Exergy Analysis of CI Engine Fuelled with Diesel and Biodiesel-A Review

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Abstract— The present study deals with the exergy analysis of engine cylinder of CI engine. As the energy analysis (first law of thermodynamics) deals with the quantity of energy only. So to determine the quality of energy there is need of exergy analysis i.e. second law of thermodynamics. In this, an overview of detailed thermodynamic model approach will be covered. This paper deals with the review of exergy analysis by comparing experimental results with simulation software. The main objective of this study deals with the mathematical modeling of engine cylinder. The computer simulation of the process in the CI engine is the key role for reducing cost in the development of more efficient combustion engine.

Keywords: Exergy analysis, CI engine, Biodiesel, Simulation

I. INTRODUCTION

Energy is the basic requirement for economic development. As time flows, the consumption of energy has been raising all over the country. As this growth in consumption of energy results in increase demand of fossil fuels such as coal, oil and gas. Most countries find themselves under considerable energy constraints. Recent studies show that almost 1/3 of the energy of a fossil fuel is destroyed during the combustion process in power generation. This will lead to enhance interest in energy and exergy analysis [2]. The energy analysis is based on first law of thermodynamics. However first law is inadequate for evaluating features of energy resource utilization. In order to analyse the engine performance, second law analysis is used. The term availability represents the maximum useful work. As the energy, the exergy will also be destroyed. The factors responsible for destruction of exergy are from thermal, mechanical and chemical processes. In the working process of IC engine, fuel chemical energy converts into thermodynamic energy of gas medium through combustion. Then, some of thermodynamic energy is used to push the piston and remaining is lost due to cylinder wall heat transfer as well as exhaust gas loss and other irreversible loss. As all the process occurring in the CI engine is irreversible process. Some researchers have studied that the biodiesel fuels and their blends with diesel fuel as an alternative energy source in the compression ignition engine, and so the performance, emissions and combustion characteristics of the engine were analyzed. The results obtained is found that biodiesel fuels provided increase in brake specific fuel consumption since biodiesel fuels have lower heating values. Based on these studies, biodiesel can be used as a substitute for diesel in diesel engine. The investigators were examine the effects of using biodiesel as an alternative fuel in a Low Heat Rejection engines, LHR, to determine any significant effects on performance and exhaust gas emissions [1].

The maximum work output obtainable from a certain heat input in a cyclic heat engine is called available energy or the available part of energy that is supplied to the engine. The minimum energy that has to be rejected to the sink is called unavailable energy or unavailable part of energy supplied. The unavailable part of energy is also called as anergy. Some investigators were conducted the studies on exergy analysis of IC engine at fixed dead temperature using same characteristics using different fuels. Investigators also investigate the variation of chemical exergy for atmospheric gases and gaseous fuels to variations in ambient conditions. The result shows that the exergetic efficiency increases as the dead temperature decreases. As the combustion process is most important stage in the IC engine. 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.

The process of combustion in a diesel engine is inherently very complex due to its transient and heterogeneous characters that will be controlled mainly by turbulent mixing of fuel and air in the fuel jets issuing from the nozzle holes. High speed photography studies and in-cylinder sampling techniques have observed that some interesting features of combustion. The first attempts to simulate the diesel engine cycle substituted the ‘‘internal combustion’’ by ‘‘external heat addition’’. Apparent heat release rates were empirically correlated to fuel injection rates and eventually used in a thermodynamic cycle calculation to obtain the cylinder pressure in a uniform mixture. Models based on droplet evaporation and combustion, while still in a single zone mixture, can only take into account the heterogeneous character of diesel combustion.

Mathematical modelling is the most suitable way to perform first law and exergy analysis. Mathematical modelling can be defined as process of describing the physical phenomena in a particular system with the help of mathematical equations.

Thermodynamic model contribution [14]:

(1) Formulating the model by understanding the engine process completely.
(2) Key controlling variables can be useful to develop less costly experimental setup.
(3) Modelling the engine to predict the engine behaviour as well as to optimize design and control.

