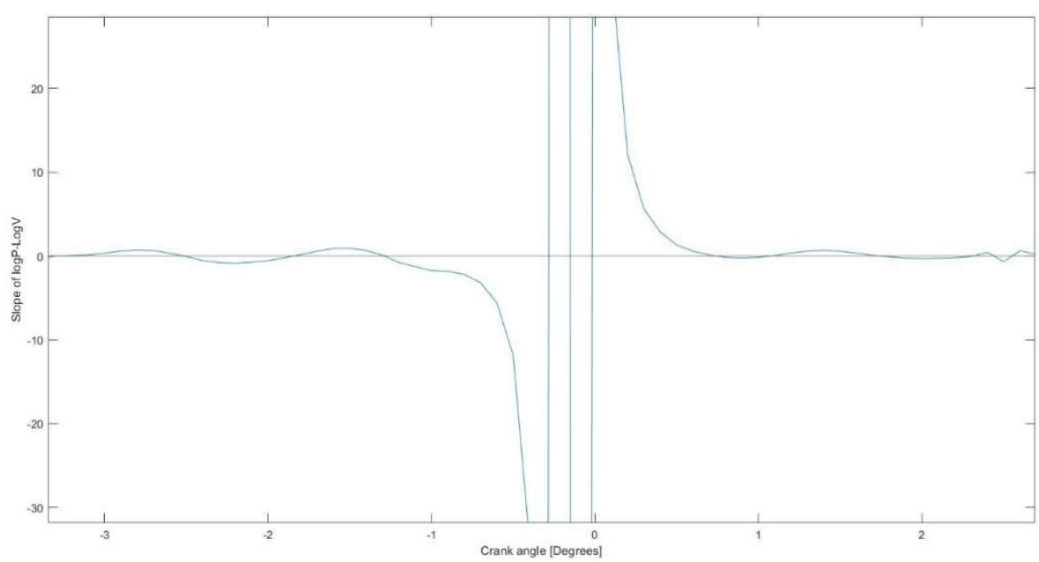

Figure 4:Change of slope of LogP-LogV graph

4.4 Determination of the polytropic index

A) LogP-LogV method [2]

On log-log plot the compression and expansion curves follow a straight line between some interval and equation of this straight line can be given by equation no.19 where slope of the line gives the polytropic index. So, this data is fitted using linear fit method to get the slope in compression and expansion stroke. These slopes represent the index of compression and expansion respectively. For compression index the line is fitted between the start of compression stroke to start of combustion and for expansion index the line is fitted between the end of combustion to end of expansion stroke.

$$\mathrm{n_c} = \text{Slope of LogP} - \text{LogV} \quad \theta_{\text{start comp}} < \theta < \theta_{\text{start comb}} \qquad (22)$$

$$\mathrm{n_e} = \text{Slope of LogP} - \text{LogV} \quad \theta_{\text{end comb}} < \theta < \theta_{\text{end exp}} \qquad (23)$$

