Exergy Analysis of CI Engine Fuelled with Diesel and Biodiesel

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Abstract— This paper deals with the application of second law of thermodynamics to internal combustion engine. The general exergy balance equation of the engine cylinder and for their subsystem has been studied. Special attention is given to the identification of work exergy and exergy loss in heat transfer through engine cylinder by using diesel and B10 biodiesel (Jatropha oil methyl ester) fuel. Also the comparative in-cylinder temperature is studied for diesel and biodiesel fuel. MATLAB 13 software is used for the simulation purpose. Comparative results are drawn for the experimental and cumulative exergy for B10 biodiesel fuel with varying load with respect to crank angle.

Key words: Exergy analysis, CI engine, Biodiesel, Simulation

I. INTRODUCTION

Internal combustion engine simulation modeling has long been established as an effective tool for studying engine performance and contributing to evaluation and new developments. Thermodynamic models of the real engine cycle have served as effective tools for complete analysis of engine performance and sensitivity to various operating parameters. The availability content of a material represents its potential to do useful work. Unlike energy, availability can be destroyed which is a result of such phenomena as combustion, friction, mixing and throttling [15].

During the working process of IC engine, fuel chemical energy converts into thermodynamic energy of gas medium through combustion. Then, part of thermodynamic energy is used to push the piston, while the rest is lost due to cylinder wall heat transfer, exhaust gas loss and other irreversible loss. Obviously, all the processes occurring in IC engine are irreversible process. According to the second law of thermodynamics, irreversible process inevitably leads to exergy loss. Consequently, both the quantity and quality relationship among various forms of energy should be taken into account in IC engine. As a result, exergy analysis based on the second law of thermodynamics is another useful way to evaluate the energy utilization efficiency of IC engine, and it has become a new hotspot which is concerned by scientists and scholars recently [13].

Compression ignition engines, commonly known as diesel engines, are important components of the transportation and energy sectors of the world. Millions of units are used on a daily basis and therefore the emission of CI engines is an important aspect of pollution control. CI engines are designed to operate on less refined petroleum distillate than gasoline which contains less energy content. Yet CI engines are more efficient at converting fuel energy content into output than the spark ignition engine. CI engines also have fewer overall emissions than spark ignition engines and are preferred for emissions reductions [8].

II. TRANSESTERIFICATION OF OIL

Various processes have been developed for the production of biodiesel, from which transesterification process is widely used.

For the formation of methyl ester by transesterification process of vegetable oil needs raw oil (Jatropha oil) which is mixed with 15% of methanol and 5% of KOH on mass basis. Excess alcohol is required to drive the reaction with an alcohol in presence of catalyst to produce methyl ester. In this reaction, Glycerol is produced as by-product. The above mixture was heated at temperature of 55°C to 60°C and stirred continuously and then it will settle under gravity in separating funnel. Two layers were formed in which upper layer was jatropha methyl ester and lower was glycerol. The jatropha methyl ester was then blended with pure diesel to be used in CI engine to conduct various tests.

III. EXPERIMENTAL SETUP

The experiments are conducted in a single cylinder, four stroke direct injection diesel engine fueled with jatropha methyl ester. The engine is connected to water cooled eddy current dynamometer for loading. The brief engine specification is: bore 80 mm, stroke 110 mm, CR 16. The engine produces 3.7 kW rated power with diesel at full load at a rated speed of 1500 rpm. The optical crank-angle sensor delivers a signal for each degree rotation of crank shaft. These signals are then interfaced to computer through engine indicator to measure rpm of the engine. The setup has a stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring burette. All the analog signals recorded from different locations of the test rig are supplied to the software for performance analysis.

The engine is first run using diesel at standard diesel specification; CR of 16. As the load is increased, the engine speed reduces. In order to maintain a constant BP, the engine consumes more fuel resulting a higher heat release, and hence, a higher temperature inside cylinder. This increases temperatures at the outlet of the cooling water and exhaust gas. When the full load condition is achieved, the engine is allowed to run for few minutes and the temperatures at the outlet of cooling water and exhaust gas are monitored closely at the computer display until it reaches a steady state condition. This indicates that the combustion inside the cylinder becomes steady and the engine is ready for data acquisition. The readings of temperatures, air and fuel flow rate, speed, cylinder and fuel pressure variation are automatically recorded by data acquisition device. Thereafter, the engine is brought back to no load condition slowly and allowed to run for few minutes. Later, JME is tested in the engine at various loading conditions.

