# Modeling and Energy Analysis of a Diesel and Biodiesel Fuelled Engine

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**Abstract:** *Modeling has been used to investigate the combustion performance of a single cylinder direct injection diesel engine fueled by biodiesel like cotton seed oil. The focus of the present study is to review the different available model used for modeling of CI engines. The modeling of CI engine is divided into single zone, multizone and multi-dimensional model. The model evaluation is made based on the time complexity, space complexity, and prediction accuracy using the developed computer program like MATLAB. Our focus is on single zone model which further subdivided in many submodel i.e. heat release rate, heat transfer, ignition delay period, droplet evaporation, intake and exhaust flow and combustion model. The numerical simulation was performed with the standard specification of a CI engine by using MATLAB software with least time.*

**Keywords:** Transesterification, CI engine, Numerical modeling, Combustion parameters, Simulation

## 1. Introduction

Engine simulation has been extensively used to improve the engine performance. Compression ignition direct injection (CIDI) diesel engines have been widely used in heavy-duty vehicle, marine transportation and now have been increasingly being used in light duty vehicles, particularly in Europe and Japan Experimental work which is aimed at fuel economy and low pollutants emission for IC engine requires change in input parameter which is highly demanding in terms of money and time. So, in order to overcome this drawback, an alternative simulation of engine performance with the help of mathematical model and powerful digital computers lowers the cost and time.[2]

In these simulation models, the effect of various design structures like design of combustion chamber input parameters (intake pressure, injection timing, etc.) and operation changes (compression ratio, speed, etc.) can be estimated in fast and non-expensive way provided that main mechanism are recognized and modeled perfectly to meet the experimental results. [5]

Depending upon the various possible applications different types of models for diesel engine combustion process have been in use. In the order of increased complexity and increased computer system requirements these can be classified as single zone model models, quasi dimensional phenomenological models and Multidimensional computational fluid dynamics models. These models can reduce the number of experiments. [7]

In case of single zone model cylinder temperature, pressure and mass can be obtained from ordinary differential equations by using the first law of thermodynamics and equation of state in each process. Biodiesel (cotton seed oil) have become an alternate to petro diesel in the view of the faster depletion of petro diesel. Understanding the aspects of biodiesel combustion is now possible with the simulation models. The measured pressure rise in an engine is used to tune the model and helps in calculating the rate of heat release from the engine cylinder.[6]

## 2. Transesterification of Oil

Several processes have been developed for the production of biodiesel, among which trasesterification process is widely used.

The formation of methyl esters by transesterification of vegetable oil requires raw oil (Cotton seed oil), 15% of methanol and 5%of KOH on mass basis. However, transesterification is an equilibrium reaction in which excess alcohol is required to derive the reaction with an alcohol in presence of a catalyst to produce methyl esters. Glycerol was produced as a by-product of transesterification reaction. The mixture was heated at temperature of $55^0$C to $60^0$C and stirred continuously and then allowed to settle under gravity in a separating funnel. Two distinct layers form after gravity settling for 24 hrs. The upper layer was of Cotton seed oil methyl esters and lower was of glycerol. The lower layer was separated out. The separated Cotton seed oil methyl ester was mixed with some warm water (around 10% volume of ester) to remove the catalyst present in ester and allowed to settle under gravity for another 24 hrs. The catalyst got dissolved in water, which was separated and removed the moisture. The cotton seed oil methyl ester was then blended with mineral diesel in various concentrations for preparing biodiesel blends to be used in CI engine for conducting various engine tests. [15]. In this study biodiesel is used as an alternate fuel in diesel engine. Prepared biodiesel is mixed with neat diesel in various concentrations (10%,&20%) by volume and is termed as BD10, BD20 respectively.

