Impact of Initial Temperature and Pressure on Ignition Delay Period of Di-Methyl Ethyl (DME)

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***Abstract: -* Internal combustion engines have witnessed much advancement due to numerous researches which were and are still being undertaken by scholars to improve its performance in terms of power output, efficiency and emission reduction. Ignition delay is a very important parameter in combustion phenomenon; it is the time interval between the start of injection and the start of combustion, and it exerts a great influence on the engine design and its performance.**

Di-methyl ethyl which is an alternative to Diesel fuel was utilized in the model by importing it from the relevant files into the chemical reaction interface using the relevant governing equations and solved with COMSOL 5.0 which employs the finite element method of solution.

Optimal engine performance was gotten at a compression ratio of 18, initial pressure of 1.0e5Pa and initial temperature of 400K. The delay period obtained was 0.018s and peak pressure was 1.6e6Pa.

***Keywords;* Bottom Dead Centre (BDC), Comsol 5.0, Di-methyl ethyl (DME), Ignition delay period, Top Dead Centre (TDC)**

I. INTRODUCTION

Ignition delay is a very important parameter in combustion phenomenon; it is the time interval between the start of injection and the start of combustion. This period is also called the preparatory phase during which some fuel which has already been admitted into the combustion chamber is yet to be ignited. This period is counted from the start of fuel injection into the combustion chamber to the point where the pressure-time curve separates from the motoring curve indicated as start of combustion. Delay period in the diesel engine exerts a very great influence on both engine design and performance and it's a function of ambient temperature, pressure and compression ratio. Longer delays between injection and ignition lead to unacceptable rates of pressure rise (diesel knock) because too much fuel is ready to burn when combustion eventually occurs, thus an optimal delay period is required for optimal engine performance.

Ignition period delay also has effect on NOx emission as longer delay period results into greater NOx emission.

Di-methyl ethyl burns like diesel in a compression ignition engine with similar torque and can serve as a zero soot alternative to diesel.

The effect of temperature and pressure on the ignition delay period of a compression ignition engine operated on Di-methyl ethyl (DME) was investigated.

II. LITERATURE REVIEW

Since the start of ignition in the cylinders and the duration of the combustion have a direct impact on the engine performance and its emission characteristics, Valipoue (1) studied the effect of injection pressure on ignition delay and combustion period of Jatropha biodiesel blended with diesel varying ambient pressure between 5 and 25 bar. Using a constant volume combustion chamber of 54.2mm length, 95mm diameter and7.5mm thickness, His study revealed that ignition delay reduced with increases in injection pressure for all test fuel (20%, 40% blend of biodiesel and diesel, and pure diesel) and the combustion duration though least for pure diesel, also showed a marked reduction with increases in injection pressure. The results were corroborated by Agarwal et al (2) who extended the research to involve different compression ratio "16.5:1, 17.5:1 and 18.5:1" and injection pressures of 200, 225 and 250bar. Biodiesel from sources other than jatropha like Methanol, Ethanol and Pangomia biodiesel were also used in their studies. An increase in NOx and decrease in HC and CO emissions with increasing values of compression ratio and injection pressure was however also reported for all their test fuels.

Chauhan et al (3) summarized the effect of alternative fuels for an HCCI engine combustion process. In their study it was concluded that IMEP increased with increasing premixed ratio of fuel at low and medium loads with a significant reduction in NOx and smoke for the tested combustion modes in comparison to conventional diesel engine. A study on alternative fuels for HCCI engines and the recent developments was undertaken by Rajendra et al (4) where they concluded that despite the huge prospects for better fuel economy and emission reductions, the HCCI engines is still taken back by the effect of rapid pressure rise which is akin to experiencing "knock" as like a spark ignition engine and also the problem of combustion timing, which must be further researched on to make the technology a viable one.

