

A Review on Second Law Analysis of Homogeneous Charge Compression Ignition on Single Cylinder Four Stroke Diesel Engine

A. N. Pise¹, M. M. Deshmukh²

M.Tech student, Thermal Engineering, Govt. College of Engineering, Amravati (M.S), India¹

Associate Professor, Mechanical Engineering Dept., Govt. College of Engineering, Amravati (M.S), India²

ABSTRACT:In this research, a single-cylinder, four-stroke cycle, diesel fuelled homogeneous charge compression ignition engine has been used to evaluate the first and second laws of thermodynamics terms. 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 homogeneous charge compression ignition engine. Hence, the analysis can be used to determine the optimized diesel HCCI engine for the purpose of various correlations like Annand, Woschni, Hohenberg, Eichelberg, Wolfer, Arrhenius, Watson and Hardenberg and Hase.

KEYWORDS:Homogeneous charge compression ignition (HCCI); Diesel Engine; Second Law Analysis; Engine Modelling

I. INTRODUCTION

The day to day challenges facing today is the increased emissions, which is the environmental challenge. The new combustion concept, namely Homogeneous Charge Compression Ignition (HCCI), has taken the advantage of the working principles of both the Spark Ignition (SI) and Compression Ignition (CI) engines. A single cylinder, four stroke, diesel engine is used in this research work. The port fuel injection is mainly for creating the homogeneous mixture, which is fully controlled by electronic control unit (ECU).

In engineering, modeling a process has come to mean developing and using the appropriate combination of assumptions and equations that permit critical features of the process to be analyzed. The modeling of engine processes continues to develop as our basic understanding of the physics and chemistry of the phenomena of interest steadily expands and as the capability of computers to solve complex equations continues to increase. Modeling activities can make major contributions to engine engineering at different levels of generality or detail.

Several heat transfer models have been proposed over the years, mostly based on correlations of dimensionless numbers, derived from similarity analysis, with experimental data. Models can be categorized according to their spatial resolution, specifically global one-zone, zonal (multi-zone), one-dimensional and multi-dimensional fluid dynamic models. These models typically feature area-averaged, empirical heat transfer coefficients derived from the relationship 'Nu = aRe^m' based on dimensional analysis of the energy equation. Substituting for Nu and Re with physical properties, the global heat transfer coefficient can be written as ,

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

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 a specific engine geometry. A value for the exponent m has been proposed by several different authors.

The heat transfer coefficient by Nusselt is given by ,

$$h = 0.99(1+1.24C_m) \cdot \sqrt[3]{P^2 \cdot T} + \frac{0.362}{(1+\xi_g + \frac{1}{\xi_w})} \cdot \frac{(\frac{T}{100})^4 - (\frac{T_w}{100})^4}{T - T_w}$$

where, ξ_g – Emissivity of gas, ξ_w – Emissivity of a wall, C_m – Mean piston speed, P – Pressure.

Diesel Engines often during combustion result into accumulation of residual trapped gases in the engine cylinder. In compression ignition engines, high nitrogen oxides (NO_x) and their particulate matter (PM) emissions are the biggest handicap. It is not possible to reduce both of NO_x and PM emissions simultaneously in conventional compression ignition combustion. Complex and expensive after treatment exhaust emission systems are required to eliminate these emissions. However, emission norms get harder and harder with each passing day. The current after treatment systems may be insufficient in the near future to meet stringent emission regulations. Another problem of the after treatment systems such as diesel particulate filters, lean NO_x trap and selective catalytic reduction is cost and durability. Therefore, it is required to improve combustion process. For this reason a great deal of importance is given to the in cylinder combustion processes.

Presently, compression ignition engines have attracted a great interest due to their high thermal efficiency, reliability, durability and high specific power compared to spark ignition engines. In spite of these advantages of compression ignition engines, high nitrogen oxides (NO_x) and their particulate matter (PM) emissions are control. It is not possible to reduce both of NO_x and PM emissions simultaneously in conventional compression ignition combustion. Complex and expensive after treatment exhaust emission systems are required to eliminate these emissions. However, emission restrictions get harder and harder with each passing day. The current after treatment systems may be insufficient in the near future to meet stringent emission regulations. Another problem of the after treatment systems such as diesel particulate filters, lean NO_x trap and selective catalytic reduction is cost and durability. Therefore, it is required to improve combustion process. For this reason a great deal of importance is given to the in cylinder combustion processes.

