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Simulation Of Compression Ignition Engine Using Model Predictive Controller And PID Controller

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Abstract**—*Help of mathematical equations and solving we can understand the nature of modeling in science and engineering. Recent years, engineers concentrates in direction of designing better performing engines with lower emissions. In this reason, modeling of engine combustion processes supposes to be importance. Modeling has been used to analyses the combustion performance of a single cylinder direct injection diesel engine fueled by biodiesel like cotton seed oil. Modeling is based on the time complexity, space complexity, and prediction accuracy using the developed computer program like MATLAB. In our work focus on single zone model which further subdivided in many sub model like heat release rate, heat transfer, ignition delay period, droplet evaporation, intake and exhaust flow and combustion model. The simulation was presented with the standard specification of a CI engine by using MATLAB software with least time. Finally proposed results compare with existing PID controller and get best results.***

Keywords—CI engine; heat transfer;MPC;PID controller

I. Introduction

Engine simulation has been widely used to increase the engine performance. Compression ignition direct injection (CIDI) diesel engines have been extensively used in heavy-duty vehicle, marine transportation and now have been improvingly being used in soft duty vehicles, particularly in china and Japan Experimental work which is aimed at fuel economy and less pollutants emission for IC engine requires change in input parameter which is highly need in terms of money and time. So, in order to overcome this disadvantages, an another simulation of engine efficiency with the help of mathematical model and powerful digital system reduce the cost and time.[2] In these project simulation models, the effect of more other design structures like design of combustion chamber input constants (intake pressure, injection timing, etc.) and operation variations (compression ratio, speed, etc.) can be valued in fast and low cost way provided that main mechanism are accepted and modeled perfectly to meet the experimental results. [5] Provisional upon the various possible applications variant types of models for diesel engine combustion process has been in use. In the order of expanded complexity and expanded computer system needs these can be classified as single zone models, quasi dimensional models and Multidimensional computational fluid dynamics models. These models can decrease the number of experiments. [7].

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

II. Literature Review

Many authors have directed experiments in the area of simulation of IC engine. Few of them have been discussed below.

A S Ramadhaset al. (2006) described a theoretical and mathematical model to check and analyze the performance characteristics regarding the compression ignition engine. The various effects like the compression ratio, heat release analysis, fuel air ratio are checked using the model. Results of the experimentation and simulation were compared. M P Sudeshkumaret al. (2011) the paper depicts the thermodynamic model and heat transfer model using a numerical simulation that helps to simulate and predict the combustion characteristics of a compression ignition using Diesel as a fuel. A two zone model is used for this purpose. One zone called burned zone and other called unburned zone. To get cylinder pressure and the corresponding temperature, first rule of thermodynamics and combustion calculations were used. An experimentation setup is done inorder to compare the results which is obtained by the help of simulation. Results were almost same in both experimentation and simulation. Ajay Kolheet al. (2015) describes the development of models for analysing the combustion constants, of IC engine. The mathematical model is developed using Computational Fluid Dynamics. Experimentation setup is done using single cylinder compression engine. Parameters measured are cylinder pressure and heat release. Modelling of Diesel peak is also carried out. Then the experimentation and numerical simulation results are compared to analyze the correlation between the two results obtained, which includes cylinder pressure, heat release. ParamustJuntarakodet al. (2014) represents the multi zone model development for simulating IC engine using diesel as a fuel. This paper shows the performance characteristics and thermal efficiency. Even a quasi-dimensional thermodynamic model is improved using MATLAB software. Zero dimensional model is also worked for diesel cycle simulations. The ultimate results was calculated and some constants were less close to actual result and some were almost similar enough regarding both the experimentation and simulation results. Marcin Slezaket al. (2007) Various assumptions are made for the development of thermodynamic and fluid model. Thermodynamic, chemical kinetics model were developed for analyzing and simulating the combustion process in compression ignition engine and to estimate the engine parameters. The engine is used four stroke single cylinder. The temperature between the walls of the cylinder and the temperature of the charge, their difference is measure using the mathematical model. And, finally both the experimentation and the simulated results are compared. Dheeraj Deshmukh, et al. (2013) shows the development of mathematical model for stationary compression ignition engine and analysis. Modeling is carried out for obtaining the variables for stationary engine. Load on engine, back pressure, engine speed are considered. The back pressure acting on engine is the key factor which basically deteriorates the engine and emission control parameters.

