Energy Analysis of Diesel and Biodiesel Fuelled C.I. Engine using First Law of Thermodyanamic - A Review

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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.
Key words: Diesel Engine Modeling, IC Engine, Biodiesel, Simulation

I. 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. [1]

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. [2]

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. [3]

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.[4]

II. Energy Analysis

In engineering, modeling a process has come to mean developing and using the appropriate combination of assumption and equation that permit critical feature of the process to be analyzed. The modeling of engine process continues to develop as our understanding of the physical and chemistry of the phenomena of interest steadily expand and as the capability of computers to solve complex equation continues to increase.[1]

A. Types of Models:

These can be two categorized.

1) Thermodynamic model.
   – Zero-dimensional single zone.
   – Quasi-dimensional multi-zone.
2) Fluid dynamic model.
   – Multidimensional model.

1) Thermodynamic Model:

Thermodynamic energy conservation based model are zero-dimensional (since in the absence of any flow modeling, geometric feature of the fluid motion cannot be predicted), phenomenological (since additional detail beyond the energy conservation equation is added for each phenomenon in turn), and quasi-dimensional (where specific geometric feature, example, the spark-ignition engine flame or diesel fuel spray shapes, are added to basic thermodynamic approach).

In single zone models, the working fluid in the engine is assumed to be a thermodynamic system, which undergoes energy and/or mass exchange with the surroundings and the energy released during the combustion process is obtained by applying the first law of thermodynamics to the system.[1]

2) Fluid Dynamic Model:

Fluid-dynamic based model are often called multi-dimensional model due to in their inherent ability to provide detailed geometric information on the flow field based on solution of the governing flow equation. [1]

III. Research Studies

The following references were studied for analysis of experimental results by using different model and biodiesel in different working conditions on First law of Thermodynamic

A. Vivek Kumar Gaba, Prerana Nashine and Shubhankar Bhowmick(2012):

Developed a combustion model for a diesel compression ignition (CI) engine for constant pressure combustion process. The work analytically examines the performance of a CI engine with the minimum use of diesel fuel as pilot fuel, and bio-diesel as secondary fuel. The combustion model has been developed for an ideal 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 was critically analyzed. The specification of a standard CI engine was used for numerical calculations. The variation of temperature with different equivalence ratio were studied and reported. The thermal efficiency of a pure diesel engine was observed to decrease exponentially from 67% to 47% as the equivalence ratio increases from 0.7 to 1.3. It was also observed that B- 20 and B-40 formed a good mixture among all other blends and the efficiency of pure bio-diesel was comparatively less than diesel as well as for other blends.

A sharp increase in work output was observed as the equivalence ratio increases due to more fuel injection. It was also observed that efficiency of pure bio-diesel is comparatively lesser than all other blends, but the maximum cycle temperature for this blend is least. This indicates that NOx emission was not present in case of pure diesel; hence pure biodiesel can be used resulting in less pollution despite of less efficiency & work output.

Work aims to develop a combustion model for a diesel compression ignition (CI) engine for constant pressure combustion process. The work analytically examines the performance of a CI engine with the minimum used of diesel fuel as pilot fuel, and bio-diesel as secondary fuel. The combustion model had been developed for an ideal 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 had been critically analyzed. The specification of a standard CI engine had been used for numerical calculations. The variation of temperature with different equivalence ratio is studied and reported. 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.

The work in a one-dimensional combustion model, employing constant eddy diffusivity and a one-step chemical reaction had been developed and applied to study the flame propagation in a Spark Ignition (SI) engine at 1600 and 4200 rpm under fuel rich conditions using one and two zone thermodynamic models. The thermodynamic models had been compared with 1-D model for average mixture temperature, the temperatures of the burned and unburned gases and the flame surface area and indicate that the one-dimensional model predictions are very sensitive to the eddy diffusivity and reaction rate data where as the two-zone thermodynamic model predicts, first, a monotonically increasing flame surface area with time and, then, a monotonically decreasing surface area.

B. BORDET Nicolas, CAILLOL Christian, HIGELIN Pascal (2010).

This paper presented a new 0D phenomenological approach to predict the combustion process in Diesel engines operated under various running conditions. The aim of this work was to develop a physical approach in order to improve the prediction of in-cylinder pressure and heat release for developing a tool for engine pre-mapping. The main contribution of this study was the modeling of the premixed part of the Diesel combustion.

In phenomenological Diesel combustion models, the premixed combustion phase was sometimes modeled as the propagation of a turbulent flame front. However, experimental studies had shown that this phase of Diesel combustion was actually a rapid combustion of part of the fuel injected and mixed with the surrounding gas. This mixture ignites quasi instantaneously when favourable thermodynamic conditions are locally reached. A chemical process then controls this combustion. they were worked on Spray and entrained surrounding gas model, two states turbulence model: K-k modified model, Vaporization model, Premixed Combustion Model, Diffusion Combustion Model, Extended Model for Multi Injection.

Results were measured engine data are compared with computed results using the developed combustion model. Injection rates were modeled with Hermits polynomials optimized for each injection. The determined model parameters were then kept constant for the whole range of engine operating parameters. This experimental apparent energy rate was compared with the apparent energy rate calculated from the simulated pressure traces.

