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CORRELATION BETWEEN IGNITION DELAY TIME AND CETANE NUMBER OF FUEL USING A SHOCK TUBE.

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Abstract: *The objective of this study is to correlate the ignition delay times of Diesel S25 (25ppm), ethanol with 5% additive enhancer cetane number, Biodiesel B100 and Diesel reference, measured in a shock tube with cetane numbers of the respective fuels. The shock tube is a metal tube that the gas at low pressure and high pressure are separated by a diaphragm. When the diaphragm (make of material cupper and aluminum) breaks on predetermined conditions (high pressure in this case) produces shock waves that move from the high pressure chamber (known the compression chamber or Driver section) for low pressure chamber (known the expansion chamber or Driven section). The tests were performed under the following initial conditions of the driver section: 30 bar of pressure breakup diaphragm and temperature of 100 °C. For determining and recording the ignition delay time it was used pressure sensors with high acquisition rate (differential sensors) and detect sensor flame. With information from pressure sensors and sensor flame the delay time was determined. Were obtained in testing the speed of propagation of shock waves incident and reflected. It is measured ignition delay times of ethanol additive, Diesel S25, Diesel reference and biodiesel B100. The results was compared with the ignition delay times measured for other authors. It was concluded that the delay time of ethanol with 5% additive was at least twice that of the delay time Diesel S25. The delay time of biodiesel B100 was approximately four times greater than the time delay Diesel S25. The delay time of the Diesel reference was smaller than the S25*

Keywords: *shock Tube,combustion,cetane number.*

1. INTRODUCTION

A shock tube is a metal tube in which a gas at low pressure and a high pressure gas are separated by a diaphragm. This diaphragm when it breaks in predetermined conditions produces shock waves moving the high pressure chamber know as a compression chamber or Driver chamber to the low pressure chamber know as expansion or Driven. Were obtained in testing the ignition delay times Ethanol additive, diesel and biodiesel, and also measured the propagation velocity of the shock wave direct and reflected. A shock tube is a device used to create the gas flow in order to simulate conditions which are difficult to achieve in other test devices and ascertain the effects of thermal and dynamic fluid flow that, for example, the initial effects of an explosion. They are also used for studying aerodynamic flows under varying conditions of temperature, pressure, compressibility effects and conditions of combustion gases. In the simplest configuration one shock tube is a tube of great length with constant cross-sectional area formed by two closed sections and separated by a diaphragm. The figure 1 shows the design of a simple shock tube.

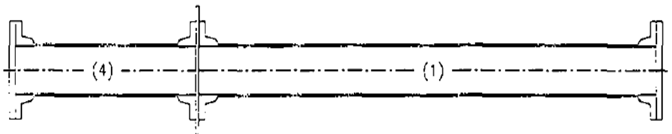

Figure 1 - Simple Shock Tube.
Source: Antonio (1997).

First of these sections called Driver section is pre-filled with a gas or gas mixture until a certain pressure, while another section called Driven remains at a pressure lower than the Driver section. When the pressure difference between the two sections is sufficient makes the diaphragm ruptures and a shock wave compression is driven toward the low pressure section (Driven). Instantly a wave of expansion propagates toward the high pressure section (Driver). The gases in the sections may or may not be from the same species as may or may not be at different temperatures before rupture of the diaphragm. After the rupture of the diaphragm compression shock wave causes movement of the mass of gas increasing the temperature and pressure in the section Driven. The wave of expansion decreases the temperature and pressure of the gas when it moves to the Driver section. The figure 2 shows the sections of high and low pressure shock tube before the rupture of the diaphragm.

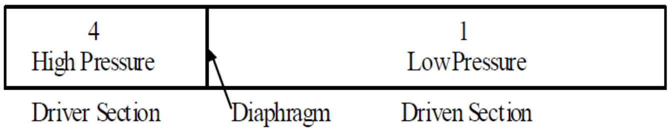

Figure 2 - Representation of the sections of the shock tube before rupture of the diaphragm.
Source: Mcmillan (2004).

The figure 3 shows the propagation of the shock wave, shock wave reflected, expansion wave, reflected expansion wave and the contact surface as a function of time after the rupture of the diaphragm shock tube.

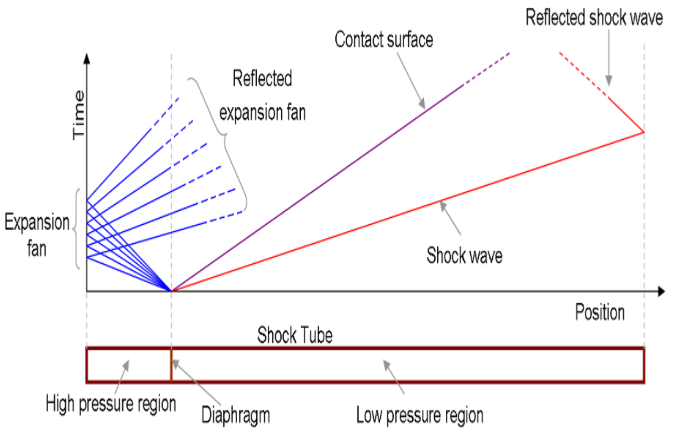

Figure 3 - Propagation of shock wave and expansion after rupture of the diaphragm Tube Shock.
Source: McMillan (2004).