II. LITERATURE REVIEW

T. Karthikeya Sharma , G. Amba Prasad Rao and K. Madhu Murthy[1] have given the computational study on Effective reduction of in-cylinder peak pressures in Homogeneous Charge Compression Ignition Engine. The results showed that swirl ratio has a considerable impact in limiting the peak pressures of HCCI engine. The analysis resulted in achieving about 21% reduction in peak pressures are achieved when a swirl ratio of 4 with 30% EGR is adopted when compared to a swirl ratio of 1 with 0% EGR. The study revealed that out of the four operating parameters selected, lower compression ratios, higher EGR concentrations, lower equivalence ratios, lower boost pressures and higher swirl ratios are favorable in reducing the peak pressures.

ZHarisankar Bendu n, S. Murugan[2] have done the work on Homogeneous charge compression ignition (HCCI) combustion Mixture preparation and control strategies in diesel. This paper reviews the strategies of different external and in-cylinder mixture preparation methods which were adopted and proposed in the recent years. The different strategies of controlled auto-ignition by HCCI combustion are also discussed in this paper.

T. Karthikeya Sharma , G. Amba Prasad Rao, K. Madhu Murthy[3] have done the work on effective reduction of NO_x emissions of a HCCI (Homogeneous charge compression ignition) engine by enhanced rate of heat transfer under varying conditions of operation. The effect of swirl in enhancing the convective heat transfer and reduction of NO_x emissions was discussed in this paper. The results showed that apart from adopting higher compression ratios and boost pressures use of high swirl ratios is observed to be contributing to a large extent in enhancing the rates of heat transfer which would lead to significant reduction in cylinder temperatures suitable for low NO_x emission formation in HCCI mode.

Gowthaman S, Sathiyagnanam A.P[4] done the work on Performance and Emission Characteristics of Diesel Fuelled Homogeneous Charge Compression Ignition (HCCI) Engine. The HCCI engine is a suitable replacement for compression ignition engine (CI). The results show that the specific fuel consumption is decreased for diesel fuelled HCCI mode engine compared to DI-CI engine. The brake thermal efficiency of HCCI mode engine is even as same or slightly increased. From the result observed that the value of oxides of nitrogen (NO_x) and particulate matter (PM) emissions are very low than the DI diesel engine. The rate of reduction of NO_x and PM are about 20% and 5% respectively. But the exhaust emission of un burnt hydrocarbon (UHC) and carbon monoxide (CO) are higher than DI mode diesel engine.

C. D. Rakopoulos and E. G. Giakoumis[5] 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.

H. An, W.M. Yang, J. Li [7] have done numerical modeling on a diesel engine fueled by biodiesel-methanol blends. A modeling study was conducted to investigate the impact of methanol addition on the performance, combustion and emission characteristics of a diesel engine fueled by biodiesel. 3-D CFD simulations were conducted using the KIVA4 code coupled with CHEMKIN II for neat biodiesel and its blend fuels with 5%, 10% and 15% (in vol.) of methanol under 10%, 50% and 100% loads and a fixed engine speed of 2400 rpm conditions. A skeletal reaction mechanism was developed to mimic the significant species and reaction pathways of biodiesel and methanol fuels, and it was validated by performing the ignition delay calculations for biodiesel and methanol, as well as 3D numerical simulations against the experimental results for biodiesel. Good agreements in terms of ignition delay, cylinder pressure and heat release rate predictions were obtained. The simulation results revealed that with partial replacement of biodiesel by methanol, tangible improvement on the cylinder pressure was observed under 10% load condition especially for the case with 5% methanol blend ratio. Whereas, under 50% and 100% engine load conditions, only comparable cylinder pressure curves were seen. In terms of performance characteristics, almost linearly increased indicated thermal efficiency with respect to methanol blend ratio were observed under all the engine load conditions. Overall, the indicated CO and soot emissions decreased.

C. D. Rakopoulos and E. G. Giakoumis [8] 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.

Zehra Sahin and Orhan Durgun [9] have done multi-zone combustion modelling 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 behaviour in sensible agreement with the theoretical and experimental results.

F. Payri, P. Olmeda, J. Martín and A. García [10] 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. Many efforts are taken to improve the original model of Woschni. 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 [11] 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 is a decent concurrence between foreseen and measured values.

Claude Valery Ngayihi Abbe, Robert Nzengwa, Raidandi Danwe, Zacharie Merlin Ayissi and Marcel Obonou [12] have done a study on the 0D phenomenological model for diesel engine simulation with application to combustion of Neem methyl ester 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 operation points with fair accuracy and few adjusting numerical coefficients. The results obtained were satisfactory in terms of accuracy, simplicity and computer price.