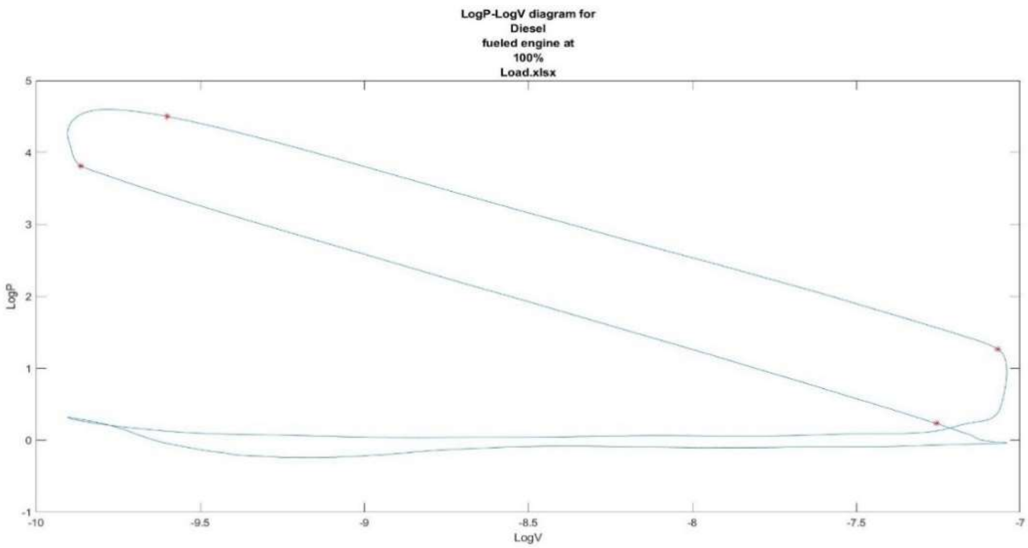

Figure 5:LogP-LogV graph for diesel at 100 % load

4.5 Determination of the Wiebe parameters

As the MBF data is calculated using two methods so the curve fitting is done using least square model to fit in the following equation with the corresponding θ_0 and $\Delta\theta$ values for particular method.

$$\mathrm{x_b} = \left\{1 - \exp\left[-\mathrm{a}\left(\frac{\theta - \theta_0}{\Delta\theta}\right)^{\mathrm{m}+1}\right]\right\} \qquad (24)$$

After fitting the data, we will get the values of Wiebe parameters 'a' and 'm'. This procedure is repeated for different fuels at different loads to get the effect of fuel and operating conditions on Wiebe parameters. Fig.6 shows the Wiebe curves fitted for the MBF data obtained by energy. All the corresponding values has been shows in the graph. General values of 'a' and 'm' are '5' and '2' [6].

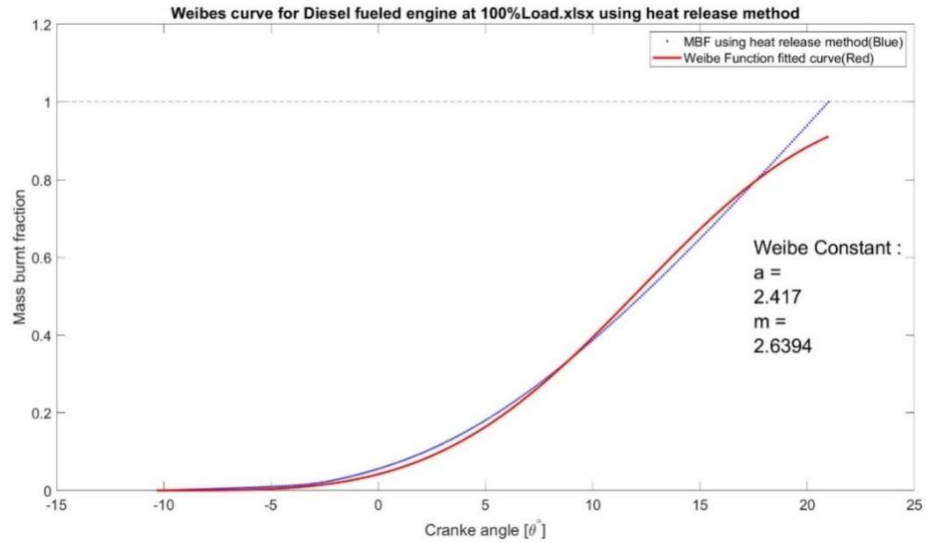

Figure 6:Wiebe fit curve for diesel at 100 % load with heat release method

5.0 Results and Discussion

All the computations were done using the available pressure data at engine speed of 1400 rpm. The specifications of the test engine on which the data were obtained are given in the Appendix 1. This section provides the results obtained from the calculated data for different fuels at different engine load in percent.

i) **Peak pressure, rate of pressure rise, second derivative of pressure rise, max heat release, rate of heat release, second derivative of heat release and occurrence of each of them are obtained from graphs.** There numeric values for these parameters are provided in Table 1 below. For want of space, a typical energy release rate curve for the diesel fuel at 100% load is shown in Fig.7.

Table 1: Different evaluated properties for three fuels at various load

Load in %		0	20	40	60	80	100
Diesel	P_{max} (bar)	55.95	76.07	82.65	91.9	99.23	99.16
	θ @ P_{max} (degree)	5.51	6.91	7.51	8.81	9.01	9.01
	max $(\frac{dp}{d\theta})$ (bar/degree)	7.7	13.21	10.38	9.06	8.45	8.93
	θ @ max $(\frac{dp}{d\theta})$ (degree)	1.31	-0.4	-0.9	-2.5	-2.7	-2.8
	max $(\frac{d^2p}{d^2\theta})$ (bar/degree2)	6.02	8.89	7.38	6.91	5.59	6.77
	θ @ max $(\frac{d^2p}{d^2\theta})$ (degree)	0.81	-0.6	-2.2	-2.9	-1.7	-3.4
	max $(\frac{dQ}{d\theta})$ (J/degree)	99.94	177.14	142.78	126.99	123.59	131.01

