Evaluation of the impact of initial temperature of the constant volume combustion chamber on a determination of ignition delay of N-heptane

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Abstract. Several methods have been applied to determine the ignition delays as so the cetane number of fuels including the shock tube, rapid machine compression (RMC), Cooperative Fuel Research (CFR). In the last decades, the constant-volume combustion chamber system designed to measure ignition delay of low-volatility fuels were developed. The purpose of this article was analysed the behavior of the combustion and ignition delay of the n-heptane obtained in Fuel Ignition Tester (FIT). The N-heptane is the primary reference fuel for determination of ignition delays. The preliminary results are important because small temperature changes can generate wrong results of ignition delay.

Keywords: Diesel fuel; Cetane Number; Ignition Delay; Quality; Fuel Ignition Tester

1. Introduction
The ignition delay in a diesel engine is defined as the time interval between the start of injection and the start of combustion [1]. This period is composed of a physical delay, (encompassing atomization, vaporization, and mixing), coupled with a chemical delay (consisting of pre-combustion reactions in the fuel/air mixture). The two-time scales are occurring simultaneously [2].

The ignition delay in direct-injection diesel engines have been associated directly with the heat release rate and the timing of the onset of ignition in the thermodynamic cycle and indirectly have an influence of the engine performance, the effect on engine noise and pollutant formation [3]. Many authors have been reported possible pollutants from biodiesel storage [4] and combustions [5,6].

Several methods have been applied to determine the ignition delays of differs fuels including shock tube [7], rapid machine compression (RMC)[8,9], Cooperative Fuel Research (CFR) or the ignition delay can be obtained directly from engines. But these methods require complex equipment and high-qualified professionals to operate ones. In the last decades, the constant-volume spray combustion system designed to measure ignition delay of low-volatility fuels were developed. These systems are simple and cheaper and no requires exhaustive training.

In this work, we use the constant-volume spray combustion system to analyses the ignition delays curves of N-heptane tester with several starter temperatures.
2. Methodology

The ignition and combustion behavior of the different vegetable oils was determined in a Fuel Ignition Tester (FIT™), a constant volume combustion chamber described by ASTM D 7170. The components of FIT are an insulated and heated high-pressure cylinder, an injection system with exchangeable injection nozzles, a heated fuel tank, a piezoelectric pressure transducer for measuring the combustion chamber pressure and a needle lift sensor to detect the start of injection [10]. The combustion chamber is filled with synthetic air that is exchanged after each injection. Technical specifications of the FIT apparatus can be consulted elsewhere [10,11] and the resume can be found in table 1.

| Table 1. Technical specifications of start injection of fuel FIT |
|---------------------------------------------------------------|
| Properties                                                  | Initial Conditions (before injection) |
| Combustion chamber volume                                   | 0.63 L                                |
| Combustion chamber pressure                                  | max. 3.5 MPa                          |
| Combustion chamber temperature                               | 572°C – 593°C                         |
| Injection nozzle                                            | Single hole nozzle                    |
| Nozzle hole diameter                                        | 0.25 mm                               |
| Injection nozzle opening pressure                            | 33.0 MPa                              |
| Injection pump                                              | Single cylinder injection pump        |

The determination of ignition delay has been obtained throw Fuel ignition tester (FIT – Waukesha – GE). 100 mL of the sample take a place in the sample vessel, the initial combustion chamber temperature was setting from 573 °C to 593°C and 15 minutes was allowed to stabilize the temperature. The injection period was adjusted to 2ms, and the ignition delay was set to start (4.75 ± 0.25) ms for the three test injections. The water recirculation system was set to about (30 ± 1) °C. After the three system check injections, where collecting data from 25 injections about pressure and elapsed time.

The FIT software calculates the mean and standard deviation of the ignition delay time values of the 25 injections and provides this value in a worksheet. To determine the derived cetane number the FIT uses the following formula (1) where ID is the ignition delay [12].

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\text{Number of cetane derivative} = 150.4 \frac{1}{\text{ID}} + 5.3
\]  

3. Results

Figure 1 presents the combustion curve of N-heptane on several temperatures. Roman numbers indicate the main phases of combustion on the graph. Injection period is the time of fuel injection into the chamber. The ignition delay is the period between the start to fuel injection and the start of combustion [13]. The ignition delay determination depends on the method of determination. The FIT determines the ignition delay period when an internal threshold response to the combustion pressure rising a set + 0.2 bar (0.02 MPa ) [10] above the base pressure 24bar (2.4 MPa). This methodology can cause erroneous determination of the ignition delay periods due to low-temperature combustion can result in a small pressure rise prior to primary ignition [14].e paragraph text follows on from the subsubsection heading but should not be in italic.
Figure 1: Pressure Curve of N-heptane for several temperatures: I- Start the injection; II- Start the ignition; III- Rapid Combustion Phase; IV- Mixing-controlled Combustion Phase; V- Late Combustion Phase

Three distinct phenomena can be identified in figure 1 based on the pressure increases. The first phase is associated with rapid combustion and presents higher speed increasing. Phase two is the mixing-controlled combustion phase when the burning rate is controlled by the rate of the mixture of air/fuel is available to burn. The last phase is the late combustion phase when occurring the fuel still not burned start to burn. This curve is not like the classical curve presented by Heywood [13] because FIT uses the constant volume chamber while Heywood curve used variable volume chamber.

The curves for all temperatures presented the same three distinct regions. There are not evidence low-temperature combustion phenomena thus, the determination of the ignition delays can be obtained by the methodology of FIT.

All phenomena observed in figure 1 had been impacted by temperature variation. The start of ignition occurs early for higher temperatures, and higher initial pressure was observed for curves with higher temperature. These both facts directly impact the determination of ignition delays. In figure 2 are plotted the ignition delays vs temperature for the n-heptane.

The curve fitting shows good correlation with data (R>0.9) with a slope close to 0.04 ms/ºC, its means each one degree Celsius can affect the cetane number on 0.73% (based on ignition delay in 573ºC). Thus, it is important to perfect control of the starter temperature of the experiment to avoid higher uncertainty.
4. Conclusion

The results show that even small temperature changes can generate wrong results of the ignition delay and the derivative cetane number (DCN). The error on ignition delays can reach 0.73% per degree Celsius. Beyond, the ID, other phases of combustion are impacted the initial temperature of the experiment. Therefore, the control of the initial temperature on FIT experiment should be careful to avoid the increases of uncertainty.

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