C.D. Rakopoulos and E.G. Giakoumis [13] 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 is 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 [14] have done analysis of internal combustion engine using the second law of thermodynamics. The paper presents the research work done by various authors who have done research in the application of the second law of thermodynamics in analysis of the internal combustion engine and in analysis of the thermodynamics of the combustion process in an engine cylinder in spark-and compression-ignition engines. For several decades now, various authors have been trying to optimize processes in the internal combustion engine, where energy degradations occur during combustion. It is essential to get a better insight and understanding of the sources for this energy degradation to avoid or diminish them, striving to achieve higher efficiencies of internal combustion engines as the most effective heat engine. One of the most suitable ways in research of energy degradation is application of the second law of thermodynamics in analysis of the process in internal combustion engines. Through the application of the second law of thermodynamics in analysis of the combustion process, the connection between all thermodynamic data with entropy was achieved. By applying the numerical simulations in modeling the ICE engine processes together with the analysis by the second law of thermodynamics, we get a very potent tool for better insight and optimization of spark- and compression-ignition engines achieving lower fuel consumption and lower emissions

N. Watson and A. D. Pilley [15] in the paper has given the combustion correlation for diesel engine simulation. The use of cycle simulation computer programs has become an established part of turbocharged diesel engine research and development. However, the utility of these programs has in the past been limited by the need for combustion information at the operating point. This difficulty has been overcome by the development of an empirical correlation simulating the combustion process (heat release) via an analytical expression whose governing parameters are linked to in-cylinder conditions. A method of deriving the governing parameters from only a minimum of experimental test data is presented, but enabling performance to be predicted over a wide range of operating conditions. The use of the combustion correlation enables the effects of changing ambient conditions, turbocharger match, valve timing and other engine design parameters to be predicted automatically, and includes their influence on combustion as well as the turbo charging process in an engine design as well as ambient conditions to be predicted, including their effects on the combustion process. The correlation is based on experimental AHRR data, and was initially derived from a large quantity of such information obtained from a typical truck type engine. However, it will be shown that the correlation can be applied to other engines for which only a limited amount of experimental data is available.

N. D. Whitehouse and E. Clough [16] in their paper have obtained Heat release data from a 5 in bore direct injection diesel engine operating over a range of conditions including off-design conditions, such as running at low air to fuel ratios, using six-hole injector nozzles in place of the standard three-hole nozzles, and reducing compression ratio and thereby swirl ratio at TDC. The paper shows that when operating with adequate utilized air fuel ratios (A/Fs) the experimental heat release data could be correlated with a single zone combustion model and that changing the number of nozzle holes or compression/swirl ratio had little effect on the correlation after the initial period of heat release. At inadequate A/Fs a modification to the model to allow for partial combustion was introduced. This improved correlation and enabled reasonable heat release prediction in the cycle synthesis program.

Donald J. Patterson [17] Cylinder pressure variation is a fundamental and widespread combustion problem in spark-ignited engines. The basic factors causing this problem are variations both in the start and in the rate of combustion. These variations occur not only from cycle to cycle within each cylinder but may also show up as consistent differences between cylinders. Our test results indicate that the major cause of cyclic combustion rate variation is the mixture velocity differences that exist within the cylinder near the spark plug at the time of ignition. As yet we do not know how to reduce the cyclic mixture velocity variations and thus reduce the problem at its origin. However, it is possible to circumvent some effects of cyclic pressure variation by increasing the average combustion rate.

H. Hiroyasu and T. Kadota [18] In order to determine spray droplet size in a diesel engine, fuel was injected into high-pressure, room-temperature gaseous environments with a diesel engine injection system. Droplet size was measured using the liquid immersion sampling technique with a mixture of water-methylcellulose solution and ethanol

used as an immersion liquid for diesel fuel oil. The volume distribution of diesel spray droplets is well correlated with chi square distribution with freedom, $\phi = 8$, in the range of this investigation. The Sauter mean diameter increased with increasing back pressure, with the amount of fuel in a spray, and with decrease in pump speed. An empirical correlation was developed between effective injection pressures, air density, the quantity of the fuel delivery, and the Sauter mean diameter of spray droplets, the swirl atomizer, air blast atomizer, and rotating-cup atomizer has been measured by numerous investigators, but only a few studies of droplet size in the diesel combustion chamber have been made. The lack of sufficient data of droplet size distribution in diesel spray is due to the difficulty in measurement which arises from the large number of droplets to be sampled, intermittent characteristics of the spray, and its liquidity.