II. RESEARCH STUDIES

Numerous scholars have done the work for engine modeling and availability analysis. Here is the overview of some of them.

A. Perhan Sekmen, Zeki Yilbasi (2011):

In the study, combined first and second Laws of thermodynamics were employed to analyze the quantity and quality of energy in four-cylinder, direct injection diesel engine by using petroleum diesel fuel and biodiesel fuel. The steady-state tests is used to collect the experimental data for accurate measurements of fuel, air and cooling water flow rates, engine load, and all the relevant temperatures. Balances of energy as well as exergy rates for the engine were determined and then various performance parameters of the engine and energy and exergy efficiencies were calculated for each fuel operation and compared with that of biodiesel. The results of tested biodiesel will give similar energetic performance as petroleum diesel fuel. In addition to this, the exergetic performance parameters usually follow similar trends according to the energetic performance parameters [1].

B. C.D. Rakopoulos and D.C. Kyritsis (2001):

In this, the second law analysis has been used. The results of n-dodecane (n-$C_{12}H_{26}$) fuel are compared with the result of similar analysis of gaseous (CH_4) and an oxygenated (CH_3OH) fuel. The first and second law analysis is used to calculate the rate of entropy production as a function of fuel reaction rate. In the modelling of engine, a three-hole injector nozzle was used for dodecane injection. Theoretically, the decomposition of lighter molecules generates less entropy. Using the extensive experimental data available for the case of n-dodecane (n-$C_{12}H_{26}$) injection, which typically represents the diesel fuel in the study of automotive or smaller size diesel engines, the fuel reaction (combustion) rate is determined. In this study, the environment is dry atmospheric air with P_o =1bar and T_o =298K. So that the thermal equilibrium is achieved when there is no heat exchange between system and environment. Similarly the chemical equilibrium is achieved when no system component can react with the environment. Combustion irreversibility is analytically calculated as a function of the fuel reaction rate with the use of second-law analysis and a chemical equilibrium hypothesis. A single-zone model is used to simulate the engine operation. The wibbe function is used for the reacted fuel distribution in the analysis. The angle of onset of combustion is treated as a parameter of the wibbe function determined by the least square algorithm. The wibbe function offers a flexible and accurate approximation to the reacted fuel quantity [2].

C. C.D. Rakopoulos and E.G. Giakoumis(2004):

In this, the energy and exergy performance of a turbocharged diesel engine operating under transient load condition by performing computer analysis has been studied. The model contains some novel features for the simulation of transient operation, such as, separate consideration for the processes of each cylinder during a cycle ("multicylinder" model), detailed analysis of mechanical friction and mathematical modeling of the fuel pump. The exergy terms were analyzed for the diesel and its subsystem. In this a single zone model is used as the basis for the thermodynamic process evaluation. The method is used for the calculation of friction inside the cylinder in which the total amount of friction is divided into six parts i.e. ring viscous lubrication, ring mixed lubrication, piston skirt losses, valve train, auxiliaries and loaded bearings. The model's energy results were confirmed with experimental tests. The particular study spotted specific engine processes and parameters apart from the well-known in-cylinder irreversibilities (such as the exhaust manifold irreversibilities, the cylinder wall insulation and the after cooler effectiveness) which could, according to the exergy analysis, improve the engine processes. For example, the use of insulated cylinder wall is a proposal for better engine performance according to (transient) second-law analysis [3].

D. S.Patil (2013):

The work on compression ignition engine by using computer simulation framework for compression ignition engine cycle simulation is developed and engine performance is predicted. So that Double wiebe's function is used to model the rate of heat release due to combustion to predict both heat released during premixed as well as diffusive phase of combustion from the engine. Suitable correlations are established between adjustable parameters of wiebe's function, relative air-fuel ratio and engine operating conditions, so that the simulated heat release rate profile matches with experimental results. The simulated model which is used to analyze the performance, emission and combustion characteristics of single cylinder diesel engine fuelled with Diesel, Palm Oil Methyl Ester (POME) and POME-diesel blends. So the model is validated by comparing the predicted parameters with experimental results. This model is also used to predict net heat release rate, exhaust gas temperature, No_x and soot of diesel engine [4].

