IGNITION DELAY PERIOD FOR A COMPRESSION IGNITION ENGINE OPERATING ON DIESEL AND BIODIESEL B20

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In the current study, the ignition delay period for a compression ignition engine fueled with Diesel and biodiesel B20 at engine speeds 1400 rpm and 2400 rpm under full load operating conditions has been experimentally identified. The experimental results of Diesel fuel are compared with the ignition delay predict by four known correlations, while the results of biodiesel B20 are compared with only one correlation. The results showed that the ignition delay period of biodiesel B20 is shorter than that produced from Diesel fuel at all operating conditions. The Assanis correlation is approximately reaching the experimental results for both speeds when using Diesel fuel. Regarding the biodiesel B20, the correlation results are significantly different than the experimental results at all operating conditions.

Keywords: Biodiesel B20, compression ignition engine, ignition delay period.

1. Introduction

After many debates, the Renewable Energy Directive has been setting the rules for European Union (EU) to achieve it's 20% energy renewable target by 2020 [1]. Therefore, the use of biofuels and especially the use of biodiesel and its blends mixed with Diesel fuel related to Diesel engines operation is more likely because of their better physical and chemical properties comparing to those of the other biofuels. The biodiesel physical and chemical properties depend on feedstock. However, biodiesel has a higher bulk modulus, higher cetane number, higher flash point, lower sulfur and aromatic contents compared to Diesel fuel. The elevated cetane number of biodiesel provide superior qualities regarding ignition delay and combustion process [2,3]. Biodiesel has higher viscosity compared to Diesel fuel

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and this property considers the constraints of the biodiesel utilization as pure fuel in the Diesel engines.

Combining the benefits of Diesel engines fueling Diesel and biodiesel blends, many studies highlight B20 to be one of the most appropriate corresponding to the main goals meaning lower pollution emissions (carbon monoxide, unburned hydrocarbon, and smoke), better engine lubricant and better efficiency in terms of brake specific fuel consumption BSFC [4]. One of these studies refers to the combined use of Diesel fuel, CNG and B20 in a single cylinder DI Diesel engine (3.7 kW at 1500 rpm) [5]. The experimental results in term performance showed that the BSFC was lowered by 3% when using B20 although both combustion phases (premixed and diffusive) were similar. However, the NOx emissions were slightly increased compared to that produced by the others fuels [5]. Other similar research conducted on a D243 DI four-cylinder, naturally aspirated Diesel engine rating 60 kW fueled with rapeseed methyl ester at blends B10 (10 rapeseed methyl ester mix with 90% Diesel fuel, by volume), B20, B40 and B60 fuel, highlighted similar promising results but higher NOx emissions corresponding to the use of B20 at maximum rated torque operating regime [6]. Despite the fact that better volatility and viscosity characteristics provided by B20 play a key role in the increase of the atomization rate during injection process it is preferable to use multi-injection strategy in order to ensure adequate pre-conditions of mixture ignition and combustion control. However, a reliable relationship between the injection mode selected and the measured ignition delay could not be yet established [7,8].

Several studies regarding the use of biodiesel and its blends in the compression ignition engines have reported that the ignition delay period of biodiesel is shorter compared to that of diesel fuel at all operating conditions [9,10,11]. Aldhaidhawi et al. [12] confirmed this general trend from their already cited collection of .studies with biodieselFew studies have been conducted to establish a correlation to predict the ignition delay period of Diesel engine fueled with biodiesel [10, 13]. There is only one study published on this subject of ignition delay correlation for a compression ignition engine fueled with Jatropha biodiesel B20 [13]. Thus, in the case of a DI single-cylinder Diesel engine, with 582 cm3 displacement, at full load and 1000 rpm speed fueled with (Jatropha) B20, the proposed correlation using Heywood relationship and adjusted to the use of B20 fuel is [13]:

$$\tau B20 = 74.32\, p^{-1.32}\ \ \varphi^{-1.39} \exp(\frac{1022}{T}) \tag{1}$$

Where: τ ignition delay (ms), *P* cylinder pressure (bar), φ equivalence ratio (-), *T* temperature (K)

The aim of this paper is to analyze the effects of biodiesel B20 on ignition delay period for a compression ignition engine running at full load and at 1400 rpm and 2400 rpm speeds, fueled with Diesel and biodiesel B20 (rapeseed oil). Therefore, the experimental results obtained by test bench data acquisition are compared to those estimated from correlations proposed in previous studies.