J. C. Dent and Pramod S. Mehta [19] A phenomenological model is presented for prediction of the combustion characteristics of a Quiescent Chamber Diesel engine. Predictions with the model have shown acceptable agreement with a range of experimental data. The major physical processes controlling combustion have been characterized, and the dominant role of air entrainment and turbulent mixing confirmed quantitatively.

N. Watson and M. Kamel [20] The lower efficiency of the indirect-injection diesel engine, with respect to the direct injection type, is due to additional heat transfer from the combustion chamber, gas pumping between chambers, later injection timing and a different burning rate schedule. The paper describes a project to isolate and quantify these reasons for low efficiencies, using a mathematical model, supported by experimental verification. The model is based on a two-zone system (main and pre-chamber), with component models for heat transfer, gas flow through the passage etc. Experimentally derived heat release schedules in main and pre-chamber are used. It is shown that for a 0-1 m bore engine, with a Ricardo Comet V b pre-chamber, the different burning rate schedule is the major contribution to the difference in efficiency, with injection timing and gas pumping being the least significant.

W. T. Lyn and E. Valdmanis [21] The effects of physical factors on ignition delay have been studied on a motored research engine using a single injection technique. The fuels used included a high cetane number reference fuel, gas oil and M.T. 80 petrol. The primary factors investigated are those pertaining to the fuel spray, such as injection timing, quantity, and pressure (affecting drop size, velocity and injection rate) hole diameter (affecting drop size and injection rate) and spray form (nozzle type); and those pertaining to the engine, such as temperature, pressure and air velocity. Engine operating variables such as speed and load affect the ignition delay because they change the primary factors such as injection pressure, compression temperature, pressure and air velocity. It has been found that inner normal running conditions, compression temperature and pressure are the major factors. All other factors have only secondary effects. Under starting conditions, when ignition is marginal, mixture formation becomes as important as compression temperature and pressure. Such factors as air velocity and spray form which affect the mixing pattern can have a very pronounced effect on ignition delay. Published data on ignition delay are compared with those obtained in the present investigation and a generalization of the data is recommended for engine design and computational work.

Aysegul Abusoglu and Mehmet Kanoglu [22] have done first and second law analysis of diesel engine powered cogeneration systems. In this article, the thermodynamic analysis of the existing diesel engine cogeneration system is performed. The exergy analysis is aimed to evaluate the exergy destruction in each component as well as the exergetic efficiencies. They stated that such information can be used in the design of the new energy efficient systems and for increasing the efficiency of existing systems. This detailed analysis provide a powerful and systematic tool for identifying all cost sources and for optimizing the design of diesel engine powered cogeneration systems.

Claude Valery Ngayihi Abbe, Robert Nzenywa, Raidandi Danwe, Zacharie Merlin Ayissi Marcel Obonou [23] have done a study on the 0D phenomenological model for diesel engine simulation: Application to combustion of Neem methyl ester biodiesel. The model addresses some specific aspects of diesel engine modeling found in previous studies such as the compromise between computers cost, accurateness and model simplicity, the reduction of the number of empirical fitting constant, the prediction of combustion kinetics with reduction of the need of experimental curve fitting, the ability to simultaneously predict under various loads engine thermodynamic and spray parameters as well as emission characteristics and finally the ability to simulate diesel engine parameters when fueled by alternative fuels. The heat transfer is modeled using the approach proposed by Woschni. They state that the model is able to predict diesel engine operating characteristics in different operating points with good accuracy and few adjusting numerical coefficients. The results obtained were found satisfactory in terms of accuracy, algorithm simplicity and computer cost.

C.D. Rakopoulos, E.G. Giakoumis [24] have done second-law analyses applied to internal combustion engines operation. This paper surveys the publications available in the literature concerning the application of the second-law of

thermodynamics to internal combustion engines. A detailed reference is made to the findings of various researchers in the field over the last 40 years concerning all types of internal combustion engines, i.e. spark ignition, compression ignition (direct or indirect injection), turbocharged or naturally aspirated, during steady-state and transient operation. Main differences between the results of second- and first-law analyses are highlighted and discussed. It is believed that engine operation optimization based on the second-law of thermodynamics can serve as a powerful tool to the engine designer.