The properties of different biodiesel blends were found out which are as follows;

**Table 1:** Properties of diesel and biodiesel

| Properties | Diesel | B20 | KME (B100) |
|---|---|---|---|
| Density [kg/m3] | 831 | 836 | 875 |
| Viscosity at 40° C [cSt] | 2.6 | 4.9 | 5.2 |
| Flash point [° C] | 55 | 110 | 174 |
| Calorific value [MJ/Kg] | 43 | 42.8 | 38.3 |

## 3. Test Engine and Experimental Procedure

The experiment was conducted on 4 stroke, single cylinder, direct injection diesel engine. It is integrated with speed sensors, pressure transducers, thermocouples, air flow meters, fuel flow meters and in-line torque meter. The specification of test engine is given is table 2.

**Table 2:** Specifications of test engine

| Make | Comet |
|---|---|
| Type | 4 Stroke, direct injection |
| Bore | 80 mm |
| Stroke | 110 mm |
| No. of Cylinder | 1 |
| Injection Pressure | 200 bar |
| Compression ratio | 16:1 |
| Rated power | 3.7 KW @ 1500 rpm |
| Cooling type | Air cooled |
| Loading type | Eddy current dynamometer |

The control panel is attached with the test engine for monitoring the engine operations. This control panel is connected with the computer on which we can visualize the performance and combustion characteristics. The test rig is installed with ICE software for obtaining various curves and results during operation. Calorimeter is provided to find out the heat carried away by exhaust gas. Test engine is equipped with eddy current dynamometer as shown in figure 1.
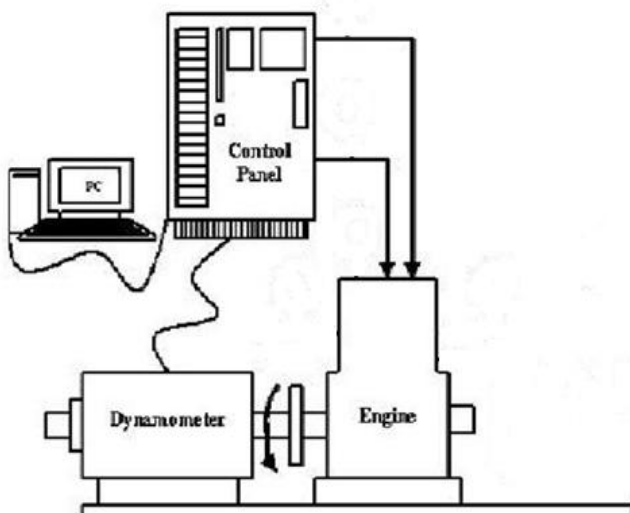


**Figure 1:** Schematic diagram of Experimental Setup

Initially, the experiment was conducted on pure diesel at constant speed 1500 rpm. The engine was operated for 10 minutes at each load without taking data to stabilize the engine under new condition. This is done to ensure that fuel from previous measurements remaining in flow meter, fuel filter and fuel pipes have been removed. The basic input values of engine parameters and fuels were provided and the experiment is carried out. The results were recorded for variable loads using eddy current dynamometer. The above procedure was repeated at same operating conditions for all the biodiesel blends. The types of blends (B10 & B20) were used in this experiment.

## 4. Theoretical Analysis

The present work is deals with the combustion modeling of CI engine. This combustion modeling is carried out on the basis of first law of thermodynamics. Suitable correlations and models are considered to find out the combustion parameters.

### 4.1 Pressure Vs Crank Angle

Pressure is predicted by using first law with heat release rate modeled with wiebe function and compare with experimental pressure data at different loads. Pressure curves for various heat release pattern can be calculated by solving ordinary deferential equation using forth order Runge Kutta method.[1]

$$\frac{dP}{d\theta} = \frac{\gamma - 1}{V}\left(\frac{dQ_{gr}}{d\theta} - \frac{dQ_w}{d\theta}\right) + \gamma\frac{P}{V}\frac{dV}{d\theta}$$