E. K. Hareesh, Rohith Teja. N., B. Konda Reddy (2014):

In this work, a computer simulation has been developed using MATLAB software to determine the performance parameter of a four stroke compression ignition internal combustion engine. The modeling will begins with the simulation of one cylinder of the four stroke IC engine allowing for computation of peak performance which is assumed to have an ideal pressure-volume (p-V) relationship. The computer simulation is modeled for Ideal Cycle System in relationship with thermodynamic laws of heat transfer and then it is also modeled for the emissions liberated from engine. The next phase of the model focuses on fuel cycle system where all the real factors are to be considered for the prediction of performance parameters and emissions. Performance parameters computed include brake power and brake specific fuel consumption for an engine's entire operating range With the use of thermodynamic model to compute heat release of CI engine, some standard models like Woschni and Annand models are also used to predict the heat release. [5].

F. Lukas Lnsky (2008):

In this, the modeling and control processes in the cylinder of the diesel engine has been done. The work is divided into two parts. So in the first part of work, detailed description of a Matlab-Simulink model of cylinder is given, which includes description of cylinder thermodynamics, geometry, mass flow, combustion process and engine performance. The second part is focused on design of a controller for the control of engine output torque. The behavior of closed-loop

is compared. This model is used to simulate cylinder pressure and temperature developed with respect to crank angle. The validation is done through output torque (maximum error is less than 4%) and air/fuel ratio (maximum error is less than 15%). There are many simplification n the modeling of diesel engine process so that model give satisfactory result. The performance of PI and H∞ controllers was compared with non-linear Simulink model [6].

G. B.Rajendra Prasath, P.Tamilporai, and Mohd. F.Shabir (2010):

The simulation of combustion and performance characteristics of biodiesel fuel in direct injection low heat rejection diesel engine has been done. As well as the combustion characteristics that is heat release, peak cylinder pressure and performance characteristics like specific fuel consumption and brake thermal efficiency are carried out. CI engine cycle simulation was developed and modified into LHR engine for both diesel and biodiesel fuel. By using first law of thermodynamics the properties at each degree crank angle was calculated. In this, the reaction rate model was used to calculate instantaneous heat release rate. ANNAND's combined heat transfer model is used for gas-wall heat transfer calculation with instantaneous wall temperature to analyze the effect of coating on heat transfer. The validation of simulated results will be done by using experimentation on test engine under operating condition on a turbocharged diesel engine. In this analysis 20% of biodiesel (jatropha oil) blended with diesel and used in both conventional and LHR engine. The simulated combustion and performance characteristics results are found satisfactory with the experimental value [7].

H. V.Kumar Gaba, P. Nashine and S. Bhowmick (2012):

The aim of this work is to develop combustion model for CI engine for constant pressure combustion process. The examination for the performance of CI engine has been done analytically with the minimum use of diesel fuel as pilot fuel, and biodiesel as secondary fuel. The combustion model has been developed for diesel engine using blends of biodiesel ranging from 20% to 100%. Using the first law of thermodynamics and equation of state in each process, the cycle has been analyzed. The specification of a standard CI engine has been used for numerical calculations. The variation of temperature with different equivalence ratio is studied and reported in the result. The thermal efficiency of a pure diesel engine is observed to decrease exponentially from 67% to 47% as the equivalence ratio increases from 0.7 to 1.3. It is also observed that B- 20 and B-40 formed a good mixture among all other blends and the efficiency of pure bio-diesel is comparatively less than diesel as well as for other blends [8].