	θ @ max $(\frac{dQ}{d\theta})$ (degree)	1.31	-0.4	-0.9	-2.5	-2.7	-2.8
	max $(\frac{d^2Q}{d^2\theta})$ (J/degree2)	78.1	122.68	105.54	104.2	90.99	108.68
	θ @ max $(\frac{d^2Q}{d^2\theta})$ (degree2)	0.81	-0.6	-2.2	-2.9	-1.7	-3.4
	IMEP (MPa)	0.47	0.88	0.9	1.05	1.17	1.17
Karanja	P_{max} (bar)	59.35	70.17	81.59	93.82	104.89	114.38
	θ @ P_{max} (degree)	5.41	5.71	5.21	7.21	7.41	7.81
	max $(\frac{dp}{d\theta})$ (bar/degree)	5.93	9.75	13.98	12.78	9.01	8.74
	θ @ max $(\frac{dp}{d\theta})$ (degree)	-0.8	-2.1	-2.3	-3.3	-4.3	-5.2
	max $(\frac{d^2p}{d^2\theta})$ (bar/degree2)	3.48	6.32	12.6	13.43	6.52	4.85
	θ @ max $(\frac{d^2p}{d^2\theta})$ (degree)	-1.4	-2.9	-2.5	-2.3	-3.3	-5.8
	max $(\frac{dQ}{d\theta})$ (J/degree)	71.07	119.82	181.09	167.29	115.86	115.96
	θ @ max $(\frac{dQ}{d\theta})$ (degree)	-0.8	-2.1	-2.3	-3.3	-4.3	-5.2
	max $(\frac{d^2Q}{d^2\theta})$ (J/degree2)	44.74	82.72	171.44	189.6	96.74	74.96
	θ @ max $(\frac{d^2Q}{d^2\theta})$ (degree2)	-1.4	-2.9	-2.5	-2.3	-3.3	-5.9
	IMEP (MPa)	0.43	0.64	0.91	1	1.07	1.23
Palm	P_{max} (bar)	59.55	71.44	83.29	93.25	103.51	109.59
	θ @ P_{max} (degree)	5.71	6.01	6.31	7.41	7.61	8.01
	max $(\frac{dp}{d\theta})$ (bar/degree)	6.72	9.01	10.73	8.42	8	7.11
	θ @ max $(\frac{dp}{d\theta})$ (degree)	-2.9	-2.3	-2.8	-4	-4.9	-5.1
	max $(\frac{d^2p}{d^2\theta})$ (bar/degree2)	5.33	3.95	9.22	5.62	6.18	3.91
	θ @ max $(\frac{d^2p}{d^2\theta})$ (degree)	-3.3	-4	-1.7	-4.5	-5.4	-5.5
	max $(\frac{dQ}{d\theta})$ (J/degree)	77.35	108.98	133.28	103.3	98.73	96.4
	θ @ max $(\frac{dQ}{d\theta})$ (degree)	-2.9	-2.3	-2.8	-4	-4.9	1.41
	max $(\frac{d^2Q}{d^2\theta})$ (J/degree2)	67.98	52.24	124.66	77.69	88.81	59.09
	θ @ max $(\frac{d^2Q}{d^2\theta})$ (degree2)	-3.3	-4	-1.7	-4.5	-5.4	-5.5
	IMEP (MPa)	0.46	0.65	0.81	0.92	1.06	1.18