Numerical studies of the effect of intermediates and initial conditions of pressure and temperature, exhaust gas recirculation (EGR) and equivalence ratio on the flame propagation in a real HCCI engine have been conducted, and it was reported that; the flame speed increased monotonically with the increase in crank angle in a three-region mode, equivalence ratio and EGR ratio not only distinctly decrease the flame speed but also advance the crank angle of flame speed, initial temperature and pressure just advance of crank angle of flame speed but have little influence on its value. The flame speed was said to be mainly dominated by the temperature rise due to compression and heat release from combustion with the increase of crank angle. (5)

The brake thermal efficiency of an engine fuelled in a dual mode operated on biogas and karanja oil biodiesel on one part and biogas and diesel on another were reported to be lower compared to that of single fuelled modes at all engine loads. The test engine was a 4- stroke single cylinder constant speed direct injection compression engine with rated power of 3.78KW at 1500 rev/min. The NOx , HC and CO emissions were lower for the dual fuelled modes compared to the single fuel modes. (6).

Ignition delay of fuel is one of the important parameters in determining the knocking characteristics of diesel engines. Ignition delay depends upon many factors such as compression ratio, the inlet pressure, injection parameters and the properties of the fuel. The higher the Cetane number (CN), the shorter is the ignition delay, and vice versa. The ignition delay of methyl esters and its blends was found to be significantly lower than that of diesel and decreases with increase in the percentage of methyl ester in the blend. Neat esters record the lowest ignition delay when compared to their blends and diesel. (7)

III. METHODOLOGY

The engine specifications used in this model are depicted in table 1;

Table 1 Model Parameters

ENGINE SPECIFICATION	VARIABLE	VALUE
Cylinder Bore	D	0.0875m
Stroke	S	0.11m
Connecting rod length	Lc	0.2m
Crank arm	La	0.055m
Engine speed	RPM	1500
Compression ratio	CR	15 & 18

Comsol 5.0 software was utilized as the numerical tool in solving the governing equations in 0-D.

Di-methyl ethyl (DME) chemical reaction mechanism which is an alternative to Diesel fuel was utilized in the model by importing it from the relevant files into the chemical reaction interface.

Energy and mass balances describing the combustion of the fuel in a variable-volume system were solved.

The combustion of the fuel is governed by the generalized Navier Stokes equation;

$$\rho\frac{\partial\Theta}{\partial t} + \rho\,(\Theta.\,\Delta)\,\Theta = \Delta.\,[-\,\rho l + \mu\,(\Delta\Theta + (\Delta u)^{T})] + F \qquad 1$$

Where Θ is a dependent variable such as momentum, energy, turbulence e.t.c

F is the source term for the Θ variable

The reactor energy balance is;

$$Vr\sum_i CiCp,i\,\frac{dT}{dt} = Q + Qext + Vr\frac{dP}{dt} \qquad 2$$

Where Cp,i is the species molar heat capacity (J/(mol·K)), T is the temperature (K), and p gives the pressure (Pa). Q is the heat due to chemical reaction (J/s)

$$Q = -\,Vr\sum_j Hjrj \qquad 3$$

Where Hj is the enthalpy of reaction (J/(mol·K)), and rj equals the reaction rate (mol/ (m^3·s)). Qext denotes heat added to the system (J/s), and for this model it is zero as adiabatic conditions is assumed.

The mass balances describing a perfectly mixed reactor with variable volume are summarized by

$$\frac{d(Vci)}{dt} = VRi \qquad 4$$

Where ci represents the species concentration (mol/m^3), and Ri denotes the species rate expression (mol/ (m^3·s)).

The stoichiometric requirement of the oxidizer (air) to combust DME is found from the overall reaction:

$$CH_3OCH_3 + 3\,(O_2 + 3.76N_2) \longrightarrow 2CO_2 + 3H_2O + 11.28N_2 \qquad 5$$

Assuming that the composition of air is 21% oxygen and 79% nitrogen, the stoichiometric air-fuel ratio is

$$(A/F)stoic = \left(\frac{\text{mass of air}}{\text{mass of fuel}}\right)stoic = \frac{4.76*3*\text{mass of air}}{1*\text{mass of fuel}} \qquad 6$$

Initial temperature values of 300K, 350K, 400K, 500K and 600K at a pressure of 1.0e5N/m^2 were used and the impact observed on the ignition delay period. Likewise, initial pressure values of 1e5N/m^2, 1.5e5N/m^2, 2e5N/m^2 and 3e5N/m^2 at a temperature of 300K, 350K and 400K were used to observe the effect on ignition delay period of the fuel.

IV. RESULTS AND DISCUSSION

Combustion in compression ignition engines was carried out numerically and one of its key performance criteria ‘ignition delay period’ was observed using a compression ratio of15 and 18, engine speed of 1500rpm at different values of initial temperature and pressure.