2. Experimental setup

Several indicating devices were installed on a four-cylinder, four-stroke, naturally-aspirated, tractor, DI compression ignition engine used to measure the engine performance, combustion characteristics and exhaust gas emissions as shown in Fig1. Themain engine specifications are listed in table1. One AVL QL21D pressure transducer with a sensitivity of 2.5 pC /bar was used to measure the high-pressure line values. Two AVL GM 12 D pressure transducers with a sensitivity of 15.76 pC/bar were used to measure the in-cylinder pressure rate and to compute the heat release rates and then to identify the start of combustion SOC. Finally, the engine fuel system was adapted for multiple fuels operation, allowing the engine to be alternatively fueled with pure Diesel and biodiesel B20. The results were collected with the engine running at 1400 rpm (maximum brake torque speed) and 2400 rpm (rated power speed) and at full load.

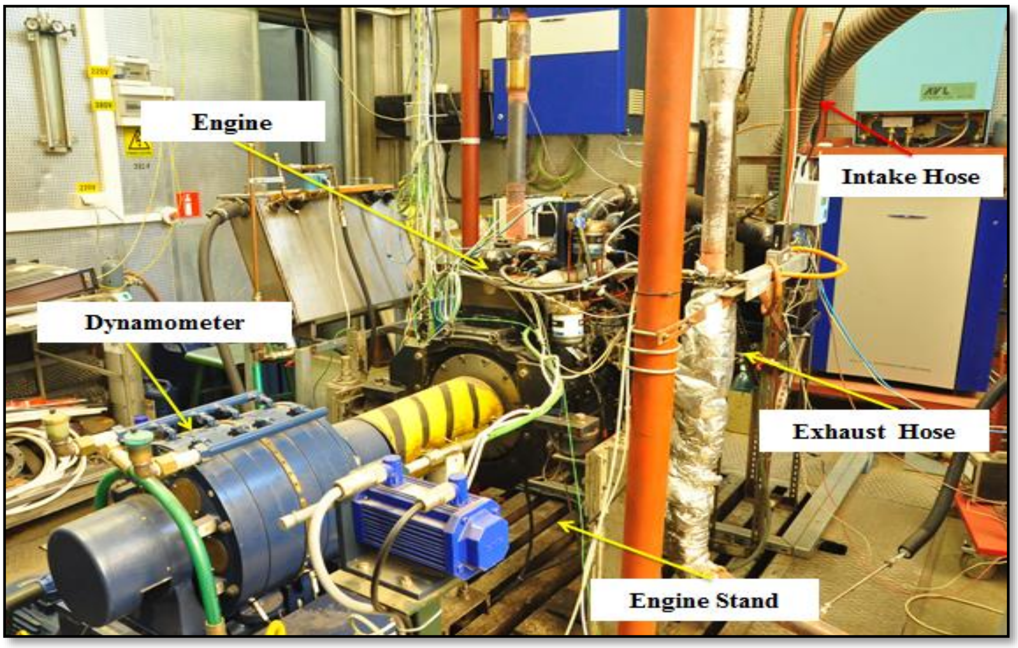

Fig.1. The assembly of the experimental test-bed

Table 1

The main engine specifications

Tractor Diesel engine	4-stroke
No. of cylinders	4 in line, vertical
Bore x stroke (mm)	102 x 115
Displacement (cm^3)	3759
Fueling system	Direct injection (DI)
Maximum brake torque (Nm) at 1400 rpm	228
Rated power (kW) at 2400 rpm	50
Compression ratio	17.5:1

3. Simulation procedure

AVL Boost_2016 software was used to predict the combustion characteristics, engine performance and exhaust gas emissions of the Diesel engine. All the engine describing elements, as the intake manifold, the exhaust manifolds the system boundaries, the cylinder, the air filter and the catalyst, are linked together by pipes, as shown in Fig 2. The thermodynamic state of the cylinder charge was calculated based on the first law of thermodynamics. The AVL-MCC combustion model and Woschni 1990 heat transfer model were chosen for the current simulation.

