

# A Review on Second Law Analysis of Ignition Delay Period of a Diesel Engine with Hydrogen and LPG as Secondary Fuel

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**ABSTRACT:** In this study, experiments were performed on single cylinder four stroke diesel engine by using hydrogen, liquefied petroleum gas (LPG) and mixture of LPG and hydrogen as secondary fuels. The experiments were performed to measure ignition delay period at different load conditions and various diesel substitutions. The experimental results have been compared with ignition delay correlation laid down by other researchers for diesel and dual fuel diesel engine. It is observed that the ignition delay of dual fuel engine depends not only on the type of gaseous fuels and their concentrations but also on charge temperature, pressure and oxygen concentration.

**KEYWORDS:** Second Law analysis, Diesel Engine, Ignition Delay Period, Modelling.

## I. INTRODUCTION

The ignition delay period may be defined as the time lag between the commencement of diesel injection into the cylinder and the point of first detectable rise in cylinder pressure due to exothermic energy release within the mixture.[2] During the ignition delay period a unified physicochemical process takes place in which all transformations, both physical and chemical, occur simultaneously.

The start of combustion is more difficult to define. At the end of compression process, when high-pressure diesel fuel is injected into the cylinder having gaseous fuel-air mixture at high temperature and pressure, the sprays of small diesel droplets form. The rate of vaporization of these fuel droplets depends on the size of droplets, pressure and temperature, volatility of the fuel, their distribution and velocity. The fuel evaporates from each droplet of fuel and mixes with gaseous fuel-air mixture to form a flammable mixture.

In gaseous dual fuel diesel engine the ignition delay period is affected by the temperature, pressure and concentration of the charge. It changes the physical and chemical properties of the charge such as specific heat ratio, availability of oxygen concentration, pre-ignition reaction and afterward the related energy release and also the formation of active species during the combustion of fuels [4]. But this variation in the physical and chemical characteristics of the charge and formation of combustion products in dual fuel diesel engine can neither be explained by temperature and pressure at the time of injection of pilot fuel nor on the basis of reduction in partial pressure of oxygen. Hence the manner in which ignition delay period is affected by the physicochemical processes in gaseous dual fuel diesel engine is different than the pure diesel fuel engine. This gaseous fuel affected pre-ignition processes in an unknown manner to make significant variation in ignition delay of the pilot fuel.[2]

## II. LITERATURE REVIEW

Neilson et al investigated experimentally the effect of gaseous fuels (hydrogen, carbon monoxide, or methane) on the ignition delay period in dual fuel diesel engines by using n-heptane or cetane as pilot fuels. The introduction of nitrogen was used to remove the influence of changes in oxygen concentration and specific heats, while helium was introduced to increase compression temperature of the gaseous-air mixture. It was observed that cylinder charge

temperature, pilot fuel quantity and flow of combustible gas mostly influenced the ignition delay period of dual fuel diesel engine.[5]

Samuel et al. [13] presented an analytical approach for vaporization, ignition and combustion of liquid fuel droplets in a heated environment of homogeneously mixed methane-air mixture at constant pressure in dual fuel diesel engine. The results were obtained for ignition delay and combustion of n-heptanes droplets which were initially introduced into a heated homogeneous surrounding of methane air mixtures in cold condition.

Gunea et al. [9] experimentally investigated the effect of cetane number of diesel liquid pilot fuel on the ignition delay period in dual fuel engine run on pure methane, propane and mixture of methane and low heating value gases like nitrogen and carbon dioxide with different pilot fuel quantities. The variation in ignition delay period due to increased gaseous fuel addition depends on the quantity and quality of the pilot fuel. The smaller quantity of pilot fuel with higher cetane number was observed to be enough to ignite the gaseous fuel air mixture.

A.Vamshikrishna Reddy, T.Sharathkumar, D.K.Tharunkumar, B. Dinesh and Y.V.S. SaiSantosh[4] have done Energy and Exergy Analysis of I.C. Engines. In this paper the author has carried out energy and exergy analysis of the biogas run dual fuelled diesel engine. The study is done by coupling 1<sup>st</sup> law and 2<sup>nd</sup> law of thermodynamics. This gives a clear picture on fuel consumption, brake thermal efficiency, exergy efficiency and different availabilities with the varying load and compared to the corresponding diesel values.

C. D. Rakopoulos and E. G. Giakoumis [7] 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 [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 modeling for the prediction of diesel engine cycles and engine performance parameters. In this, quasi-dimensional phenomenological combustion model developed by Shahed and Otikkutti 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 [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. 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 [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's a decent concurrence between foreseen and measured values.

Claude Valery Ngayih Abbe, Robert Nzengwa, Raidandi Danwe, 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 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 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 [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'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 [14] have done analysis of internal combustion engine thermodynamic using the second law of thermodynamics. 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

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 turbocharging 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 pressure, 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 characterised, 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 Vb 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 under 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.

### III. THE CORRELATIONS USED BY VARIOUS RESEARCHERS

For diesel fuels a reasonable estimate of the delay, ID is achieved by Wolfer, [19]

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

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 [7]

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

where,  $tid$  = Ignition delay,  $\Phi$  = 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 [15]

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

the constants  $A$ ,  $N$  and  $B$  are adjustable.

The correlation developed by Hardenberg and Hase is given by, [3]

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

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

The Prakash et al equation for ignition delay for dual fuel diesel engine operated biogas as secondary fuel-[1]

$$\tau_{\text{odf}} = C(\text{Odf})^k (0.36 + 0.22M_{\text{FSE}}) \exp \left[ E_A \left( \frac{1}{RT_m (v_c)^{0.7}} - \frac{1}{17190} \right) + \left( \frac{21.2}{P_m (v_c)^{0.5} - 12.4} \right)^{0.63} \right]$$

Where, C, k, Odf = modified coefficient constant and oxygen concentration of dual fuel engine respectively.

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:

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

#### IV. CONCLUSION

The review work is carried out to study the researchers work with different ignition delay models. Also the experimentations carried out by second law of thermodynamics are also studied.

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. The ignition delay correlations models of Wolfer, Arrhenius, Watson, Hardenberg and Hase and Prakash et al are found to be most effective.

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