Future work should improve the model to take into account large EGR rates as well as in-cylinder temperature distribution. To improve the existing model, interaction between sprays must be taken into account in multi-injection cases. Furthermore, a more detailed spray model can improve general results especially in cases with multi-injection.

C. Zehra Sahin, Orhan Durgun (2008).

In the presented study, the aim was to develop a complete cycle model and to prepare a computer code for determining complete cycle, performance characteristics, and exhaust emissions of diesel engines. For this purpose, a computer program had been developed. To compute diesel engine cycles, zero-dimensional intake and exhaust model developed by Durgun,. Details of fuel spray formation, fuel–air mixing, swirl and heat transfer had been taken into account in this model. Also, an emission model based on the chemical equilibrium and kinetics of NO had been developed to calculate the pollutant concentrations within each zone and the whole of the cylinder. Using the developed computer program, complete engine cycle, engine performance parameters and exhaust emissions could be determined easily. The values of the cylinder pressure and engine performance parameters predicted by the presented model matched closely with the other theoretical models and experimental data the accuracy of a newly developed model, like the presented one, must be controlled comparing with the experimental and theoretical values given in the relevant literature. Numerical results obtained from the presented model were compared with the experimental results and with the theoretical models, the results of which were accepted to be at sufficient accuracy. These indicate that cylinder pressure values obtained from the presented model are lower than Bazari's results. However, formation and vaporization of fuel droplets were modeled, and spray wall impingement was also taken into account in detail in Bazari's model, and in the presented model and in Bazari's models, Annand's correlation has been used for the calculation of heat transfer.

In future studies, it is planned to take into account a detailed wall impingement model and evaporation model. The effects of the residual gases in the cylinder could be used and a more detailed heat transfer model would also be included in the calculations.

D. C.D. Rakopoulos and E.G. Giakoumis (2006):

This paper surveys the publications available in the open literature concerning diesel engine simulations under transient operating conditions. Only those models that include both full engine thermodynamic calculations and dynamic power train modeling are taken into account, excluding those that focus on control design and optimization. Most of the attention is concentrated to the simulations that follow the filling and emptying modeling approach. One of the main purposes of this paper is to summarize basic equations and modeling aspects concerning in-cylinder calculations, friction, turbocharger, engine dynamics, governor, fuel pump operation, and exhaust emissions during transients. The various limitations of the models are discussed together with the main aspects of transient operation (e.g. turbocharger lag, combustion and friction deterioration), which diversify it from the steady-state.

The stringent regulations concerning engine exhaust emissions dominate the automotive industry, forcing manufacturers to new developments. Sophisticated, high pressure common rail injection systems, exhaust gas recirculation and variable geometry turbochargers are applied for reduction of fuel consumption, pollutant emissions and noise. In this work the publications concerning transient diesel engine simulation will be surveyed, provided they include both engine thermodynamic and powertrain dynamic submodels. To maintain the paper size at an acceptable level, it was decided that works which put emphasis on controllers design rather than thermodynamics, i.e. applying optimization algorithms, or Bode diagrams, will not be covered. Most of the attention will be paid to the simulations that follow the filling and emptying modeling technique. This, to the opinion of the authors, had proven so far to be the best approach to adequately shed light into the engine processes during transients. Moreover, taking into account its computational requirements, it was the most promising one for successful transient exhaust emissions predictions.

The transient response of compression ignition engines forms a significant part of their operation and it was of critical importance, owing to the often non-optimum performance involved as regards turbocharged engines. Moreover, the launch of emission directives, in the form of Transient Cycles, have directed engine manufacturers to deal with overall (vehicles') transient performance, since it was well established that the transient operation contributes much more to the total amount of emissions than the corresponding steady-state one. The majority of transient diesel engine simulations are based on the filling and emptying approach, which combines adequate insight into the relevant phenomena and requires limited computational time. Quasi-linear models are met often, owing to the low computational time required that makes them ideal for real time simulations.

Reliable study of pollutants emissions during transient operation via the use of suitable models is the most important objective for the future. Its accomplishment is, for the moment, limited, due to the high computational time required for the analysis of hundreds of cycles. Fortunately, experimental investigations of transient operation and computational power of personal computers both flourish during the last years, forming a sound basis for an even more successful investigation of dynamic engine operation in the near future.

E. Donepudi Jagadish, Ravi Kumar Puli and K. Madhu Murthy (2011):

A zero dimensional model had been used to investigate the combustion performance of a single cylinder direct injection diesel engine fuelled by biofuels with options like supercharging and exhaust gas recirculation. The numerical simulation was performed at constant speed. The indicated pressure, temperature diagrams are plotted and compared for different fuels. The emissions of soot and nitrous oxide are computed with phenomenological models. Content was prediction of heat release and gas properties, Calculation of ignition delay, Nitric Oxide Formation, Frictional Power Calculations, Indicated Power and Brake Power calculations, Combustion duration, Prediction of soot formation, Frictional Power Calculations.