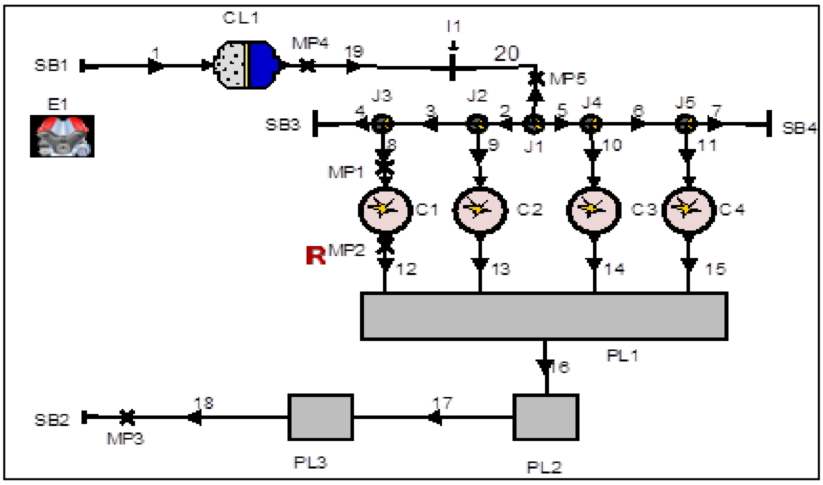

Fig.2. The AVL-BOOST- Simulation Model

4. Results and Discussions

In this study, the cylinder pressure, the cylinder temperature, the needle lift, the rate of heat release and the ignition delay period were investigated in the case of the engine running at full load and at 1400 rpm and 2400 rpm speeds, fueled with Diesel fuel and biodiesel B20.

4.1. Model validation

Experimental data for Diesel fuel have been used as a comparison to the simulated cylinder pressure results for both operating conditions, as shown in Figs 3 and 4. It can be seen from these compared curves, a good agreement between the experimental data and the simulation results, for both tested conditions over the entire operating cycle evolution, with a relative deviation of peak fire pressure lower than 2%.

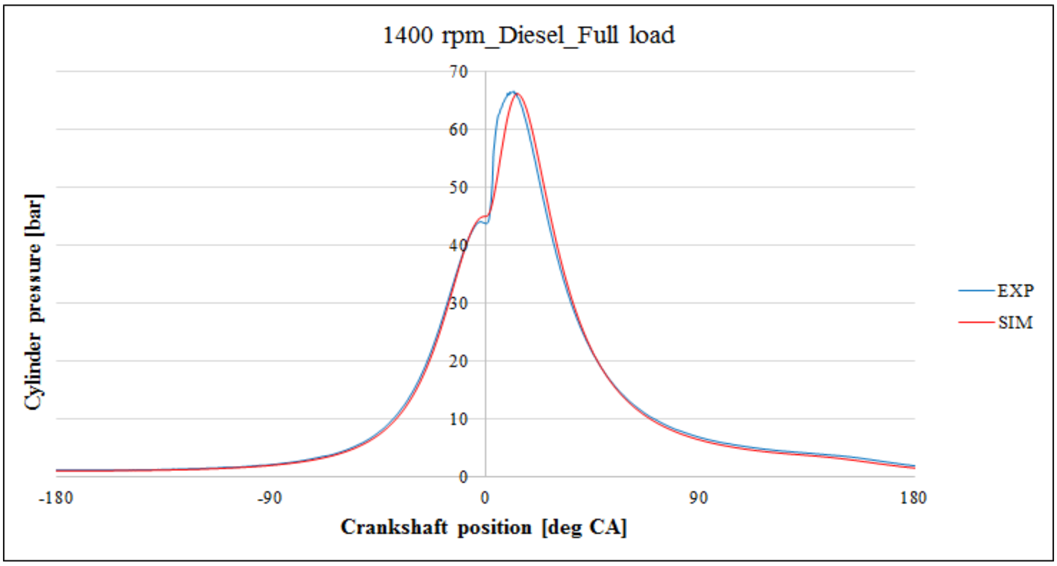

Fig.3. In-cylinder pressure Vs. Crank angle at full load, and 1400 rpm engine speed

