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Effects of the diesel engine parameters on the ignition delay

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ABSTRACT

Together with renewed legislations, the automotive industry and research centers continue their efforts to develop internal combustion engine (ICE) technologies that consume less fuel and more environmentally. The basic step in developing efficient and environmentally ICEs is to ensure that the parameters affecting the in-cylinder combustion and the exact combustion. Although there are many parameters that affect each other, such as fuel consumption, emissions and noise, the main source of these results is the in-cylinder combustion event. Control of combustion initiation, ignition delay, and combustion must be well understood as all output will affect it. Although many parameters in today's ICE technology such as fuel temperature are controlled by sensors and instantly evaluated with Electronic Control Unit (ECU), optimization of feedback is provided by analyzing the factors affecting ignition delay. The factorial design method is used in this optimization study which examines the parameters of engine speed, load and fuel temperature. In this optimization study, it has been found that the engine speed, load and fuel temperature significantly influence ignition delay in different sizes.

1. Introduction

Understanding and reliable prediction of the combustion phenomena, including important explosion parameters such as ignition delay, flammability limits, temperatures and pressures, are required for achieving safe and optimal performance of internal combustion engines and creating new equipment [1]. As looked at diesel fuel properties and engine operating conditions effects on ignition delay, ignition delay increases non-linearly with decrease in the cetane number of the fuel, increasing rapidly at cetane numbers below 35. In some studies, changes in the volatility and ignition quality of the front-end of the diesel fuel were found to have no effect on ignition delay and ignition delay was also shortened by increasing the turbocharger, as well as the oil, coolant and intake-air temperatures. The turbocharge rise delay is generally shorter and more reproducible than the illumination delay. The analysis indicated that the turbocharge rise delay is affected by physical and chemical factors as well as thermodynamic parameters that control the several forms of energy during the delay period. Under fully warmed-up conditions, the engine was found to perform well at high torque even when using a low cetane fuel. However, under low torque and partially warmed-up conditions, the engine misfired frequently and resulted in sluggish performance [2,3]. As examined the effects of physical factors on ignition delay on a motored research engine, under normal running conditions, compression temperature and pressure are the major factors and 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 [4,5]. According to studies, the ignition delay variation with increased gaseous fuel admission showed a strong dependence on both the quantity and the quality of the pilot fuel used and the use of high cetane number pilot liquid fuels permitted smaller pilot quantities to be used satisfactorily [6]. The ignition delay of the pilot fuel in a dual fuel engine is different from that in a diesel engine because the primary fuel alters the properties of the charge, reduces the oxygen available and undergoes pre-ignition reactions during compression. The ignition delay in dual fuel engine operation, in principle can be correlated in terms of the type of gaseous fuel employed, its concentration and other operating conditions [7,8]. A theoretical model for the physical part of the ignition delay period in a direct injection diesel engine is derived, based on single droplet calculations. It is used in a parametric study to examine the influence of air pressure and temperature, initial fuel temperature, and mean droplet size and velocity on the physical processes that precede the chemical reactions. In this literature also it is used to correlate the results of an experimental investigation of the effects of using different pressures and different injection nozzles on the magnitude of ignition delay [9,10]. Emulsified Diesel fuels effects on the ignition delay also were investigated in literature. These results indicate that the addition of water in the form of emulsion improves combustion efficiency, engine torque, power and brake thermal efficiency with the faster ignition delay. In gaseous fuels such as natural