Once it is solved for pressure, temperature can be calculated using the equation obtained from the equation of state,

$$T_{cal} = P_{cal}V_{cal}\frac{T_{ref}}{P_{ref}V_{ref}}$$

$$tmp = x + (y/4) + 3.773 * \lambda * y_{cc} + (\lambda - 1) * y_{cc} \quad (3)$$

### 4.2 Volume at any crank angle

The cylinder volume at any crank angle is calculated from given equation [8]:

$$V = \frac{Vd}{r-1} + \frac{Vd}{2}\left[R + 1 - cos\theta - \sqrt{(R^2 - sin^2\theta)}\right] \quad (4)$$

Where,
r – Compression ratio
L – Connecting rod length
S – Stroke
Θ – Crank angle position

### 4.3 Pressure and Temperature During Compression

The initial pressure and temperature at the beginning of the compression process is calculated as follows [8];

$$P_2 = \left(\frac{V_1}{V_2}\right) * \left(\frac{T_2}{T_1}\right) * P_1 \tag{5}$$

and

$$T_2 = T_1 * \left(\frac{V_1}{V_2}\right)^{\frac{R}{C_v(T_1)}} \tag{6}$$

### 4.4 Heat Transfer Model

The gas-wall heat transfer is found out using following formula [3]:

$$\frac{dQ_{ht}}{dt} = h_c A_c (T_g - T_w) \tag{7}$$

Where,
 hc - Heat transfer coefficient (w/m2K)
Ac - Convection heat transfer area (m2)
Tg & Tw are gas and wall temperature respectively (K)

Heat transfer coefficient correlation given by Hohenberg has been used to calculate convective heat transfer [16]:

$$h = 130. V^{-0.006}. p^{0.8}. T^{-0.4} (\bar{v}_p + 1.4)^{0.8} \tag{8}$$

Where,
P - Pressure
T - Temperature
V - Volume of the cylinder
V p - Mean piston speed, V p = 2LN/60

### 4.5 Combustion Model

The combustion of fuel and air is a very complex process, and would require extensive modeling to fully capture. In this work Wiebe model is used which some time is spelled Wiebe function to simulate the combustion process. [12]
Rate of heat release can be predict using following weibe formula

$$\frac{dQ}{d\theta} = na \frac{Q_{in}}{\theta_d} \exp\left[-a\left(\frac{\theta-\theta_s}{\theta_d}\right)^n\right] \times \left(\frac{\theta-\theta_s}{\theta_d}\right)^{n-1} \quad [9]$$

Where
$\theta =$ Crank angle
$\theta_s =$ Start of combustion
$\theta_s =$ X+ID
X= fuel injection angle
ID= ignition delay in deg
$\theta_d =$ Heat release duration
$n =$ Weibe form factor
$a =$ Weibe efficiency factor
$Qin = m_f \times L.H.V.$
Pressure prediction from predicted heat release rate

$$\frac{dP}{d\theta} = \frac{\lambda-1}{\gamma}\left[\frac{dQ}{d\theta} - \frac{dQ_w}{d\theta}\right] - \gamma\frac{P}{V}\frac{dV}{d\theta}$$

### 4.6 Ignition Delay

Ignition delay in direct injection diesel engines is of great interest to researchers and engineers because of its direct impact on the intensity of heat release rate. The delay period is composed of a physical and chemical delay. An empirical formula developed by Hardenberg and Hase for predicting the duration of the ignition delay in diesel engine. It is given in terms of crank angle [16].

$$\tau = (0.36 + 0.22V_p)Exp\left[E_a\left(\frac{1}{RT} - \frac{1}{17190}\right)\left(\frac{21.1}{P-12.4}\right)^{0.63}\right] \tag{11}$$

Where,
 V p - Mean piston speed (m/s)
R - Universal gas constant (8.3143 J/mol-K)
Ea - Apparent activation energy
Ea = 618840/ (CN+25)
CN - Cetane number.

