Second Law Analysis of Diesel Engine by Comparing Different Heat Transfer Models – A Review

C. R. Makode
Mechanical Engineering Department
Government College of Engineering
Amravati, Maharashtra, India

M. M. Deshmukh
Mechanical Engineering Department
Government College of Engineering
Amravati, Maharashtra, India

Abstract- The engine analysis is usually done on the traditional first law analysis. The second law analysis is also done by new researchers recently. Engine modeling is done to analyze the critical features of the process. The paper presents the research work done by different researchers to study the first and second law analysis of diesel engine. The heat transfer models used by different researchers are also studied to calculate the heat transfer coefficient from engine cylinder. It is found out that the second law analysis is very good tool to understand the better insights of the engine processes and thermodynamic cycle. It is also found out that the heat transfer correlations developed by Annand, Woschni, Hohenberg and Eichelberg are better to calculate the heat transfer coefficient.

Keywords- Diesel Engine; Second Law Analysis; Heat Transfer Models

I. INTRODUCTION

While the standard first-law analysis usually fails to provide the engineer the most effective insight into the engine's operation, the second-law is incredibly helpful, that contributes a brand new approach of thinking and finding out thermodynamic processes, a truth that provides a lot of field and adaptability for improvement to the engineer. To work out the direction of method, to ascertain the condition of equilibrium, to specify the utmost attainable performance of thermal systems and to spot those aspects of processes that are important to overall performance, second law analysis can be used.

The second-law analysis provides a lot of important and thorough insight into the engine processes by shaping the term of irreversibilities or availability destruction and giving totally different magnitude to heat losses terms and therefore the exhaust gases. By thus doing, it spots specific engine processes and parameters, which may improve the engine performance by doing effect on engine or subsystems irreversibilities and therefore the availability terms related to the exhaust gases (to ambient) and heat losses to the cylinder walls. The bulk of various reports and studies have investigated the influence of heat transfer, combustion, friction and mixing processes on availability destruction suggesting totally different choices to cut back energy degradation and increase portion of energy obtainable for helpful work.

In engineering, modeling a process has return to mean developing and victimization the acceptable combination of assumptions and equations that let important features of the process to be analyzed. The modeling of engine processes continues to develop as our basic understanding of the thermodynamics and chemistry expands and because the capability of computers to resolve complicated equations continues to extend. Modeling activities will create major contributions to engine engineering at totally different levels of generality or detail.

Several heat transfer models are projected over the years, principally supported correlations of dimensionless numbers and derived from similarity analysis, with experimental information. Models can be classified in step with their spatial resolution, specifically global one-zone, multi-zone, one-dimensional and multi-dimensional fluid dynamic models. The global heat transfer coefficient can be written as,

$$h_{global}(t) = \alpha_{scaling} \,.\, L\,(t)^{m-1}.k/\mu^{m}.p(t)^{m}.T(t)^{-m}.v(t)^{m} \qquad (1)$$

The global heat transfer coefficient depends on characteristic length, transport properties, pressure, temperature, and characteristic velocity. A scaling factor α scaling is used for tuning of the coefficient to match specific engine geometry. A value for the exponent m has been proposed by several different authors.

II. LITERATURE REVIEW

C. D. Rakopoulos and E. G. Giakoumis [2] have studied speed and load effects on the availability balances and irreversibilities production in a multi-cylinder turbocharged diesel engine. They used a multi-cylinder, turbocharged, in direct injection diesel engine from a view based on second-law analysis. A single-zone thermodynamics model is developed following the filling and emptying modeling technique. In all parts of the diesel engine plant a second-law analysis is performed, that provides all the present availability terms and accounts for the analysis of each component's irreversibilities. The results by first law and second law are compared. To simulate the heat loss to the cylinder walls for each the main chamber and therefore the pre-chamber, the model of Annand is employed. They highlighted however the two basic engine operation parameters, i.e. speed and load, have an effect on the operation of this engine below a second-law perspective.

C. D. Rakopoulos and E.G. Giakoumis [7] developed a computer model for studying the first- and second-law (availability) balances of a turbocharged diesel engine, operating under transient load conditions. They use the model of Annand to simulate the heat loss to the cylinder walls. They declared that second-law analysis results don't invariably go together with the first-law ones, strengthening the idea that a joint improvement of first and second-law could also be an awfully sensible choice for establishing best engine performance.