I. B.Rajendra Prasath, P. Tamil Porai, Mohd.F.Shabir (2010):

A computer code using "C" language was developed for compression ignition (C.I) engine cycle and then it will be modified into low heat rejection (LHR) engine with the help of wall heat transfer model. Combustion characteristics of engine such as cylinder pressure, heat release, heat transfer and performance characteristics such as work done, specific fuel consumption (SFC) and brake thermal efficiency (BTE) were analyzed. On the basis of first law of thermodynamics the properties at each degree crank angle of CI engine was calculated. Reaction rate model was used to calculate the instantaneous heat release rate. The effect of coating on engine heat transfer was analyzed using a gas-wall heat transfer calculations and the total heat transfer was based on ANNAND's combined heat transfer model for engine. The predicted results from the models are validated through the experiments on the engine under identical operating conditions on a turbocharged D.I diesel engine. In this analysis 20% of biodiesel (Jatropha seed oil) blended with diesel was used in both conventional and LHR engine. The simulated combustion and performance characteristics are found satisfactory with the experimental results [9].

J. L.P.Raut (2013):

Among all alternative fuels, biodiesel and its blends are considered suitable and the most promising fuel for diesel engine. The properties of biodiesel are found similar with that of diesel. Many researchers have experimentally evaluated the performance characteristics of conventional diesel engines fuelled with biodiesel and its blends. Practically the experiments require enormous effort, money and time. Hence, a cycle simulation model incorporating a thermodynamic based single zone combustion model is developed to predict the performance of diesel engine. A comprehensive computer code using "C" language was developed for C.I. engine. Combustion characteristics such as cylinder pressure, heat release, heat transfer and performance characteristics such as work done, brake power and brake thermal efficiency (BTE) were analyzed. On the basis of first law of thermodynamics the properties at each degree crank angle was calculated. The simulated combustion and performance characteristics are found satisfactory with the experimental results. In this study, it is observed that by using blend B20 the peak pressure and temperature increases and hence the resultant stresses also increases. This also shows that with the increase in compression ratio there is increase in brake power [10].

K. C.D.Rakopoulos, D.C.Rakopoulos, E.G.Giakoumis, D.C.Kyritsis (2004):

The present two zone model of a direct injection (DI) diesel engine divides the matter of cylinder into a non-burning zone of air and another homogeneous or burning zone in which fuel is continuously supplied from the injector and burned with entrained air from the air zone. The fuel spray zone, which contains a number of fuel-air conical jets which is equal to the injector nozzle holes, is carefully modeled with the help of jet mixing, thus determining the amount of oxygen available for the combustion. The energy, mass and state equations were applied in each zone to yield local temperatures and cylinder pressure. The concentration of the various constituents in the exhaust gases are calculated by developing chemical equilibrium scheme for the C–H–O system of the 11 species considered, together with chemical rate equations for the calculation of nitric oxide (NO). A model for evaluation of the soot formation and oxidation rates is included. The theoretical results determined from computer program are compared very favorably with the measurements from an experimental investigation that will be conducted on a fully automated test bed, Ricardo-Hydra standard, DI diesel engine. In-cylinder pressure and

temperature histories and calculated, nitric oxide concentration and soot density are among the interesting quantities tested for various loads and injection timings. As observed that, the model is sensitive to the selection of the constants of the fuel preparation and reaction sub-models. This leads to a better understanding of the physical mechanisms which is governed by all constants and also paves the way for construction of a reliable and relatively simple multi-zone model, which incorporates in each zone the theory of the present two zone model [11].

L. M.Venkatraman and G.Devaradjane (2011):

This work describes a theoretical investigation regarding the performance of a four strokes compression ignition engine, which is driven by alternative fuels in the form of diesel and diesel biodiesel blends. In this, single zone zero dimensional model for direct injection diesel engine is developed. The developed simulation model used to estimate the cylinder pressure, brake thermal efficiency, heat release rate, brake specific fuel consumption and engine out emissions. Zero dimensional combustion model for the prediction of various combustion parameters. The simulation model includes Honerberg's equation heat transfer model. Experiments were performed in a single cylinder DI diesel engine fuelled with a blend of pungam methyl ester (PME10, PME20 and PME30 by volume) with diesel fuel for validation of simulated results. It was observed that there is a good agreement between simulated and experimental results which reveals the fact that the simulation model developed predicts the performance and emission characteristics of any biodiesel and diesel fuel and engine specifications given as input. So that the developed model is considered as an effective tool to calculate engine operating parameters like, injection timing, injection pressure and compression ratio [12].