The peak pressures was lowered with ethanol blending with diesel. And supercharging operation resulted in little lowering the maximum combustion pressure, temperatures in comparison to no supercharging case. The peak cylinder pressures are low with biodiesel blends in comparison to diesel since the heating value of biodiesel is lower than that of diesel resulting in lower heat release. Poor atomization and slow heat release rate also the reason for lower peak pressure for pure biodiesel.

In future the experimental work is also carried out with biodiesel (palm stearin methyl ester) diesel blends, ethanol diesel blends

F. P.A. Lakshminarayanan and Y.V. Aghav:

The phenomenological combustion models are practical to describe diesel engine combustion and to carry out parametric studies. This is because the injection process, which can be relatively well predicted with the phenomenological approach, has the dominant effect on mixture formation and subsequent course of combustion. The need for improving these models was also established by incorporating developments happening in engine designs. A phenomenological model consisting of sub-models for combustion and emissions are proposed in detail in this chapter. With more and more "model based control programs" used in the ECU controlling the engines, phenomenological models are assuming importance now. The full CFD based models though give detailed insight into the combustion phenomena and guide the design engineer, they are too slow to be handled by the ECU's or for laying out the engine design.

G. Md. Moinul Islam, Mohammad Anisur Rahman, Mohammad Zoynal Abedin:

An experimental investigation had carried out for the first law analysis of a DI (direct-ignition) diesel engine running on straight soybean oil (SVO) preheated at 50, 75, 100oC with different loads at varying speeds of 1750, 2000, 2250 rpm. The results show that preheated straight soybean oil may be a practical replacement of the conventional diesel fuel with a small power and efficiency drop. The brake thermal efficiency of the engine apparently increases with increased preheats temperature of the soybean oil fuel and at 100oC it becomes very much comparable with the performance trends obtained using diesel fuel.

H. Clive Lewis

Build a one dimensional model of an CI engine. So that it is possible to calculate the speed, density, pressure and temperature of the flow in various places in the engine. One dimensional flow is defined as flow which has small changes in the conditions normal to the streamlines compared to changes along the streamlines. Because the shapes and sizes of the passages change, the air or air/fuel mixture will have different velocities so therefore one must decide if the flow is compressible or incompressible. He was calculated sub-model (piston velocity, intake condition, exhaust flow, flow pass the mouthpiece), comparison of compressible and incompressible flow. It had been shown that with relatively simple mathematical equations based upon some of the ground laws of physics, together with a collection of assumptions, it was possible to find the conditions of the flow in a number of places in the models. The limits of the engine speed are decided by the shapes and dimensions of the passages which the gas has to flow together with the size of the piston and cylinder in which it moves. It was also interesting to note that at maximum engine speed the phenomena "choking" prevents the engine from going any faster, this takes place at the critical Mach number 1. The constant improvements in the field of research and development see more and more control units included in the engine to steer everything from the temperature of the gas entering the cylinder to the amount of unburned fuel which is sent back into the cylinder after the exhaust stroke.

I. B.Rajendra Prasath et al:

Carried out the simulation of the combustion and performance characteristics of biodiesel fuel indirect injection (D.I) low heat rejection (LHR) diesel engine was carried out. Comprehensive analysis of combustion characteristics such as cylinder pressure, cylinder peak pressure, ignition delay, heat release rate and performance characteristics such as specific fuel consumption, brake thermal efficiency is carried out. The engine simulation was develop and model for both diesel and biodiesel. On the basis of first law of thermodynamics the properties at each degree crank angle was calculated. Method for preparation of biodiesel and the important correlation for the thermodynamic property measurement was presented. Preparation and reaction rate model was used to calculate the instantaneous heat release rate. To calculate preparation rate Whitehouse-Way model was used. A gas-wall heat transfer calculations are based on the Annand's combined heat transfer model with instantaneous wall temperature to analyze the effect of coating on heat transfer. The simulated results are validated by conducting the experiments on the test engine under identical operating condition on a turbocharged D.I diesel engine. In this analysis 20 percent of biodiesel (derived from 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.

IV. CONCLUSION

A comprehensive survey on First Law of Thermodynamics using diesel and biodiesel fuels is presented in this literature. Extensive theory on the energy balance is given including the application of the first law of thermodynamics, variation in heat transfer correlation for wall heat loss evaluation, thermodynamic models etc 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.

1) The single-zone thermodynamic models are comparatively easier to apply and exhibit reasonable accuracy but for better accuracy multi-zone models are preferable.
2) The engine performance improved with low quantity blends of biodiesel to diesel, this indicated by the higher maximum combustion temperature and pressure.
3) Biodiesels have lower thermal efficiency than diesel fuel .For same amount of output power, the BSFC of biodiesels is much higher than diesel fuel. The heat losses except the exhaust loss are higher while using biodiesels due to the presence of excessive oxygen molecules. Thermal insulation can be a good solution in this regard; mean while it will increase the exhaust heat loss. The brake power decreases with the increase of cetane number. The cooling water loss is comparatively higher than the exhaust heat loss for biodiesels.
4) Modifying the equations if necessary so that it could be applied over a much wider range of speed and load.

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