III. PROPOSED WORK(MPC)

Since the 1980s in synthetic plants and petroleum refineries factories has been used advanced control process by Model predictive control (MPC) method. In current years it has also been used in power system balancing and controlling models. Model predictive controllers build on productive models of the process, most times linear empirical models acquired by system identification. The main advantage of MPC is the fact that it let the current timeslot to be optimized, while keeping future timeslots in account. This is completed by optimizing a finite time-horizon, but only implementing the current timeslot. MPC has the ability to anticipate future events and can take control actions accordingly. PID and LQR controllers do not have this predicting capacity. MPC is nearly universally implemented as a digital control, although there is research into achieving faster response times with specially designed analog circuitry

Model predictive control (MPC) is a well-developed technology for advanced process control (APC) in many factorial applications like blending, factories, kilns, power station and distillation columns. This paper explains the challenges of existed MPC implementation and introduces a new configuration-free MPC implementation concept. MPC technology has the proven ability to provide control solutions using constraints, feed-forward, and feedback to handle multivariable processes with delays and processes with strong interactive loops. These types of control problems have effectively been handled in many factory applications.

Using model predictive control brings many benefits. For example, there is low change in process variables, which allows set points to be seleccted that are closer to performance boundaries, which in turn leads to an increased throughput and a higher profit. MPC brings a structured approach to solutions that would otherwise consist of combinations of feed-forward and feedback with PID (proportional integral derivative) controllers, possibly with override functions.

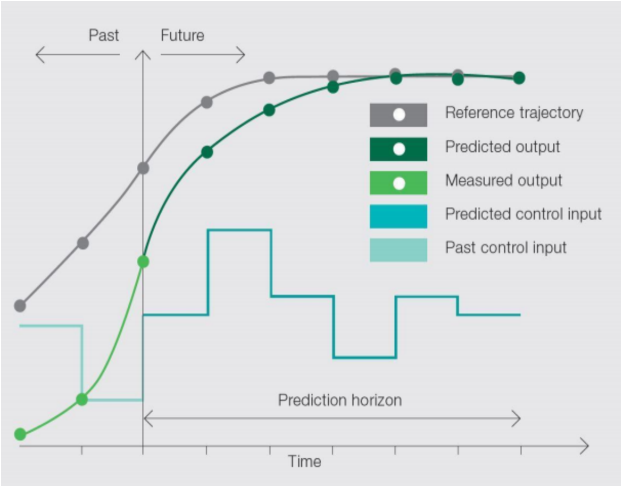

Fig. 1: Prediction horizon

Principles of MPC: Model Predictive Control (MPC) is a multivariable control algorithm that uses:

- An internal dynamic model of the process
- A history of past control moves and
- An optimization cost function over the retreating estimate horizon, to calculate the optimum control moves.

A .Test engine and experimental procedure

The research was conducted on 4 stroke, single cylinder, direct injection diesel engine. It is combined 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 1.

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Table 1: 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 connected with the test engine for monitoring the engine operations. This control panel is interfaced with the computer on which we can visualize the efficiency and combustion characteristics. The test rig is installed with ICE software for obtaining various graphs and results during operation. Calorimeter is connected to our model to find out the heat carried away by exhaust gas. Test engine is connected with eddy current dynamometer as shown in figure 2.