## 5. Results and Discussions

In this study combustion parameters like cylinder pressure, heat release rate, ignition delay and combustion zone temperature are discussed. Simulated curve has been tuned with experimental curve for various load conditions to find out the shape parameters of the functions. Correlation for these shape parameters are modified with adjusting coefficients using the least square curve fitting method.

### 5.1 Cylinder Pressure

Experimental data for 1500 rpm and different blend condition ranging 10% and 20% of 50% load has been used to fit the simulated heat release rate curve and coefficients are adjusted. Resulting model is then validated with the experimental pressure data. Figure 2 & 3 show the cylinder pressure and crank angle. it can be seen that model showing good agreement between experimental versus simulated data, for all loads at constant speed particularly for maximum pressure and respective crank angle.
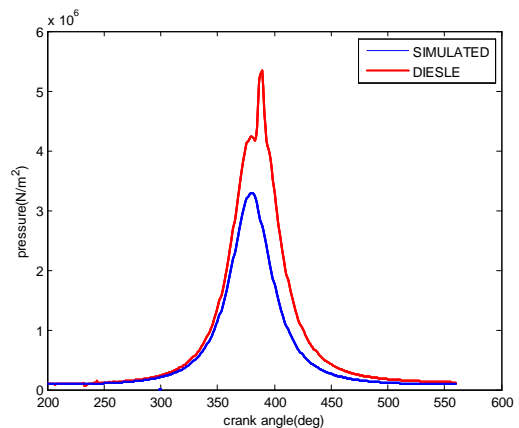


**Figure 2:** In-cylinder pressure vs. crank angle

However during post combustion pressure is over predicted by the model. This is the main drawback of this model because for the diesel engine combustion as the ideal heat release rate is having two curves one for premixed and one

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for diffusion the duel wiebe heat release approximation should have been used. It should be clear that data used for crating simulation cannot be used for validating the model because this data will show high approximation with the simulation and hence data for validation is obtained independently from the data used for simulation. And a correctly correlated (simulated) model will reproduce the accurate result for all the variations of speed and load.
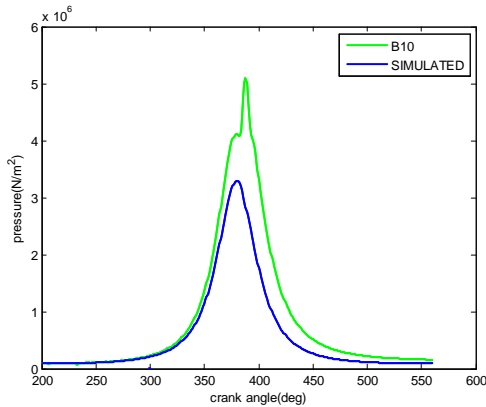


**Figure 3:** Comparison of experimental and predicted in-cylinder pressure for B10

### 5.2 Heat Release Rate

The heat release rate for different blends is shown in figure 4. Heat release rate during pre-mixed combustion is responsible for high peak pressure and high peak pressure means high rate of heat release. Superior volatility of diesel fuel ensures better air fuel mixing relatively higher heat release takes place when piston is at TDC. At lower engine loads, the heat release pattern is similar for diesel and biodiesel. However at higher loads, biodiesel blends showed quite well heat release rate during mixing controlled combustion this is due to the lower volatility and higher viscosity. Fig 4 show that Heat Release rate is peak for a small crank angle rotations.(12-25deg) at different Loads. As the load on engine reduced the heat release rate get decreases as shown in graph
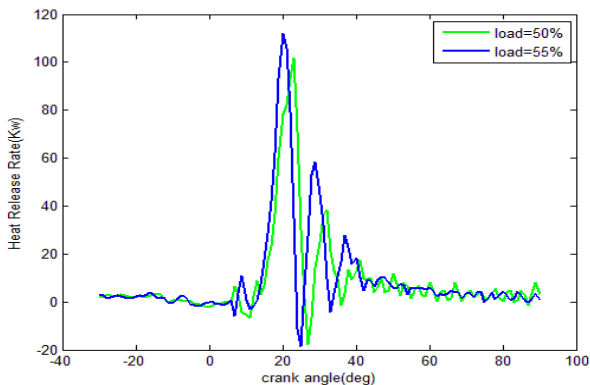