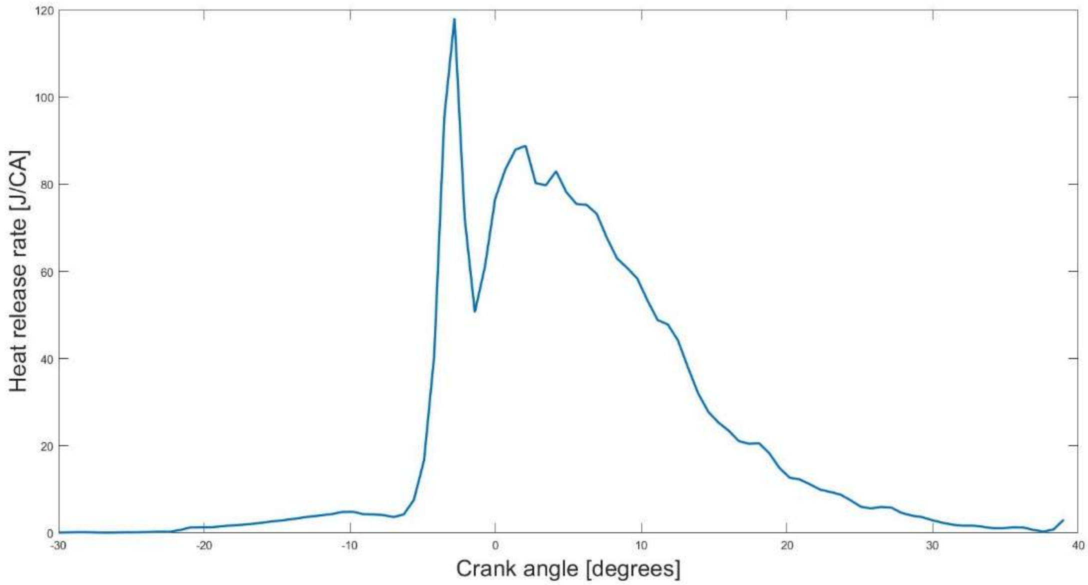

Figure 7: Heat release rate for diesel at 100% load

ii) Variation of the polytropic index with load and fuel

Table 2 shows the average values of polytropic index during compression and expansion. It is clear that the as load increase the average polytropic index increases. At higher load the variation in polytropic index is very small so at higher loads the polytropic index is more or less constant. In case of fuels, the polytropic index for the diesel fuel is somewhat higher than that of Karanja and palm. As the variation in the expansion and compression index for a given fuel is quite small, hence their average values are taken for further calculations.

Table 2: Polytropic index for different fuel at different engine loads

Load (%)	Diesel			Karanja			Palm		
	n_c	n_e	n_{avg}	n_c	n_e	n_{avg}	n_c	n_e	n_{avg}
0	1.32	1.49	1.4	1.32	1.49	1.4	1.34	1.49	1.42
20	1.35	1.39	1.37	1.34	1.43	1.38	1.35	1.42	1.39
40	1.35	1.37	1.36	1.35	1.4	1.37	1.36	1.41	1.38
60	1.35	1.33	1.34	1.35	1.37	1.36	1.35	1.39	1.37
80	1.35	1.29	1.32	1.36	1.35	1.35	1.36	1.37	1.36
100	1.35	1.3	1.32	1.36	1.33	1.34	1.36	1.34	1.35

iii) Variation of combustion duration with load and fuel

Table 3 includes the values of combustion duration for 3 fuels at different engine loads determined from energy and LogP-LogV methods. The values from LogP-LogV are somewhat higher than those obtained from the energy method. Since LogP-LogV method is based on mathematical criteria and hence believed to give more exact values than those obtained from the energy method. However, an average values of combustion duration from these two methods viz energy and LogP-LogV, as given in Table 4, are chosen for use in Wiebe function.

Table 3: Combustion duration in degrees crank angles

Load (%)	Diesel		Karanja		Palm	
	Energy method	LogP-LogV method	Energy method	LogP-LogV method	Energy method	LogP-LogV method
0	20.62	20.6	20.82	16.0	24.57	25.0
20	23.27	25.9	21.79	21.0	23.83	21.6
40	25.59	25.0	21.77	24.2	23.21	24.1
60	29.55	28.7	22.73	25.4	23.54	23.0
80	30.52	30.5	24.39	25.7	25.60	28.2
100	30.68	31.9	27.36	28.8	28.23	32.3

Table 4: Average combustion duration in degrees CA

Fuel	Load (%)					
	0	20	40	60	80	100
Diesel	20.61	24.59	25.3	29.13	30.51	31.29
Karanja	18.41	21.4	22.99	24.07	25.05	28.08
Palm	24.79	22.72	23.66	23.27	26.91	30.27

iv) Variation of Efficiency parameter

Table 5 includes the values of the Efficiency parameters for three fuels at different loads determined by MFB. It is observed that the Efficiency parameters determined from MFB curves deduced from the two methods is not significantly different. A typical mass burnt fraction (MBF) curve for diesel at 100% load using RW and energy methods is shown in Fig 8.