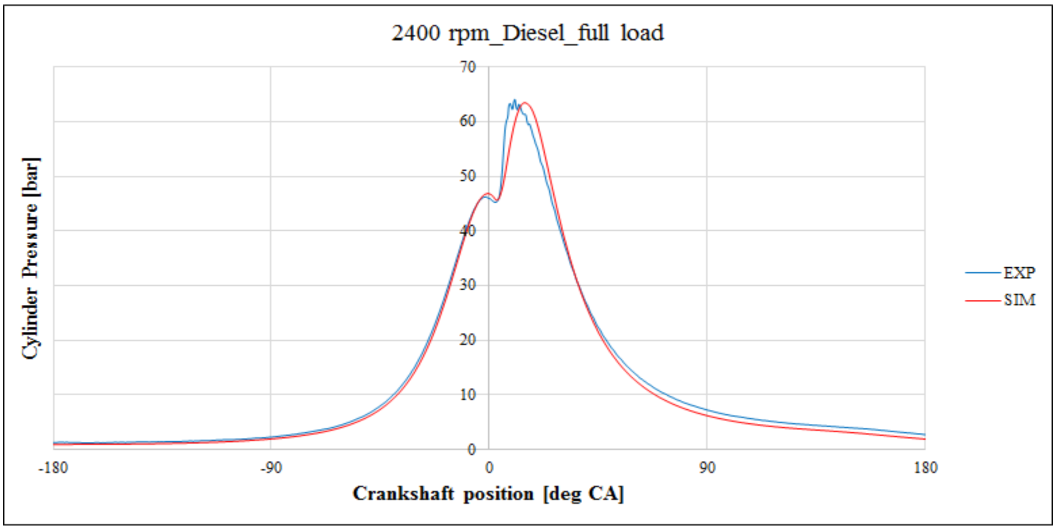

Fig.4. In-cylinder pressure Vs. Crank angle at full load, and 2400 rpm engine speed

4.2. Ignition delay period

Ignition delay (ID) is defined as the period between the start of fuel injection and the start of combustion. The start of injection is taken as the time when the injector needle lifts off while the start of combustion corresponds to the change of the slope in the heat release profile as shown in Fig 5. The variations of needle lift versus the crankshaft angle position for Diesel fuel at the engine speeds of 1400 rpm and 2400 rpm and full load operating conditions are presented in Fig 6. The needle lift data were averaged over 200 successive cycles. A large number of cycles (200 successive) is necessary in order to avoid random deviations in measurements. The experimental test was repeated three times at different dates to verify the consistency of experimental data. At engine speed of 1400 rpm the start of injection was 6 degrees before top dead center (BTDC). Regarding the engine speed of 2400 rpm, the start of injection was 5 degrees BTDC.