The time taken for the piston to travel from bottom dead center (BDC) to the top dead center (TDC) was 0.02s,

The initial temperature affect the ignition delay period, it decreases with increasing initial temperature. It was observed that DME does not ignite at initial temperatures of 300K for a compression ratio of 15 as depicted in fig. 1. For a compression ratio of 18, the peak pressures reached at the different temperatures were seen to be higher than that of compression ratio of 15. 1.6e6 at T_init of 400K as depicted in fig. 2 implying that the compression ratio have an impact on peak pressure attained during combustion.

The fuel ignites some few milliseconds after TDC (0.021s) for compression ratio of 15 at an initial temperature of 350K while the delay period was 0.013s for the fuel at an initial temperature of 600K as depicted in fig. 1.

At a compression ratio of 18, the delay period was 0.0198s for initial temperature of 350K, and 0.0128s for an initial temperature of 600K.

Relatively high inlet temperatures are often required for proper timing, however this adversely affects the engine performance as the trapped mass and the volumetric efficiency decreases, which imply that an optimal value of initial temperature must be used. Setting the compression ratio to a value that will not lead to 'knocking' can ensure a lower value of inlet temperature for proper timing.

Fig. 3 shows the pressure- time plot for compression ratio of 18 at an initial temperature 300K, figs. 4 and 5 gives the plots for a compression ratio of 15 at an initial temperature of 350K and 400K respectively. While fig. 6 gives the pressure-time plot for a compression ratio of 18 with an initial temperature of 400K.

The fuel did not ignite at all used initial pressures for compression ratio of 18 at an initial temperature of 300K and until after the top dead center (TDC) for all the used initial pressures for a compression ratio of 15 at an initial temperature of 350K.

At initial temperature of 400K and compression ratio of 15, the fuel ignites at all initial pressures before the top dead centre (TDC), and the same situation was for compression ratio of 18 and initial temperature of 400K

The delay period for compression ratio of 18 at an initial temperature of 400K as depicted in fig. 6 was 0.018s at 1.0e5Pa, 0.0178s at 1.5e5Pa, 0.0176s at 2.0e5Pa and 0.174s at 3.0e5Pa. The peak pressure attained during combustion of the fuel is a function of the initial pressure and also dependent on the compression ratio as evidenced in figs. 4, 5 and 6 consistent with literature.