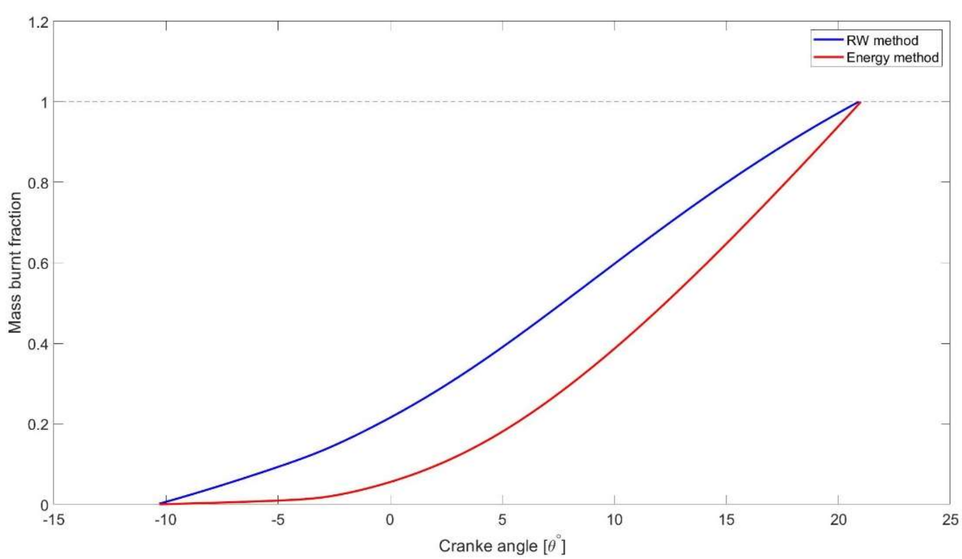

Figure 8: Typical mass burnt fraction (MBF) curves for diesel at 100% load

From the tabulated values of efficiency parameter, it is observed that even across load the variation of efficiency parameter is not much and an average value of efficiency parameter for each of these methods shown in Table 6 is chosen in calculation of the form factor, These values of the efficiency parameter which suggests how efficient is the combustion process, it is evident that the diesel combustion process seems to be somewhat better than those of two biodiesel fuels.

Table 5: Efficiency parameter 'a'

Load (%)	Diesel		Karanja		Palm	
	Energy method	RW method	Energy method	RW method	Energy method	RW method
	a	a	a	a	a	a
0	2.39	2.52	2.31	2.46	2.26	2.59
20	2.4	2.58	2.33	2.52	2.34	2.52
40	2.37	2.54	2.32	2.54	2.33	2.53
60	2.42	2.56	2.3	2.51	2.29	2.47
80	2.42	2.55	2.33	2.52	2.36	2.53
100	2.42	2.56	2.35	2.58	2.39	2.59

Table 6: Average value of efficiency parameter 'a'

Fuel	**Diesel**		**Karanja**		**Palm**	
Methods	Energy method	RW method	Energy method	RW method	Energy method	RW method
a	2.4	2.55	2.32	2.52	2.32	2.53

v) **Variation of Form factor**

Using the constant values of the efficiency parameters given in Table 7, the form factors are calculated and its variations are plotted in the Fig. 9. From the figure, it is seen that the form factor increases with respect to the load. For diesel fuel, the form factor is more than Karanja and palm.

Table 7: Wiebe Law – Suggested values of form parameter 'm'

Load (%)	Diesel		Karanja		Palm	
	Energy method (a = 2.40)	RW method (a = 2.55)	Energy method (a = 2.32)	RW method (a = 2.52)	Energy method (a = 2.32)	RW method (a = 2.53)
	m	m	m	m	m	m
0	1.96	0.89	1.64	0.82	1.5	0.66
20	1.99	1.03	1.57	0.86	1.72	0.92
40	2.18	1.11	1.58	0.89	1.73	0.95
60	2.48	1.21	1.74	0.98	1.89	1.04
80	2.62	1.26	1.85	1.04	2.1	1.09
100	2.62	1.25	1.95	1.02	2.25	1.12