E. G. Giakoumis [1] has done cylinder wall insulation effects on the first and second-law balances of a turbocharged diesel engine operating under transient load conditions. To include the second-law balance, an experimentally checked transient diesel engine simulation code has been expanded. The improved model of Annand and Ma is employed to simulate heat loss to the cylinder walls. It's disclosed that second-law analysis should be applied to evaluate the inefficiencies related to the assorted processes.

Zehra Sahin and Orhan Durgun [8] have done multi-zone combustion modeling for the prediction of diesel engine cycles and engine performance parameters. In this, quasi-dimensional phenomenological combustion model developed by Shahed and Ottikkutti are used and developed with new assumptions. Annand's correlation is employed to calculate the instantaneous total heat transfer from the cylinder contents to the combustion chamber walls. They explicit that the given model will predict the engine behavior in sensible agreement with the theoretical and experimental results.

F. Payri, P. Olmeda, J. Martín and A. García [9] have done a complete 0D thermodynamic predictive model for direct injection diesel engines. In this, a variation of the expression given by Woschni is employed to calculate the heat transfer constant. To improve the original model of Woschni, many efforts are taken. Finally the justification have been given to include the proposed sub-models for correct prediction of the engine performance and it's been quantified the error within the simulation results if these sub-model weren't enclosed.

Maher M Abou Al-Sood, Mahmoud Ahmed and Yousef M Abdel-Rahim [10] have developed rapid thermodynamic simulation model for optimum performance of a four-stroke, direct-injection, and variable-compression-ratio diesel engine. For the performance of a four-stroke, DI diesel engine a thermodynamic simulation model is developed. The Eichelberg model as changed by Rakopoulos and Hountalas is employed. The comparisons between foreseen and experimental results for various engines, in operation beneath different conditions show that there's a decent concurrence between foreseen and measured values.

Junnian Zheng and Jerald A. Caton [11] have done second law analysis on a low temperature combustion diesel engine to study the effect of injection timing and exhaust gas recirculation. They work on engine cycle simulation incorporating the second law of thermodynamics to gauge the energy and exergy distribution of different processes in the low temperature combustion diesel engine. The Hohenberg correlation is employed to calculate the cylinder heat transfer. By comparison to the standard injection timing cases, they observed that the late injection timing cases show lower proportion of heat transfer exergy and better proportion of net flow exergy, which means for the exhaust recovery process for the late injection cases a lot of exergy can be used.

Claude Valery Ngayihi Abbe, Robert Nzengwa, Raidandi Danwe and Zacharie Merlin Ayissi Marcel Obonou [12] have done a study on the 0D phenomenological model for diesel engine simulation with application to combustion of Neem methyl esther biodiesel. The Woschni approach is planned to formulate heat transfer model. They state that the model is ready to predict engine operation characteristics in several in operation points with fair accuracy and few adjusting numerical coefficients. The results obtained were found satisfactory in terms of accuracy, simplicity and computer price.

C. D. Rakopoulos and E.G. Giakoumis [4] have done second-law analyses applied to internal combustion engines operation. This paper surveys the publications offered within the literature regarding the applying of the second-law of thermodynamics to IC engines. A close reference is created to the findings of different researchers within the field over the last forty years regarding all sorts of IC engines, i.e. SI, CI, turbocharged or naturally aspirated, throughout steady-state and transient operation. Main variations between the results of second and first law analyses are highlighted and mentioned. It's believed that engine operation optimization supported the second-law of thermodynamics will function as a strong tool to the engine designer.

Maro JELIĆ and Neven Ninić [3] have done analysis of internal combustion engine thermodynamic using the second law of thermodynamics. They studied work of various authors. They expressed that one in every of the foremost appropriate ways in which in analysis of energy degradation is application of the second law of thermodynamics in analysis of the method in combustion engines and by applying the numerical simulations in modeling the IC engine processes in conjunction with the analysis by the second law of thermodynamics, we tend to get an awfully potent tool for good insight and improvement of SI and CI engines achieving lower fuel consumption and lower emissions.

Aysegul Abusoglu and Mehmet Kanoglu [13] have done first and second law analysis of diesel engine powered cogeneration systems. In this article, the thermodynamics analysis of the prevailing diesel engine cogeneration system is performed. The exergy analysis is aimed to gauge the exergy destruction in every element and in exergetic efficiencies also. They explicated that such data are often employed in development of the new energy economical systems and for increasing existing system's efficiency. This elaborated analysis give a strong and systematic tool for characteristic all price sources and for optimization of design of cogeneration systems powered by diesel engine.