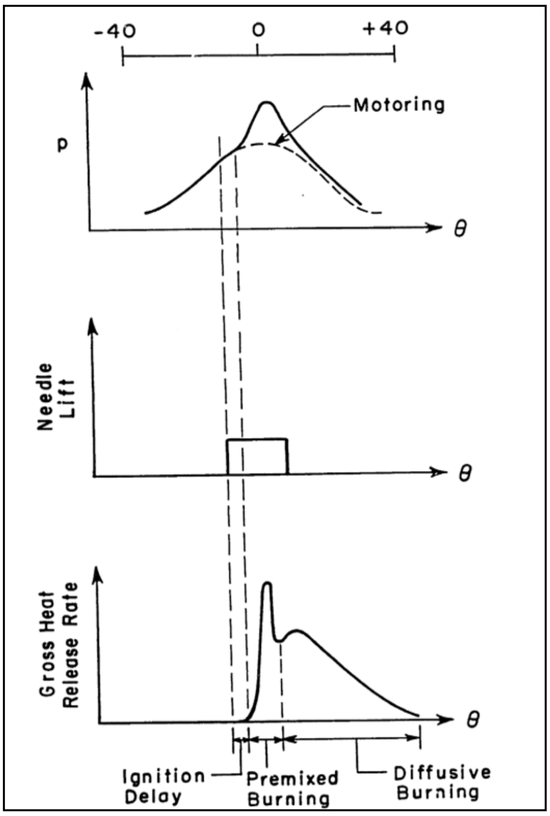

Fig.5. Cylinder pressure, needle lift and heat release profile for direct injection diesel engine [17]

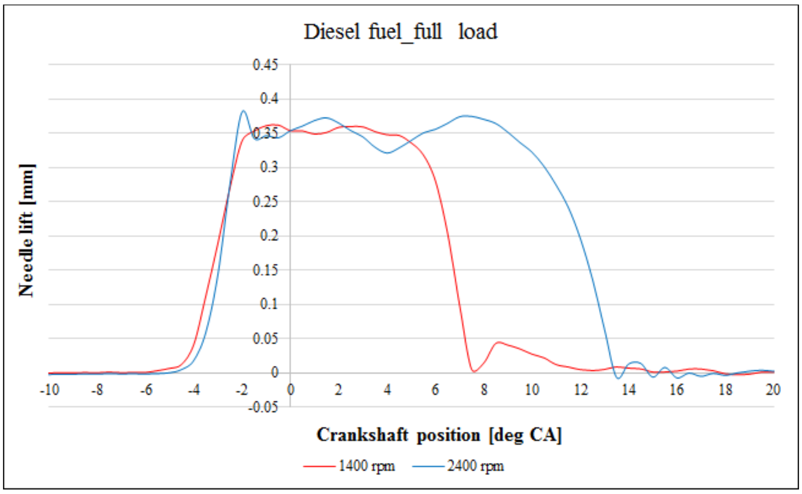

Fig.6. Average needle lift vs. crank angle at full load and 1400 rpm and 2400 rpm engine speeds

The start of combustion (SOC) is placed at the beginning of the slope change for the rate of heat release characteristic profile for both tested regimes, as presented in Fig 7. Thus, the start of combustion point was identified at 0.25 degree before top dead center (BTDC) at 1400 rpm speed and at 0.375 degree after top dead center (ATDC) at 2400 rpm speed. These values (SOI and SOC) for both engine operating conditions were taken into consideration to calculate the ignition delay period.

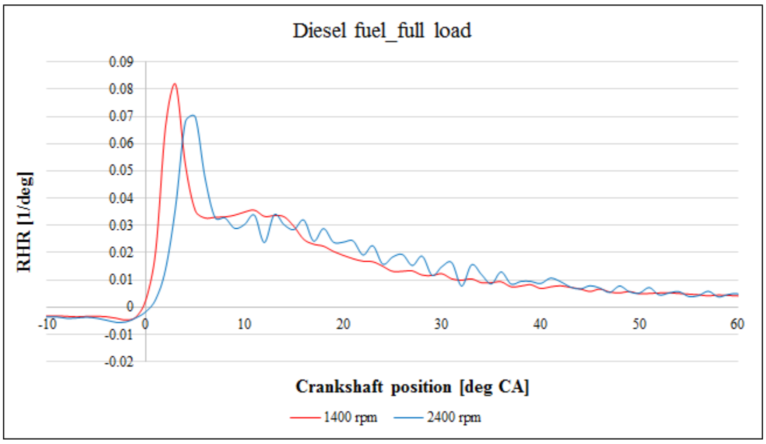

Fig.7. Rates of relative heat release vs. crank angle at full load, 1400 rpm and 2400 rpm

4.3. Cylinder temperature

Fig 8 shows the evolution of cylinder charge global temperature versus the crank angle resulted by simulation using the AVL_Boost model at 1400 rpm and 2400 rpm and full load. The average temperature value during the ignition delay period was taken and implemented in four known correlations in order to make the comparisons with the ignition delay which was experimentally measured.