Maximum Output	5Bhp / 3.7 kW@ 1500 rpm
Bore	80 mm
Stroke	110 mm
Compression Ratio	16:01
Number of Cylinder	4
Fuel	Diesel
Type	4 Stroke
Application	Industrial

Table 1: Engine Specification

Dynamometer Type	Water Cooled Eddy Current
Maximum BHP	10 @ 1500 rpm
Anemometer	Hot wire type
Output	4-20 mA
Load-cell Transmitter type	S type
Range of Load-cell Transmitter	0-25 Kg
Range of Fuel Sensor Transmitter	105 gm
Measuring Range of Pressure Sensor	0-250 bars

Table 2: Test Bed Specification

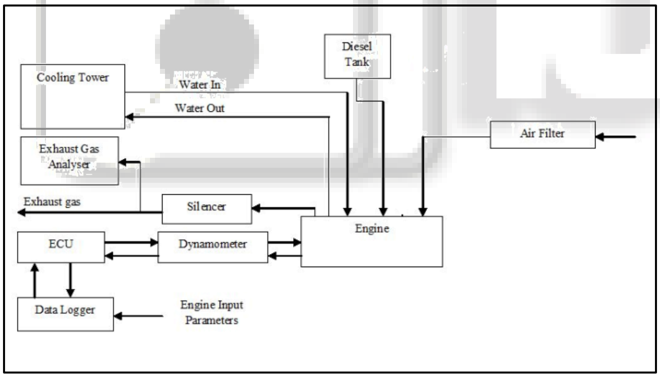

Fig. 1: Engine Setup Block Diagram

IV. THEORETICAL ANALYSIS

The present work deals with the exergy analysis of CI engine fuelled with diesel and B10 biodiesel fuel. The first law of thermodynamics is used for the energy analysis and then second law of thermodynamics is used for the exergy analysis. Suitable models are considered for exergy analysis to find out the engine parameters.

A. Temperature and Pressure during Compression:

$$P2 = \left(\frac{V1}{V2}\right) * \left(\frac{T2}{T1}\right) * P1 \qquad (4.1)$$

$$T2 = T1 * \left(\frac{V1}{V2}\right)^{\frac{R}{Cv\,(T1)}} \qquad (4.2)$$

B. Mass Fraction Burn:

For property calculation mass fraction burn at instantaneous crank angle is necessary. Mass fraction burn is calculated on the concept that the difference in pressure in the cylinder at firing and motoring pressure is in the proportion of mass fraction burn. The difference is calculated as follows

$$dPi = Pi - Pi - 1\left(\frac{V(i-1)}{Vi}\right)^{n} \qquad (4.3)$$

$$dPtotal = \sum(dP) \qquad (4.4)$$

$$MFB = x_b = \frac{dPi}{\sum(dP)} \qquad (4.5)$$

C. Work Exergy:

A_w is the exergy which is associated with the work done by the system and can be defined as

$$\frac{dA_w}{d\Theta} = (P - P_0)\frac{dV}{d\Theta}$$

D. Exergy Loss in Heat Transfer through Engine Cylinder:

A_Q is the exergy associated with heat transfer through system boundary and is given by