Immediately after rupture of the diaphragm form a region called the contact surface on which the gas sections are Driven and Driver and begin to mix. With the movement of the gas mass inside the tube that region disappears. The figure 4 shows the regions formed between the contact surfaces.

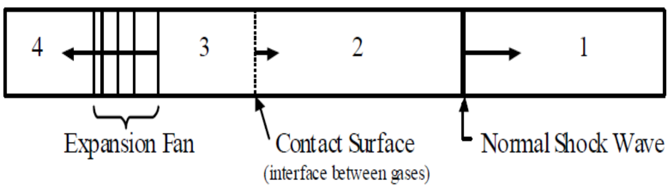

Figure 4 - Formation of the contact surface immediately after rupture of the diaphragm.
Source: McMillan (2004).

The compression wave (also called an incident) propagates to the right end of the tube; this movement causes an increase in temperature and pressure of the gas in the section Driven. Upon reaching the closed end of the tube the shock wave reflected and propagates toward the other end of the tube. In the movement of the reflected wave is back with the incident wave, the superposition of shock waves further increases the temperature and pressure of the gas in the Driven section. Therefore the reflected wave is responsible for causing often the dissociation and ionization of air. Also, the expansion wave moves toward the other end of the tube. When you reach the end, also closed, the wave is reflected and propagates back to the center of the tube. This process continues until the gas pressure and temperature to stabilize, which typically lasts less than one second.

1.1 Analytical solution Tube Shock.

There are two parameters that determine the strength of the shock: the pressure ratio between the sections Diver and Driven (P4/P1) and speed ratio of propagation of sound in the respective sections Driver and Driven (a4/a1). The ratio of the speed of sound is determined by the ratio of specific heats and molecular weights of the gases used in sections Driver and Driven [3]. The figure 5 represents the conditions of shock tube before rupture of the diagram, assuming that the two sections are at the same temperature.

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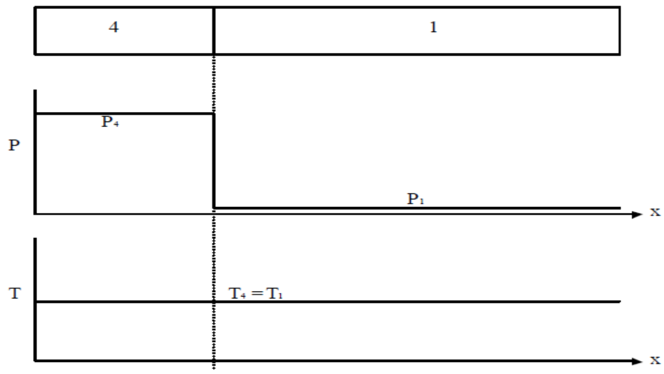

Figure 5 - Condition shock tube before rupture of the diaphragm
Source: McMillan (2004).

The principles of normal movement of the shock are used to develop the relationships between the regions 1 and 2 on each side of the compression wave and between regions 3 and 4 each side of the wave expansion. Although initially there are only two gases in the tube, after the rupture of the diaphragm there are four states gas temperature, pressure, density and specific heat well defined for each region. The front of the shock wave normal to the pressure wave of expansion, density, and temperature are the same initial conditions sections of low and high pressure respectively, that is, these regions are not affected by shock and expansion waves. Behind the normal shock wave is increased in pressure, density and temperature, while expanding wave behind these variables decrease. The region bounded by the shock wave and expansion wave is known as the contact surface. The figure 6 shows the conditions of shock tube after rupture of the diaphragm.

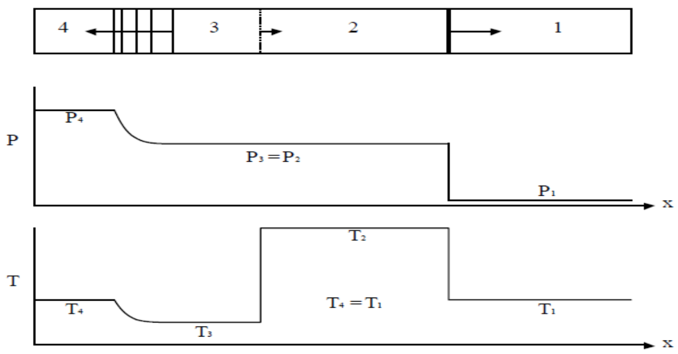

Figure 6 - Conditions Tube Shock after diaphragm rupture.
Source: McMillan (2004).

The reflected shock wave travels at a higher speed and pressure than the incident wave [3]. The figure 7 shows the conditions of shock tube after reflection of the shock wave.