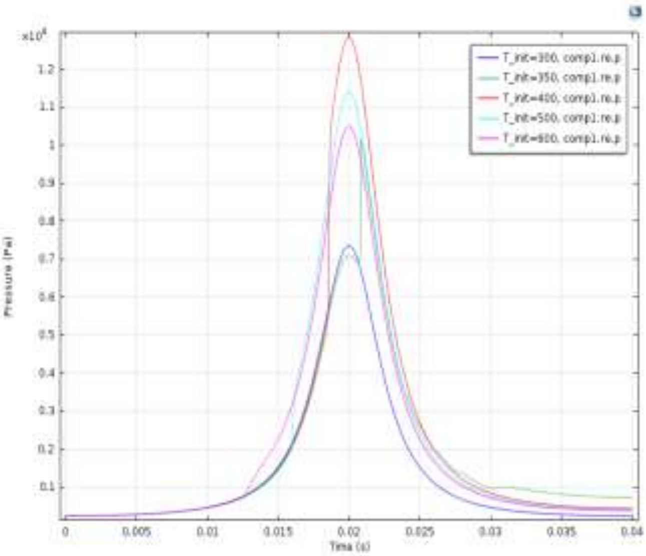

Figure 1 CR 15 Initial Pressure 1e5Pa

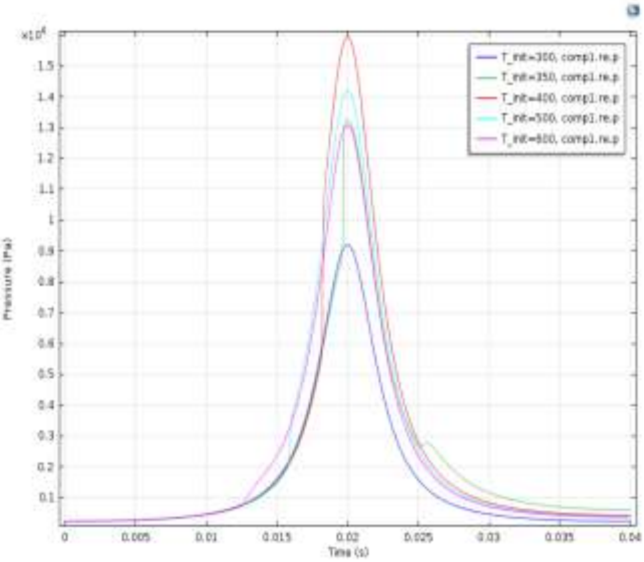

Figure 2 CR 18 Initial Pressure 1e5Pa

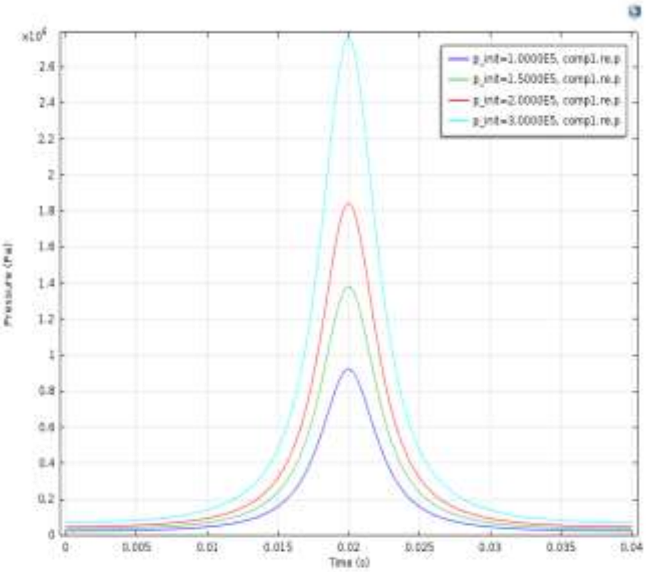

Figure 3 CR 18 Initial Temperature 300K

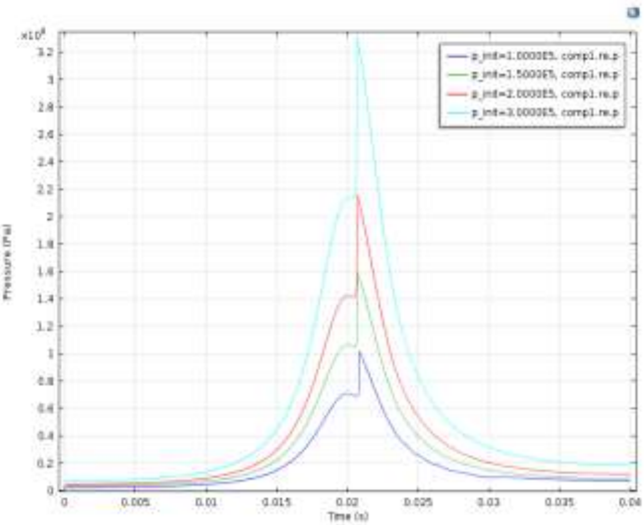

Figure 4 CR 15 Initial Temperature 350K

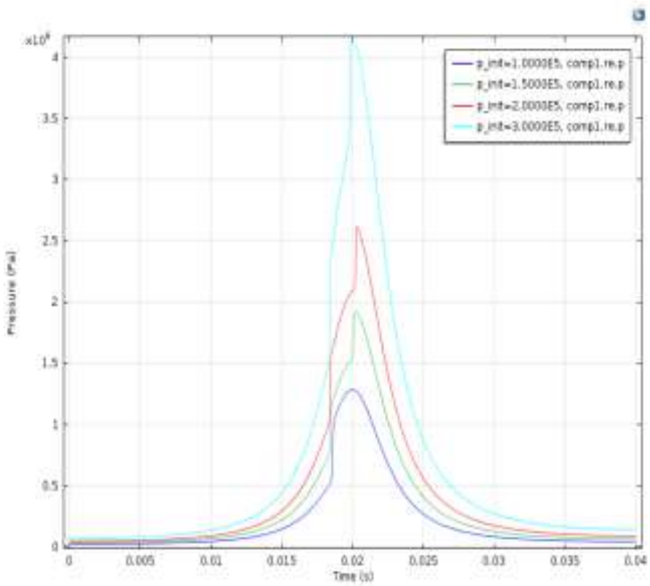

Figure 5 CR 15 Initial Temperature 400K

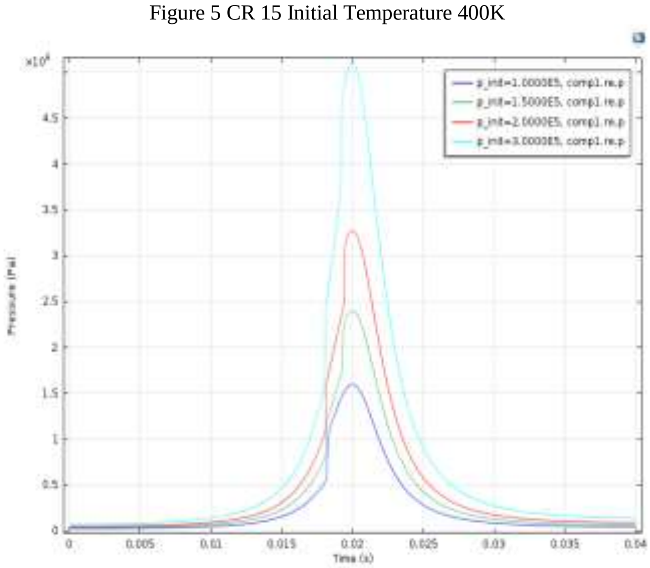

Figure 6 CR 18 Initial Temperature 400K

IV. CONCLUSION

The ignition delay period for Di-methyl ethyl (DME) was modeled using COMSOL 5.0 which employs the finite element method. The ignition delay period was shown to be a function of the engine's compression ratio, the initial temperature and the initial pressure of the fuel. For the fuel in question, optimal engine performance can be gotten for a compression ratio of 18, initial pressure of 1.0e5Pa and initial temperature of 400K, as the delay period obtained was 0.018s and peak pressure of 1.6e6Pa.

REFERENCES

[1]. Alireza Valipour. Effect of Injection Pressure on Ignition Delay and Combustion Duration of Diesel Engine with Biodiesel (Jatropha Oil) and Its Blends. IJMER | ISSN: 2249–6645 Vol. 4 | Iss. 1 | Jan. 2014

[2]. Ankit Agarwal, S. L. Soni, Dinesh Kumar Sharma, Sandeep Kumar Bhaskar. Effect of Variation of Compression Ratio and Injection Pressure on Performance and Emission Characteristics of CI Engine Using Various Alternative Fuels: A Review. (2015) International Journal of Research in Engineering and Technology Eissn: 2319-1163 | Pissn: 2321-7308