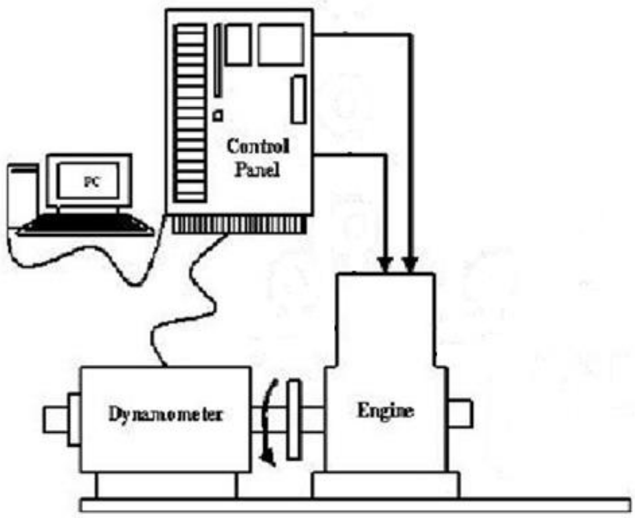

Figure 2: Schematic diagram of Research Setup

Initially, the research was conducted on pure diesel at only speed 1500 rpm. The engine was operated for 10 minutes at each load without taking data to stable the engine under new condition. This is done to ensure that fuel from existing results remaining in flow meter, fuel filter and fuel pipes have been taken away. The basic input values of engine parameters and fuels were provided and the experiment is carried out. The results were noted for variable loads using eddy current dynamometer. The above all procedure was repeated at same operating conditions for all the biodiesel blends.

B. Modeling Theoretical analysis

The present work is deals with the combustion engine model. 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.

i. Pressure Vs Crank Angle

Pressure is estimated by using first law with heat release rate modeled with wiebe function and compare with research pressure data at different loads .Pressure curves for various heat release pattern can be calculated by solving ODE using 4th 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 measured using the equation obtained from the equation of state,

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

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

ii. Volume at any crank angle

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

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

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

iii. Pressure and temperature during compression

The initial pressure and temperature at the beginning of the compression process is calculated as follows

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

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

iv. Heat transfer model

The gas-wall heat transfer is found out using following formula

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

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

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

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

v. combustion model

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

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

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

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

vi. Ignition delay

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

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

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.

IV. Results and Discussions

The figure 3 shows the comparison of Volume measured by using MPC and PID controller in a Single Cylinder Diesel Engine. It is observed that there is a difference in volume measurement. The Volume measured using MPC occurs at the start of the suction process when the Volume is around 800cc and the crank angle is 0° i.e. at the start. Then the volume dips during the compression stroke around 200cc and it again rises during combustion stroke above 800cc approx. There is a difference in measurement of MPC and PID controller that is because the PID controller considers more number of errors compared to that of MPC. Thus, the measurement done with help of PID is more accurate compared to that of MPC.

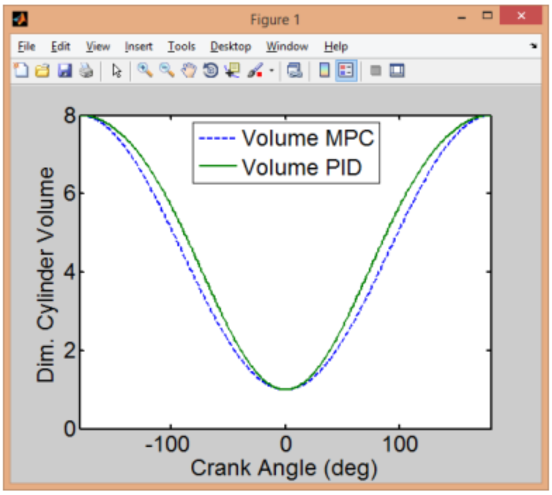

Figure 3: Volume (MPC) v/s Volume (PID)

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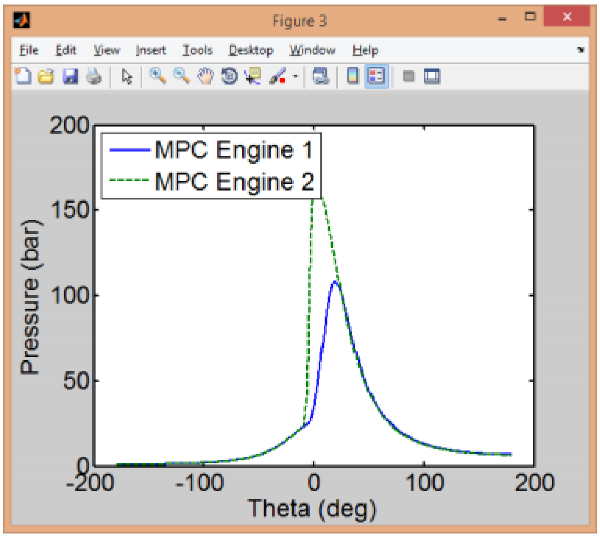