$$\frac{dA_Q}{d\Theta} = \left(1 - \frac{T_0}{T}\right)\frac{dQ}{d\Theta}$$

V. RESULT AND DISCUSSION

A. In- Cylinder Temperature Distribution:

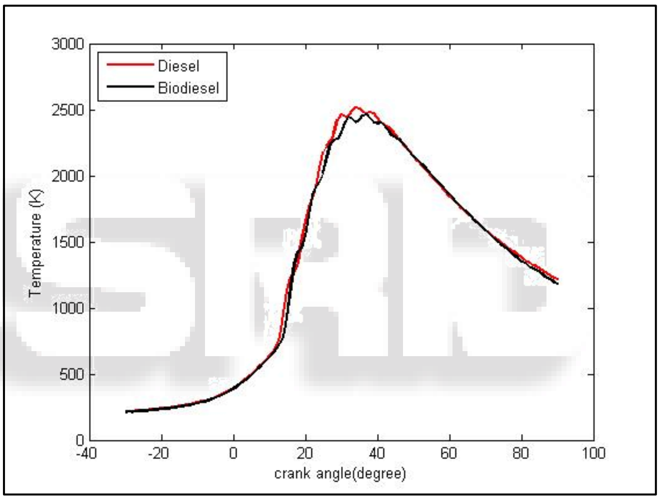

Fig. 1: In-Cylinder Temperature For 100% Load

As the in-cylinder pressure is increasing, the temperature inside the cylinder also increases. The variation in temperature in inside the engine cylinder at various crank angles is shown in Fig. 1. So the highest peak pressure is obtained for pure diesel as compared to B10 biodiesel fuel. The premixed combustion process which is present inside the cylinder is also responsible for the high pressure inside the cylinder. Due to presence of large amount of carbon content in diesel fuel as compared to biodiesel results in rapid burning rate. As the diesel fuel is volatile in nature compared to biodiesel, so the combustion phase will start earlier. Hence the temperature distribution of the engine cylinder during combustion process is high for diesel fuel. Due to oxygen content in the biodiesel fuel results in much better combustion of fuel.

B. Mass Burn Fraction:

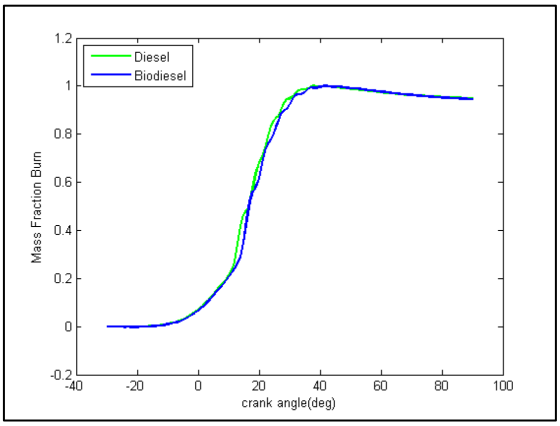

Fig. 2: Mass Fraction Burn

Fig.2. shows the mass fraction burn profile for diesel and B10 (jatropha oil) biodiesel fuel. This is clear from the graph that the mass fraction burn is same upto 12 degree and then it shows variation for different fuels. The burning rate is suddenly increases from 12 degree to 25 degree after TDC and after that too small duration the heat release rate slows substantially. The first half burning of fuel at very fast rate shows that it is burning with abundance of air. At the beginning before TDC the curve goes down to some negative values and just before TDC it started raising. That raising point before the TDC marks the start of heat release rate. The diesel fuel has high rate of mass fraction burn compared to jatropha oil biodiesel fuel because jatropha oil takes more time for complete combustion. A Jatropha oil blend contains the characteristics of low volatility and high viscosity, so that it will take more time for the atomization of fuel. The quantity of jatropha oil required is more compared to diesel fuel due to low calorific value of straight vegetable oil.

C. Work Exergy:

The Fig.3 shows the work exergy rate (J/deg) for B10 biodiesel fuel with respect to crank angle, it is observed that during compression process the transfer of work exergy is done to engine charge so it does not show any rise but fall in it up to top dead center and just after that as the piston start expanding and due to combustion also the work exergy raises. So the figure shows that as the load increases, the work exergy rate also increases.

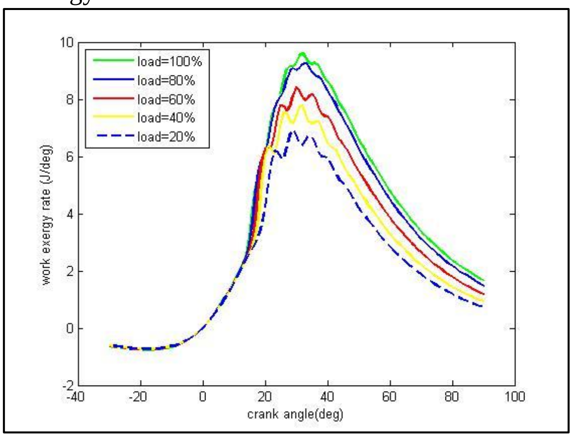

Fig. 3: Work Exergy Rate Vs Crank Angle For B10 Biodiesel Fuel

The cumulative work exergy (J) is calculated by determining the predicted pressure for B10 biodiesel fuel at various crank angle. From Fig.4, it is clear that cumulative work exergy is negative for all loads upto 15 degree and then it suddenly increases. So that there is variation in cumulative work exergy for various loads. The maximum value reach for 20% load is near about 900 J and for 100% load it is near by 1300 J.