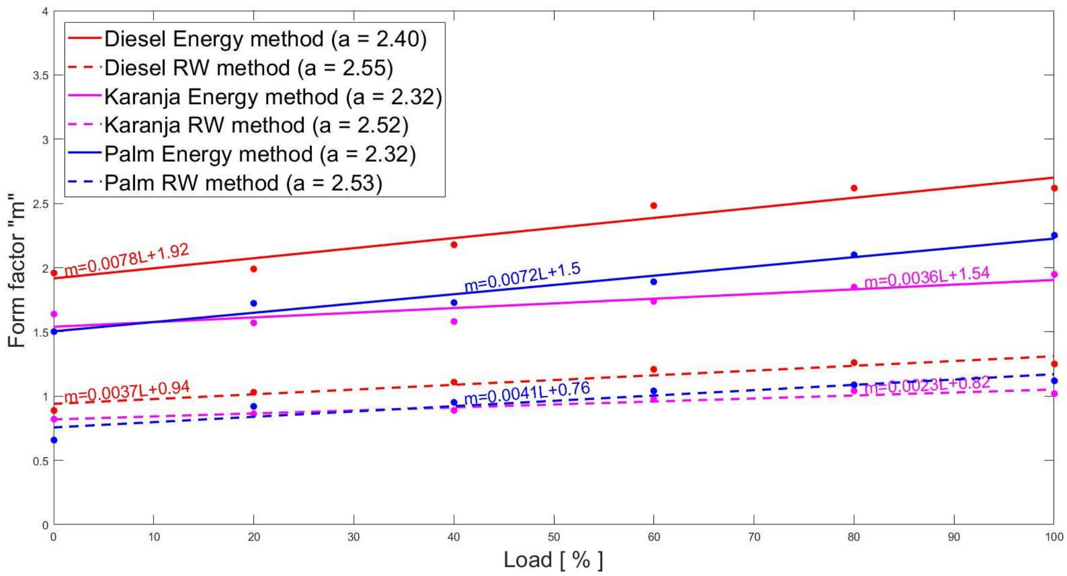

Figure 9: Variation of form factor with load and fuel

6.0 Conclusions

From the engine combustion analysis carried out in this work, the following can be summarized as useful outcome and inferences.

1) The mass burnt fractions/ energy release rate histories are deduced from experimental cylinder pressure histories at different engine loads and fuel types using two methods viz. Rassweiler-Withrow (RW) and Apparent Energy methods to establish Wiebe burn rate law
2) The values of various important combustion parameters like peak pressure, rate pressure rises, second derivative of pressure rise, maximum energy release, second derivative of energy release and occurrence for each test data are obtained as included in Table 1
3) The estimation of polytropic index, combustion duration and Wiebe parameters (form factor, and efficiency parameter) using various approaches are made in this analysis and their variations with engine load and the test fuels for which experimental pressure time data were available are shown. It is inferred that
    i) the average polytropic index in diesel engine case though slightly varies with load but more or less seems constant at higher loads. In case of fuels, the polytropic index for the diesel fuel is somewhat higher than that of Karanja and palm.
    ii) the values of combustion duration for 3 fuels from LogP-LogV and the energy methods are slightly at variance However, values from LogP-LogV method seem more accurate. However, an average values of combustion duration from these two methods viz energy and LogP-LogV are chosen for use in Wiebe function.
    iii) The variation of efficiency parameter obtained from two approaches at various loads (Table 5) is not significant. It is evident that the diesel combustion process seems to be marginally better than those of two biodiesel fuels.
    iv) It is observed that the form factor increases linearly with respect to the load. For diesel fuel, the form factor is more than Karanja and palm. The recommended values of form parameters in Wiebe Burn Rate Law for the three fuels are given in Table 7.

7.0 Future Work

Since typical diesel engine energy release curves shows two independent sages of combustion, this analysis can be extended using double Wiebe function. The approach can be implemented in ECU development to control the various parameter of engine like amount of fuel to be injected, valve timings, spark timings etc. for optimum operation.

8.0 References

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9.0 Appendix 1: Test engine specifications

Manufacturer and model	Eicher E483 TCI
Engine Type	4 stroke, 4 cylinders inline, Turbocharged, Direct Injection, Compression Ignition
Combustion system	Re-entrant type
Bore x Stroke	100 X 105 mm
Compression Ratio	17.5: 1
Bowl Dimensions (Dia. X Depth)	54 x 15.7 mm
Rated Power (kW)	70 (at 3200 rpm)
Rated Torque (Nm)	285 (at 1400 rpm)
Injection System	Rotary Distributed Type
Nozzle Opening Pressure	230 bar
Cooling System	Forced Water Circulation