**Figure 4:** Heat release rate vs. crank angle

### 5.3 Heat transfer

Heat loss through cylinder wall occurred via radiation and convection. Hohenberge's correlation is applied to calculate heat loss through cylinder wall. The variation of engine heat transfer with crank angle is shown in figure 6. It has been observed that Heat losses increase with temperature since heat loss is proportion to temperature difference inside the cylinder. It is observed that the heat loss rate is maximum at 70% load and lower in 50% load.
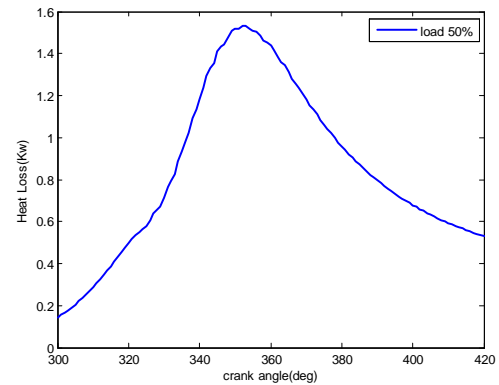


**Figure 6:** Heat loss vs. crank angle

### 5.4 In-cylinder temperature

The temperature distribution inside the engine cylinder at different crank angle position is shown in figure 6. High pressure results in high temperature. High peak pressure is obtained for pure diesel as compared to biodiesel.
1. Temperature Variations with various crank angle is obtained by the above characteristic gas equations.
2. It is observed that the temp is maximum when the piston reaches TDC and after that piston comes towards BDC that is during expansion stroke.
3. During the expansion of gases the temperature decrease Different curve at different load is plotted, it is observed that as load on engine increases the temperature increases. Higher temperature limit is obtained at 20% blend.
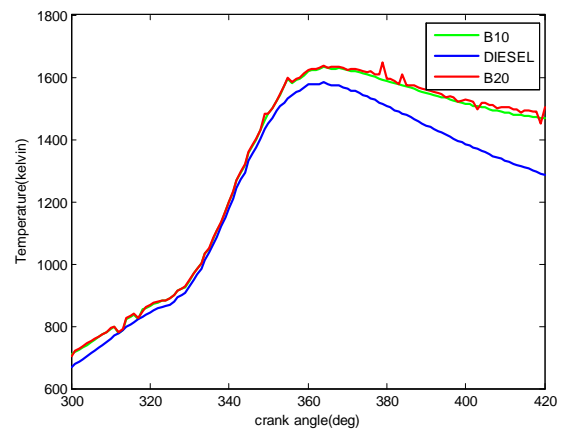


**Figure 6:** Temperature vs. crank angle

## 6. Conclusion

In a modeling and energy analysis, zero dimensional single zone combustion model simulation has been carried out to predict the single cylinder constant speed diesel engine performance. present study deals with experimental calculation and simulation of Rate of heat release and pressure for the diesel engine fuelled with biodiesel (10% & 20%). Following are the analysis done:

1. The engine performance improved with low quantity blends of biodiesel to diesel, this indicated by the higher maximum combustion temperature and pressure and are shown in graph.
2. Obtained the pressure and temperature variations inside the cylinder using the combustion correlations which give similar simulated results with experimental results
3. Heat loss can effectively studied with this simulations
4. Modifying the equations if necessary so that it could be applied over a much wider range of speed and load.
5. Simulation on model by using MATLAB software is easier and has wide scope for any micro analysis of engine performance.
6. The results of the present models are well in agreement with experimental result.

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