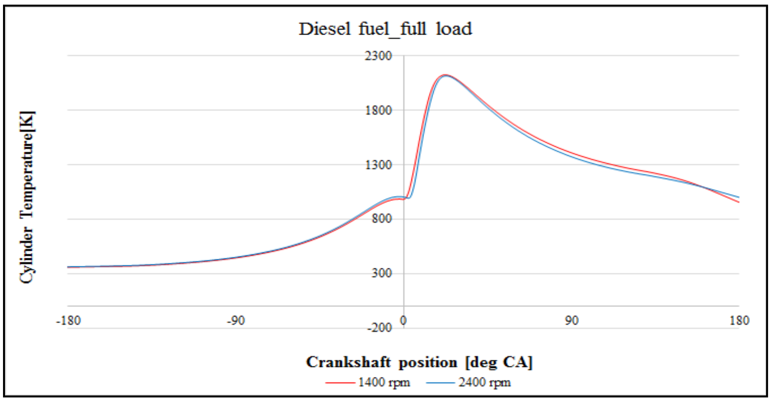

Fig.8. Cylinder temperature history vs. Crank angle at full load, speed 1400 rpm and 2400 rpm

5. Ignition delay correlations

The mean values of the cylinder pressure and temperature obtained from the experimental work and from the numerical simulation were taken and implemented in several correlations collected from previous studies in order to evaluate the ignition delay period. The four correlations used to estimate the ignition delay for Diesel fuel were as following:

- Correlation proposed by Assanis [16]

$$\tau D100 = 2.4 \frac{\exp(\frac{2100}{T})}{p^{1.02} . \varphi^{0.2}} \tag{2}$$

- Correlation proposed by Watson [15]

$$\tau D100 = 3.45 \frac{\exp(\frac{2100}{T})}{p^{1.02}} \tag{3}$$

- Correlation proposed by Rodriguez et al. [10]

$$\tau D100 = \frac{\exp(\frac{950}{T})}{p^{0.24} . \varphi^{0.04}} \tag{4}$$

- Correlation proposed by El-Kasaby et al. [13]

$$\tau D100 = 26.06 \frac{\exp(\frac{1038}{T})}{p^{1.21} . \varphi^{1.36}} \tag{5}$$

Related to Diesel fuel, the results obtained from these correlations are compared to those of the ignition delay period experimentally determined (Fig 9). As shown in this figure, there are major differences between the results based on Arrhenius type correlations and the experimental values. However, the correlation proposed by Assanis could be the closest to the experimental results, by a relative error of 12.98% at 1400 rpm speed and by 13.80% at 2400 rpm speed.