[3]. Himmatsinh R. Chauhan, Preksha K, Shyam K. Dabhi and Vivek G. Trivedi. A Technical Review HCCI Combustion in Diesel Engine. International Journal for Innovative Research in Science & Technology| Volume 1 | Issue 10 | March 2015

[4]. G. Rajendra Prasad, S. Chakradhar Goud, D. Maheswar. Alternative Fuels for HCCI Engine Techology and Recent Developments. (2012) International Journal of Advanced Research in Engineering and Applied Sciences ISSN: 2278-6252

[5]. Meng ZHANG, Jinhua WANG, Zuohua HUANG, and Norimasa IIDA. Numerical Study of Effects of the Intermediates and Initial Conditions on Flame Propagation in a Real Homogeneous Charge Compression Ignition Engine. Thermal Science: Year 2014, Vol. 18, No. 1, pp. 79-87

[6]. Bhabani Prasanna Pattanaik, Chandrakanta Nayak, Basanta Kumar Nanda. Investigation on utilization of biogas & Karanja oil biodiesel in dual fuel mode in a single cylinder DI diesel engine. International Journal of Energy and Environment (IJEE), Volume 4, Issue 2, 2013, pp.279-290

[7]. Venkata Ramesh Mamilla, M.V.Mallikarjun, G.Lakshmi Narayana Rao. Effect of Combustion Chamber Design on a DI Diesel Engine Fuelled with Jatropha Methyl Esters Blends with Diesel. Procedia Engineering 64 (2013) 479 – 490