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gas caused lower ignition delay [11,12]. When the injection time is advanced in some interval, ignition delay is experienced shorter time and efficient combustion [13]. Generally SI engines exhibits low Soot emission compared to that of the diesel engine due to higher ignition delay and causes the heat release to be separate in time from the fuel injection. It is resulted that simultaneous reductions in exhaust NO and soot concentrations are possible with the implementation of this method. SI engine has a significantly higher ignition delay for the same combustion phasing at any condition and results in very much lower NOx and smoke for a given load compared to diesel engines. Using gasoline, an IMEP of 14.86 bar could be reached with ISFC of 178 g/kWh, smoke < 0.4 FSN, peak pressure of 133 bar, NOx of 1.21 g/kWh, and ISHC and ISCO < 4 g/kWh with the high ignition delay [14–23]. In some parametric studies, the ignition delay with Jatropha oil results always higher than that of diesel under same operating conditions. Improved premixed heat release rates were also observed with Jatropha oil when the injector opening pressure is enhanced. When the injection timing is retarded with enhanced injection rate, a significant improvement in performance and emissions was noticed. In this case emissions with Jatropha oil are even lower than diesel [24]. Relationships between the ignition delay and combustion energy release were carried out on four fundamental quantities as the turbulent integral scale, the turbulent micro-scale, the turbulent intensity, and the laminar flame speed. According to results the turbulent integral scale is proportional to the instantaneous chamber height prior to flame initiation. Angular momentum is conserved in the individual turbulent eddies ahead of the flame front [25]. The variables examined in this study included. When the controlled homogeneous charge compression ignition (HCCI) was investigated, it can be seen that the ignition delay is affected by many variables as air-fuel ratio, compression ratio, fresh intake air temperature, exhaust gas recirculation rate, and intake mixture temperatures. Compression ratio, EGR rate, and air fuel ratio are the practical controlling factors in achieving exact combustion. It was found that satisfactory power settings with flame speed are possible with high EGR rates and stoichiometric fuel-air mixtures [26]. The ignition behavior of methane and ethane with oxygen in regions were investigated using a statistical Design of Experiments approach which allows the experimenter to probe a wide range of variable factors with a comparatively low number of experimental trials. A matrix of 22 mixtures was developed using this statistical approach for different fuel blends [27]. Systematic optimization of a large-scale dynamic method consisting in parameterization of simulation results as response surfaces were employed to investigate the ignition delay [28]. Likewise, the ignition delay times for mixtures of methane with ethane, propane or butane, and for a typical natural gas fuel were conducted at equivalence ratios of 0.45–1.25 for temperatures 1300–2000 K and pressures 3–15 atm. The combined data were used to develop general correlations for predicting the ignition delays of binary methane-hydrocarbon mixtures and multicomponent natural gas mixtures in terms of temperature and the initial fuel and oxygen concentrations [29]. According to studies in literature, the ignition delay is affected by many parameters and it is still needed to investigate for the exact combustion. In this study, effects of different engine parameters on the ignition delay were investigated to find out the combustion characteristics of diesel engine.

2. Experimental procedure

In this study, single-cylinder, four stroke, water cooled, direct injection, 1.16 liter diesel engine was chosen to carry out the experiment. Detailed technical specifications were given in Table 1 and also technical dimensions were given in Fig. 1. The engine has direct injection fuel system in the cylinder head. The engine setup has an AC Dynamometer to examine the performance of the engine under various load conditions. All experimental studies were conducted under controlled environments. The engine was operated from the control room by software, which connected the whole engine system with the computer as seen in Fig. 2. Parameters were controlled with software interface at the control room. Fuel temperature were measured by thermocouples and maintained at constant value with controller embedded in the user software. Ignition Delay was also controlled on the user software as CA value corresponding time between start of injection and start of combustion. The engine performance was investigated under many conditions and environments and the data was recorded digitally by various measurements. Results were processed results in the form of graphics to make them more comparable. The next stage involved the optimization of the engine parameters to get the optimum operating conditions.

Table 1
Specifications and technical data of engine.

Number of Cylinders	1
Displacement (cm^3)	1.16 L
Valves Per Cylinder	4
Bore/Stroke	0.85
Compression Ratio	14.6: 1
Power Output (kW) @ Speed (rpm)	18 @ 2400
Max. Torque (Nm) @ Speed (rpm)	80 @ 1800
Cooling	Water Cooled
Net Weight	169 kg
Max Oil Capacity	4.5 L
Combustion System	Direct Injection
Rotation	Clockwise
Maximum Valve Lift	11 mm

In this optimization study, factorial design method was used to get optimum operating conditions. During the experimental study, experiments were planned using full factorial design method then results were evaluated with the methods of analysis of variance and regression analysis.

Three factors and two levels experimental work plan was given in Table 2 in order to investigate the effects of engine speed (rpm), engine load (%) and fuel temperature (°C) on the ignition delay in crank angle degree (CAD). Experiments were run repeatedly and measurements were calibrated to get accurate results in setup. Experiments were performed on 53 kW AC dynamometer in the university engine laboratory. In addition, experimental setup was conditioned and run reach up to stable state for all measurements. Optimization parameters were defined according to 2400 rpm and 1800 rpm engine speeds and efficient operating region. Also engine load were adjusted according to test conditions. Other engine parameters such as cooling water temperature, oil temperature and pressure were controlled by software. Schematic view of engine test unit was given in Fig. 2.

2.1. Design of experiments

The full factorial experimental plan was designed with a view to determining the effect of three efficacious parameters on the ignition delay in CI internal combustion engines. The effect of parameters of engine speed (factor A), engine load (factor B) and fuel temperature (factor C) was investigated in two levels. The magnitude of theses parameters were selected based on the previous works in literature. Experiments were repeated in same conditions to see the effect of repeatability potential at different times. The techniques, which are analysis of variance and analysis of regression, were used in interpretation of results. The effect of factors and coefficients of determination were calculated to comparing models. The results was evaluated at the $\alpha = 0.05$ level of significance. To study the magnitude of effects by parameters and their interactions, results of high and low levels were averaged. In the calculation of effects for main parameters and two-way and three-way interactions, the coefficient of -1 for low level and $+1$ for high level were used. The experimental plan of triple full factorial design in two levels and the results of for sixteen experiments were given in Table 2.