A. Aziz Hairuddin, Andrew P. Wandel and Talal Yusaf [14] have done effect of different heat transfer models on a diesel homogeneous charge compression ignition engine. The mechanism of chemical kinetics influences the combustion with some cylinder wall heat losses. The result of various heat loss models in diesel HCCI engine should be investigated more. A single-zone model was utilized in this study together with three different heat loss models: Woschni, modified Woschni, and Hohenberg correlations. They found that the distinction in heat loss models ends up in a giant distinction within the heat flux, and therefore the modified Woschni model has the best heat flux among these models. The study revealed that the modified Woschni model created additional correct results, whereas the Woschni and Hohenberg models need additional standardization of constants before they will utilized in a diesel HCCI engine.

Adrian Irimescu [15] worked on convective heat transfer equation for turbulent flow in tubes applied to internal combustion engines operated under motored conditions. They developed an equation for the case of turbulent flow in tubes was applied for the study of convective heat transfer in IC engines. Calculated average heat flux values below motorised conditions were compared to measurements, results offered within the literature obtained by employing a CFD code and also the models of Woschni and Annand. Cumulative heat flux values for the four models were additionally compared to measurements at compression stroke's end and expansion's start. Average heat transfer rates were found to be expected with affordable accuracy by the planned model. They found out that this equation doesn't need any correction and the model predicts properly the higher heat transfer rates as engine variables were raised.

Junfeng Zhao and Junmin Wang [16] have studied Control-oriented multi-phase combustion model for biodiesel fueled engines. In this paper, the combustion characteristics of Diesel and biodiesel fuels are investigated and compared. Based on the experimental information obtained from a medium-duty diesel engine, a multi-phase combustion model, that is applicable to each Diesel and biodiesel fuels, is developed and it shows satisfactory accuracy at intervals of test range during this study. The Hohenberg correlation is used. It's additionally capable of modeling the premixed and mixing-controlled combustion by making use of two cascaded Wiebe functions. Through a grey-box parameter identification approach, a group of Wiebe coefficients, that are partially thermodynamics-based, are found; then the model will have an affordable accuracy for the vary of experiments conducted.

III. THE CORRELATIONS USED BY VARIOUS RESEARCHERS

The Woschni correlation is given by [15]

$$h = 3.26*B^{-0.2}.P^{0.8}.T^{-0.53}.w^{0.8} \quad (2)$$

Where, B - cylinder bore (m),
P – Instantaneous cylinder pressure (Pa),
T – Temperature (°C),
w – Local avg. gas velocity,
$w = C_1.S_p. + C_2. [V_d.T_r./(P_r.V_r)](P-P_m)$
Where, C_1, C_2 – constants to adjust according to engine,
S_p – Mean piston speed,
V_d – Displayed volume,
P_r, V_r, T_r – Pressure, volume, temperature at reference state,
P_m – Motored cylinder pressure at same crank angle as P.

The Hohenberg correlation is given by [14]

$$h = 3.26*P^{0.8}.T^{-0.4}.V^{-0.06}. (S_p+1.4)^{0.8} \quad (3)$$

Where, S_p – Mean piston speed,
V – Instantaneous cylinder volume.

Eichelberg's correlation can be expressed as, [10]

$$h(\theta) = 7.67*10^{-3}*S_p^{1/3}*\mathrm{sqrt}(P(\theta).T(\theta)) \quad (4)$$

The Annand's correlation is given as [8]

$$Q_{cyl} = A.\{[a.K/(B).Re^{0.7}.(T-T_w)] + [b_A.(T^4 - T_w^4)]\} \quad (5)$$

Where, A- heat transfer area,
K- Thermal conductivity of the cylinder gas,
Re- Reynolds number based on piston speed and cylinder bore,
T_w- the cylinder wall temperature,
$b_A = 3.267\times10^{-11}$ W/m² K⁴,
a- constant.

IV. CONCLUSION

Review work is undertaken to study the experimentation carried out by different researchers to calculate the heat release rate from engine cylinder by using first and second law analysis. It is found out that the second law analysis is the best way to study the thermodynamic processes and engine operations.

Most of the researchers used Annand and Woschni correlations, while correlation of Annand and Ma is also used. Others used Hohenberg correlation and Eichelberg correlation modified by Rakopoulos and Hountalas. It is also observed that the heat transfer correlations of Annand, Woschni, Hohenberg and Eichelberg are better to calculate the heat transfer.

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