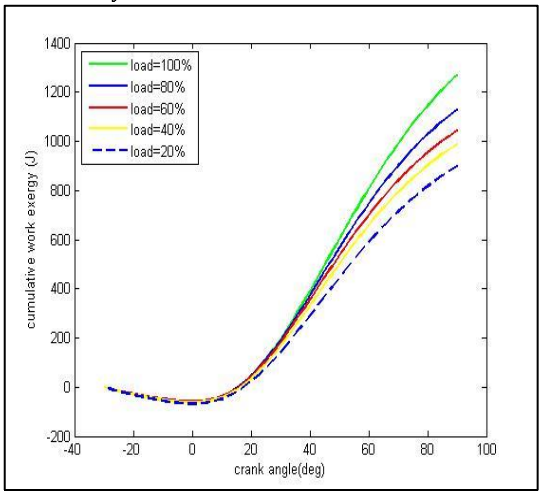

Fig. 4: Cumulative Work Exergy Vs Crank Angle For B10 Biodiesel Fuel

D. Exergy Loss in Heat Transfer through Engine Cylinder:

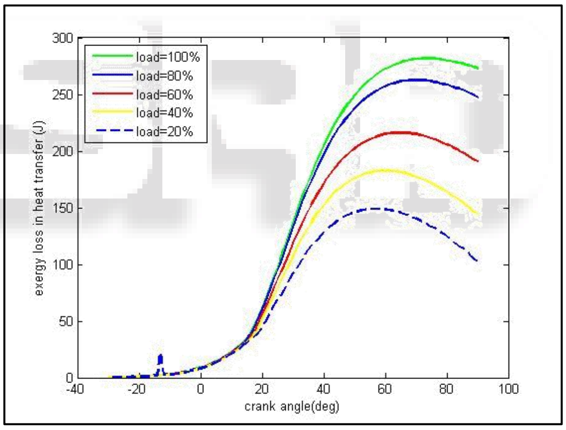

Fig. 5: Exergy Loss In Heat Transfer Vs Crank Angle For B10 Biodiesel Fuel

Fig. 5 shows the exergy loss in heat transfer through engine cylinder with respect to crank angle ranges from 320 degree to 460 degree of crank angle. When the load increases, the pressure and temperature inside the cylinder increases, consequently the heat transfer through cylinder wall also increases. As the work is done under constant speed of 1500 rpm, so that the time duration for heat transfer was same for all load conditions and heat transfer is only the function of charge temperature and convective heat transfer coefficient which in turn again depends on pressure and temperature of in-cylinder gases. Hence the parameter which causes the increase in temperature and pressure of the in-cylinder gases shows the increase in heat transfer loss from engine cylinder.

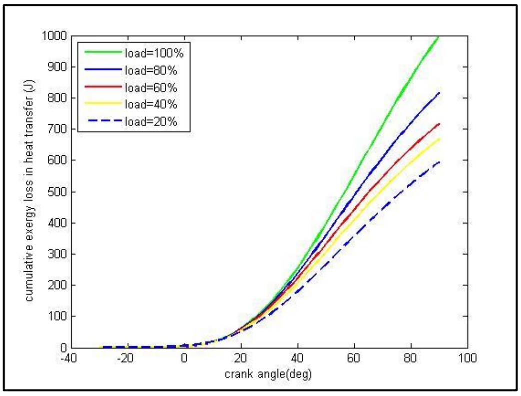

Fig. 6: Cumulative Exergy Loss In Heat Transfer Vs Crank Angle For B10 Biodiesel Fuel

Fig. 6 shows the cumulative exergy loss in heat transfer through engine cylinder which is calculated from predicted pressure. The predicted pressure is calculated from predicted heat release rate. Since the predicted heat release rate is calculated from single weibe function model.

VI. Conclusion

In this study, the experimental and simulation of exergy rates has been carried out on the compression ignition (CI) engine fuelled with diesel and biodiesel (10% by mass). The single zone zero dimensional model is developed for a closed cycle combustion process. This model predicted the in-cylinder pressure in closer approximation to that of experimental results; hence the developed model is suitable for the prediction of pressure for CI engine. Biodiesel fuel shows nearly same results like diesel fuel so that it can be used as alternative fuel for diesel engine. Temperature distribution for B10 biodiesel fuel is found to be near to the pure diesel fuel due to presence of oxygen in the biodiesel which also helps in combustion. So the maximum temperature recorded for pure diesel is 2521.2K and for biodiesel is 2463.2 K. The burning of fuel causes increase in pressure and temperature and, consequently, in cylinder exergy and heat loss.

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