III. THE CORRELATIONS USED BY VARIOUS RESEARCHERS

For diesel fuels a reasonable estimate of the delay, ID is achieved by Wolfer, [12]

$$ID = 3.45 \exp(2100/T_m) * P_m^{-1.02},$$

where, T_m and P_m are the mean temperature and pressure of the ambient during ignition delay.

The Arrhenius type of equation is used to describe ignition delay [12]

$$\tau_{id} = a \cdot \Phi \cdot k \cdot P \cdot n \cdot \exp\left(\frac{E_a}{R_u \cdot T_{cyl}}\right),$$

where, τ_{id} = Ignition delay, Φ = Equivalence ratio, E_a = Activation energy, T_{cyl} = Cylinder charge temperature, R_u = Gas constant, a , k and n = Empirical constants

The Watson model is given by [7]

$$\tau_{id} = A(BP)^{-N} \cdot P_{SOC}^{-B} \cdot \exp\left(\frac{E}{R_u T_{SOC}}\right),$$

the constants A , N and B are adjustable.

The correlation developed by Hardenberg and Hase is given by, [12]

$$\tau_{id} (A) = (0.36 + 0.22 \bar{S}_p) \exp\left[EA \left(\frac{1}{R \cdot T} - \frac{1}{17190}\right) \cdot (21.2 / (P - 12.4))^{0.63}\right],$$

where, \bar{S}_p = piston speed (m/s), R = Universal gas constant (8.3143 J/mol), EA = Apparent activation energy

$$EA = \frac{618840}{CN + 25},$$

where, CN = Cetane number

Shipinski et al attempted to correlate the Apparent heat release rate with the rate of injection by fitting a Wiebe function to experimentally determined heat release diagrams, over a range of engine test conditions. The Wiebe function can be expressed as:[6]

$$M(\tau) = \frac{m(\tau)}{m_t} = 1 - \exp(-C_1 \tau^{C_2})$$

The Woschni correlation is given by[22]

$$h = 3.26 * B^{-0.2} * P^{0.8} * T^{-0.53} * w^{0.8},$$

where, B - cylinder bore (m), P - Instantaneous cylinder pressure (Pa), T - Temperature (°C), w

- Local avg. gas velocity,

$$w = C_1 \cdot S_p + C_2 \cdot \frac{V_d \cdot T_r}{P_r \cdot V_r} \cdot (P - P_m),$$

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 [23]

$$h = 3.26 * P^{0.8} * T^{-0.4} * V^{-0.06} * (\bar{S}_p + 1.4)^{0.8},$$

where, \bar{S}_p - Mean piston speed.

Eichelberg's correlation can be expressed as, [20]

$$h(\theta) = 7.67 * 10^{-3} * U_p^{1/3} * \sqrt{P(\theta)} * T(\theta)$$

The Annand's correlation is given as [24]

$$Q_{cyl} = A \left\{ a \cdot \frac{K}{B} \cdot Re^{0.7} \cdot (T - T_w) \right\} + [b_A (T^4 - T_w^4)],$$

where, B is the cylinder bore, A is the heat transfer area, K is the thermal conductivity of the cylinder gas, Re is Reynolds number based on piston speed and cylinder bore, T is the cylinder bulk gas temperature, Tw is the cylinder wall temperature, $b_A = 3.267 \times 10^{-11} \text{ W/m}^2 \text{ K}^4$, a is a constant ranging from 0.35-0.8 depending on the intensity of charge motion.

IV. CONCLUSION

Review work is undertaken to study the experimentation carried out by different researchers to calculate the heat transfer, ignition delay, 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 justified the use of second law of thermodynamics to the engine analysis. They called it a very potent tool to for better insight and optimization of diesel engine. It is also observed that the correlations of Annand, Woschni, Wolfer, Arrhenius, Watson, Hardenberg, Hase, Hohenberg, Eichelberg and wiebe function are better to determine for the diesel homogeneous charge compression ignition engine.