III. CONCLUSION

The performance of engine was done on different biodiesels fuel to compare it with diesel fuel. So that energetic and exergetic performance parameters of the engine computed and compared with each other. The factor responsible for system inefficiency is the destruction of exergy by irreversible processes. Still there is need for research in the field of chemical exergy that is destroyed during the burning of fuel. Exergy losses are generally due to exhaust gas and heat transfer. The data will be gathered from the study of energy and exergy balance to the engine performed on both diesel and biodiesel fuel. There is need of comparison between the diesel and various biodiesel fuels.

REFERENCES

[1] Perhan Sekmen, Zeki Yibsu, "Application of energy and exergy analysis to CI engine using biodiesel fuel," Internatinal journal of Mathematical and Computational Applications, Vol. 16, No. 4, pp.797-808, 2011.
[2] C.D. Rakopoulos and D.C. Kyritsis, "Comparative second-law analysis of internal combustion engine operation for methane, methanol, and dodecane fuels," Elsevier, Energy Vol. 26, pp. 705-722, 2001.
[3] C.D. Rakopoulos and E.G. Giakoumis, "Parametric study of transient turbocharged diesel engine operation from the second-law perspective." SAE International, 2004-01-1679, 2004.
[4] S.Patil, "Thermodynamic modelling for performance analysis of compression ignition engine fuelled with biodiesel and its blends with diesel," International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Vol. 1, Issue 6, 2013.
[5] K. Hareesh, Rohith Teja. N., B. Konda Reddy, "Computer simulation of compression ignition engine through MATLAB," International Journal for Research in Applied Science & Engineering Technology (IJRASET), ISSN: 2321-9653, Issue-2, 2014.
[6] Lukas Lnsky, "Diesel engine modelling and control," Maaster's thesis, Czech Technical University in Prague Faculty of Electrical Engineering Department of Control Engineering, 2008.
[7] B.Rajendra Prasath, P.Tamilporai, and Mohd. F. Shabir,"Theoretical modeling and experimental study of combustion and performance characteristics of biodiesel in turbocharged low heat rejection D.I. diesel engine," International Scholarly and Scientific Research and Innovation, Vol. 4, No. 1, 2010.
[8] V.Kumar Gaba, P. Nashine and S. Bhowmick, "Combustion modeling of diesel engine using bio-diesel as secondary fuel," International Conference on Mechanical and Robotics Engineering (ICMRE 2012), May 26-27, 2012.
[9] B.Rajendra Prasath, P. Tamil Porai, Mohd.F.Shabir, "Two-zone modeling of diesel/biodiesel blended fuel operated ceramic coated direct injection diesel engine," International Journal of Energy and Environment, Vol. 1, Issue 6, pp. 1039-1056, 2010.
[10] L.P.Raut, "Computer simulation of CI engine for diesel and biodiesel blends," International Journal of Innovative Technology and Engineering (IJITEE), ISSN: 2278-3075, Vol. 3, Issue 2, July 2013.
[11] C.D.Rakopoulos, D.C.Rakopoulos, E.G.Giakoumis, D.C.Kyritsis, "Validation and sensitivity analysis of a two zone diesel engine model for combustion and emission prediction," Energy Conservation and Management, Vol. 45, pp. 1471-1495, 2004.
[12] M.Venkatraman and G.Devaradjane, "Computer modeling of a CI engine for optimization of operating parameters such as compression ratio, injection timing and injection pressure for better performance and emission using diesel-diesel biodiesel blends," American Journal of Applied Science, Vol. 8, No. 9, pp. 897-902, 2011.
[13] LIU Jing-ping, FU Jian-qin, FENG Ren-hua, ZHU Guo-hui, "Effects of working parameters on gasoline engine exergy balance," J. Cent. South Univ. Vol. 20: pp. 1938−1946, 2013.
[14] Heywood J.B. International combustion engine fundamentals. New York: McGrawHill; 1988.