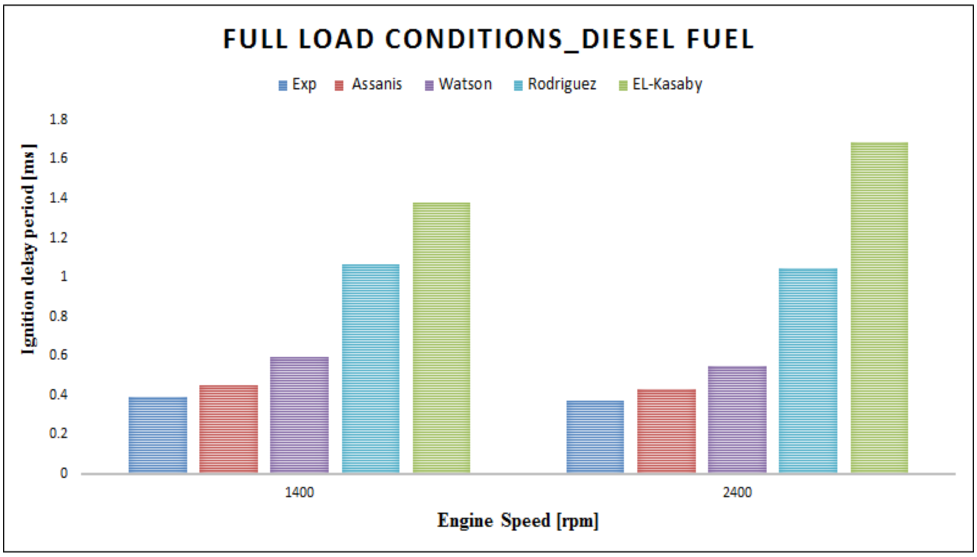

Fig.9. Ignition delay vs. Engine speed 1400 rpm and 2400 rpm at full load, Diesel fuel

The same steps were followed to establish the ignition delay period when using biodiesel B20 under the same operating conditions. The comparison between the experimental and the correlation proposed by El-Kasaby [13] for biodiesel B20 (see equation 1) is given in Fig 10. The experimental results showed that the ignition delay period for B20 is shorter than that of Diesel fuel for both operating conditions. This behavior could be explained due to the fact that biodiesel has higher bulks modulus and higher cetane number relative to Diesel fuel. It is clear from this figure that there are significant differences between the experimental results and the correlation results for both speeds. However, the relative deviations between the experimental results and the correlation results are of 75.71% at 1400 rpm speed and of 75.33% at 2400 rpm speed.

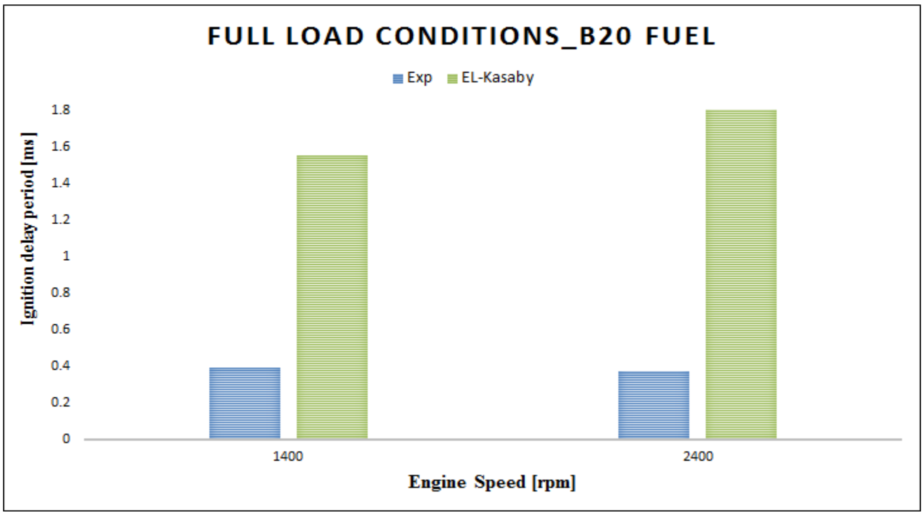

Fig.10. Ignition delay vs. Engine speed 1400 rpm and 2400 rpm at full load, B20 fuel

6. Conclusions

The ignition delay period for a direct injection Diesel engine, four-cylinders, four-stroke fueled with pure Diesel fuel and with biodiesel B20 at full load operating conditions and two engine speeds 1400 rpm and 2400 rpm were experimentally measured. The experimental results were compared to the results obtained from different correlations proposed in several studies by different authors. The main conclusions are following:

- Regarding Diesel fuel, the correlation proposed by Assanis from all the others seems to appear the closest to the experimental results for both analyzed engine operating conditions.
- The ignition delay period for B20 is shorter compared to that established for pure Diesel fuel for the same operating conditions.
- The correlations proposed by El- Kasaby to predict the ignition delay for Diesel and biodiesel B20 are far than the experimental results.
- This work marks a starting point which has to be followed by the efforts to define an own correlation for predicting ignition delay when fueling a Diesel engine with rapeseed oil biodiesel B20.

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