REFERENCES

- [1] T. Karthikeya Sharma , G. Amba Prasad Rao and K. Madhu Murthy, "Effective reduction of in-cylinder peak pressures in Homogeneous Charge Compression Ignition Engine- A computational study", Alexandria Engineering Journal (2015)
- [2] Harisankar Bendu n, S. Murugan , "Homogeneous charge compression ignition (HCCI) combustion: Mixture preparation and control strategies in diesel engines", RenewableandSustainableEnergyReviews38(2014)732–746
- [3] T. Karthikeya Sharma, G. Amba Prasad Rao, K. Madhu Murthy, "Effective reduction of NOx emissions of a HCCI (Homogeneous charge compression ignition) engine by enhanced rate of heat transfer under varying conditions of operation", Energy 93 (2015) 2102-2115
- [4] Gowthaman S, Sathiyagnanam A.P," Performance and Emission Characteristics of Diesel Fuelled Homogeneous Charge Compression Ignition (HCCI) Engine", Volume 4, Special Issue 2, February 2015
- [5] C.D. Rakopoulos, E.G. Giakoumis, "Second-law analyses applied to internal combustion engines operation", Progress in Energy and Combustion Science 32 (2006) 2–47
- [6] John B. Heywood, "Internal Combustion Engine Operation", McGraw-Hill, 2007
- [7] H. An, W.M. Yang, J. Li, "Numerical modeling on a diesel engine fueled by biodiesel–methanol blends", Energy Conversion and Management 93 (2015) 100–108
- [8] C. D. Rakopoulos, E. G. Giakoumis, "Comparative first- and second-law parametric study of transient diesel engine operation", Energy 31 (2006) 1927–1942
- [9] Zehra Sahin and Orhan Durgun, "Multi-zone combustion modeling for the prediction of diesel engine cycles and engine performance parameters", Applied Thermal Engineering 28 (2008) 2245–2256
- [10] F. Payri, P. Olmeda, J. Martín, A. García, "A complete 0D thermodynamic predictive model for direct injection diesel engines", Applied Energy 88 (2011) 4632–4641
- [11] Maher M Abou Al-Sood, Mahmoud Ahmed and Yousef M Abdel-Rahim, "Rapid thermodynamic simulation model for optimum performance of a four-stroke, direct-injection, and variable-compression-ratio diesel engine", International Journal of Energy and Environmental Engineering 2012, 3:13
- [12] W. M. Ambrós, T.D.M. Lanzasova, J.L.S. Fagundez, R.L. Sari, D.K. Pinheiro, M.E.S. Martins, N.P.G. Salau, "Experimental analysis and modeling of internal combustion engine operating with wet ethanol", Fuel 158 (2015) 270–278
- [13] C.D. Rakopoulos, E.G. Giakoumis, "Second-law analyses applied to internal combustion engines operation", Progress in Energy and Combustion Science 32 (2006) 2–47
- [14] Maro JELIĆ and Neven Ninić, "Analysis of internal combustion engine thermodynamic using the second law of thermodynamics", ISSN 0562-1887, Strojarstvo 50 (2) 85-94 (2008)
- [15] Watson, N., Pilley, A. D., and Marzouk, M.: "A Combustion Correlation for Diesel Engine Simulation," SAE paper 800029,1980.
- [16] Whitehouse, N. D., Clough, E., and Way, J. B.: "The Effect of Changes in Design and Operating Conditions on Heat Release in Direct-Injection Diesel Engines," SAE paper 740085, 1974.
- [17] Patterson, D. J.: "Cylinder Pressure Variations Present a Fundamental Combustion Problem, SAE paper 660129, SAE Trans., vol. 75,1966.
- [18] Hiroyasu, H., and Kadota, T.: "Fuel Droplet Size Distribution in Diesel Combustion Chamber, SAE paper 740715, SAE Trans., vol. 83,1974.
- [19] Dent, J. C., and Mehta, P. S.: "Phenomenological Combustion Model for a Quiscent Diesel Engine," SAE paper 811235, SAE Trans., vol. 90,1981.
- [20] Watson, N., and Kamel, M.: "Thermodynamic Efficiency Evaluation of an Indirect Injection Diesel Engine," SAE paper 790039, SAE Trans., vol.188,1979.
- [21] Lyn, W.-T., and Valdmanis, E.: "Effects of Physical Factors on Ignition Delay," SAE paper 680102,1968.

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- [22] Aysegul Abusoglu, Mehmet Kanoglu, "First and second law analysis of diesel engine powered cogeneration systems", Energy Conversion and Management 49 (2008) 2026–2031
- [23] Claude Valery Ngayihi Abbe, Robert Nzengwa, Raidandi Danwe, Zacharie Merlin Ayissi Marcel Obonou, "A study on the 0D phenomenological model for diesel engine simulation: Application to combustion of Neem methyl ester biodiesel", Energy Conversion and Management 89 (2015) 568–576
- [24] C.D. Rakopoulos, E.G. Giakoumis, "Second-law analyses applied to internal combustion engines operation", Progress in Energy and Combustion Science 32 (2006) 2–47