Figure 4: Pressure with respect to Crank Angle

The above figure depicts the use of MPC controller in a Single Cylinder Engine where the pressure is measured with respect to the crank angle. As the graph depicts two engines have been considered, the difference observed is the change in the pressure with respect to the actual cycle. As its observed the compression stroke for engine one starts at around 30bar while that of engine one starts at 20bar and for engine two the pressure rises extensively over 150bar and falls immediately after the power stroke. While, that of engine one the pressure increases gradually around 100bar and then reduces over the entire combustion process.

In the figure 5 the work done is measured in two different engines using MPC controller. The graph shows at the start of the combustion process the work done is Zero. When the crank angle increases according to the combustion process the work done increases rapidly. The work done according to the graph goes up to 20J till the end of the exhaust stroke. As we can observe the graph increases gradually. Both the engine has a slight difference from the start of the process. A slight delay occurs in Engine 2 compared to that of Engine 1.

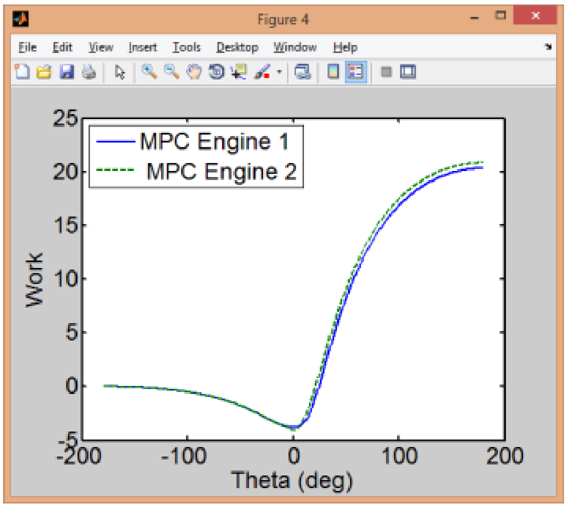

Figure 5: Work with respect with Crank Angle using MPC

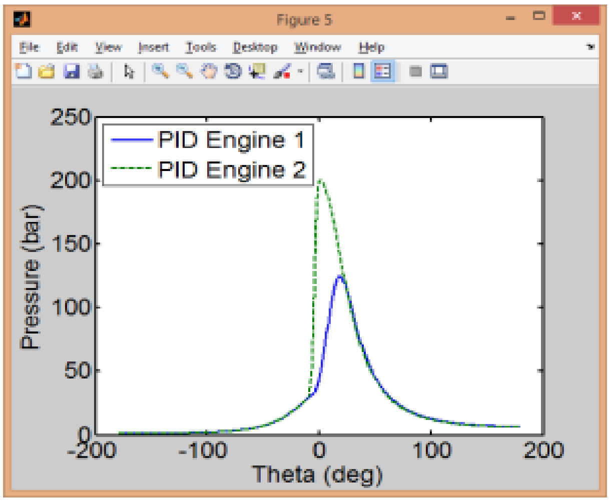

Figure 6: Pressure with respect to the crank angle using PID controller

In this figure 6 graph Two different engines with pressure parameters are compared, with respect to the crank angles. As we can observe, like MPC, there is not much change when in PID controller. The graph shows the change in pressure as the process continues. The Engine 2 pressure rapidly increases and falls immediately after the combustion stroke. Same goes with Engine 1 but the pressure achieved is very less compared to that of Engine 2. Overall it represents the actual Pressure crank angle diagram of the Diesel Cycle.

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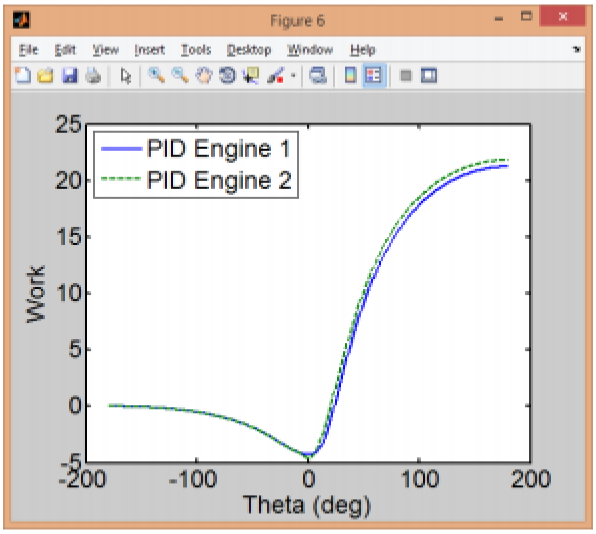

Figure 7 : Work done in terms of Crank angle using PID

As the figure 7 shows it represents work done with respect to the crank angle as the combustion progress. The work done of both the engines are almost same with a slight difference. The work done increases gradually from the start of the crank angle to the end of the process. The engine 1 represents a slight delay than the engine 2. Rest all the results do match with that of the MPC controller.

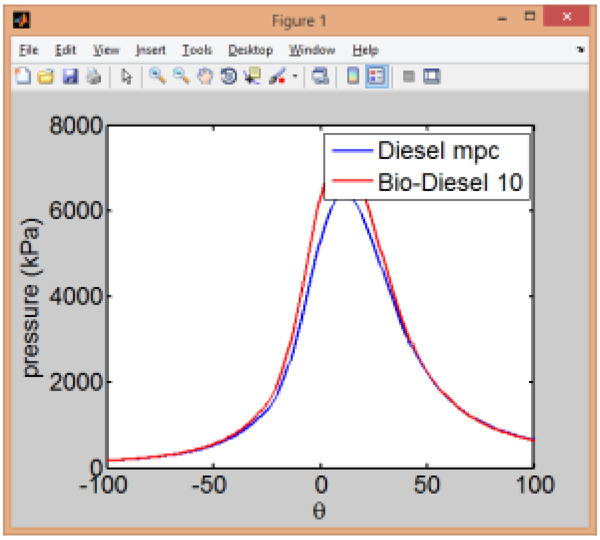

Figure 8 : Engine fuelled with Diesel and Biodiesel B10 using MPC

The figure 8 shows the pressure difference with respect to the crank angle by using diesel as a fuel.

The figure 9 depicts the temperature measured by using Biodiesel using MPC and PID controller. The temperature is almost same as that of the Diesel at the start of the combustion process. The temperature gradually increases as the combustion process takes place and achieves around 970k when measure

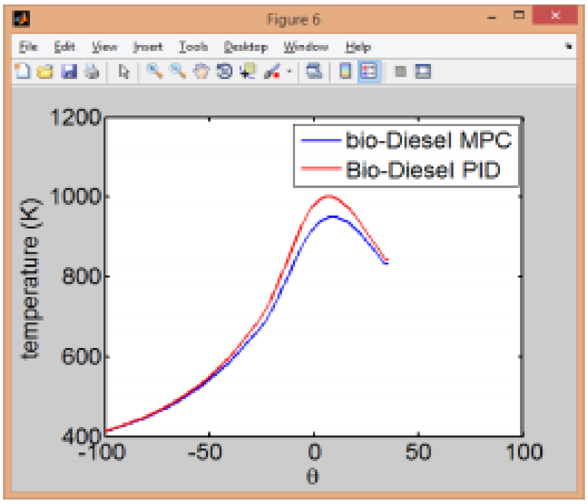

Figure 9: Temperature with respect to crank angle by using Biodiesel

by PID and around 930k when measured by PID. There is not much of a difference when we compare the maximum temperature which is measured by these controllers. But, PID controller is more apt than the MPC controller.

V. CONCLUSION

In a proposed modeling and energy analysis, zero dimensional single zone combustion model simulation has been taken out to estimate the single cylinder constant speed diesel engine efficiency 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 study with this simulation.

In future work to modifying the equations if necessary so that it could be applied over a much wider range of speed and load and also simulation on model algorithms and simulations can be carried out in an advanced way and to get more perfect results by using Artificial Neural Network (ANN).

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