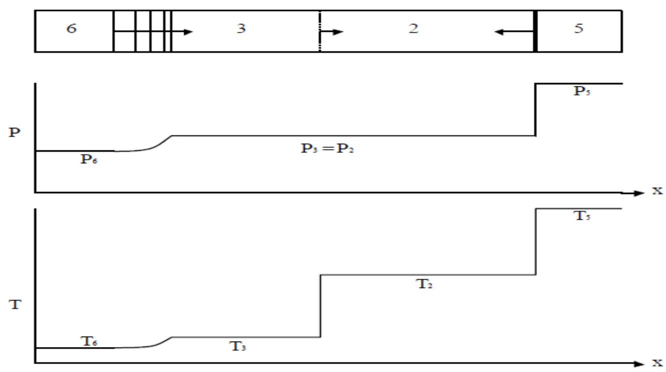

Figure 7- Conditions of shock tube after reflection of the shock wave.
Source: McMillan (2004).

2. LITERATURE REVIEW

2.1 Works conducted in Shock Tube by others authors.

Lionel Cancino in 2009 was conducted tests in the shock tube with the objective to develop kinetic models ethanol, iso-octane, n-heptane and toluene under the conditions encountered in internal combustion engines high pressures and temperatures. Ignition delay time measurements in shock tube were taken to provide data for the development and validation of detailed kinetic models. The experiments were performed in compliance with the following conditions in the Driver section (high pressure region): temperature 690-1200 K and pressure 10, 20 and 50 bar. Leonel Cancino performed approximately 100 tests involving pure ethanol and ethanol-containing hydrocarbon fuels (also called surrogate A). Assays were performed as follows: a liquid mixture containing ethanol or pure ethanol with gasoline substitute was prepared and injected into the tube (Driver section). After complete evaporation of the mixture, air was injected into obeying one section determines equivalence ratio up to a certain pressure. The table 1 shows the test with surrogate A compound. The T5 and P5 indicate respectively the temperatures and pressures of the shock wave reflected, φ represents stoichiometric ratio 1 and τing is the ignition delay time, ie the time when the compound Substitute the delay to ignite.

ϕ	T_5	p_5	τ_{ing}	ϕ	T_5	p_5	τ_{ing}
	[K]	[bar]	[µs]		[K]	[bar]	[µs]
1.0	1201	10.1	158	1.0	1016	31	555
1.0	1162	10.3	544	1.0	983	28	774
1.0	1093	9.9	939	1.0	951	30	806
1.0	1058	10.3	1438	1.0	858	31	2795
1.0	1010	10.3	2436	1.0	809	26	6944
1.0	935	9.8	3495	1.0	793	29	6962
1.0	906	10.3	N-I	1.0	764	31	4975
1.0	853	10.2	N-I	1.0	701	30	8731
1.0	806	10.3	N-I				
1.0	758	10.4	N-I	1.0	1191	50	28
1.0	683	9.8	N-I	1.0	1102	51	110
				1.0	985	49	534
1.0	1194	30	50	1.0	930	48	1705
1.0	1168	31	94	1.0	891	49	2296
1.0	1128	32	149	1.0	828	47	3792
1.0	1057	30	314	1.0	788	48	5037

Table 1 - Test realized to Leonel Cancino with surrogate A.
Source: Cancino (2009).

The table 2 shows the test with ethanol pure.

ϕ	T_5	p_5	τ_{ing}	ϕ	T_5	p_5	τ_{ing}
	[K]	[bar]	[µs]		[K]	[bar]	[µs]
1.0	1223	10.5	70	1.0	1234	53	16
1.0	1190	10.0	140	1.0	1168	52	30
1.0	1145	11.0	252	1.0	1085	48	134
1.0	1096	9.0	409	1.0	1065	52	156
1.0	1049	10.1	738	1.0	999	50	511
1.0	992	9.8	1171	1.0	937	48	1006
1.0	954	10.3	1698	1.0	881	48	2095
1.0	900	10.1	N-I	1.0	841	49	3304
				1.0	781	47	N-I
1.0	1197	30	25	1.0	769	45	N-I
1.0	1152	30	38				
1.0	1138	32	75	0.3	1183	30.2	58
1.0	1116	31	80	0.3	1151	30.8	111
1.0	1045	30	267	0.3	1107	33.7	172
1.0	999	30	547	0.3	1100	37.0	228
1.0	949	30	1244	0.3	1081	35.7	295
1.0	912	31	877	0.3	1042	26.7	621
1.0	881	31	2788	0.3	1024	35.7	686
1.0	848	30	2715	0.3	996	33.5	1029
1.0	801	30	3755	0.3	912	30.9	4759
1.0	789	29	N-I	0.3	868	31.6	13027

N-I: No Ignition within the test time

Table 2 - Test realized to Leonel Cancino with ethanol pure.
Source: Cancino (2009).

David Horning in 2011was conducted work carried out to measure the ignition delay times of propane, n-butane, n-heptane and n-decane. The experimental work was performed at the Shock Tube for gas dynamics and high temperature laboratory of Stanford University in California United States. The tests were performed under the following conditions: temperature of 1250-1750 K, pressure ranging from 1 to 6 ATM, the composition of O_2 in the mixture ranging from 2 to 20% and the ratio of equivalence from 0.5 to 2.0. The figure 8 shows the effect of pressure on the ignition delay time for n-butane with 6.5% of O_2 and ratio of equivalence 1

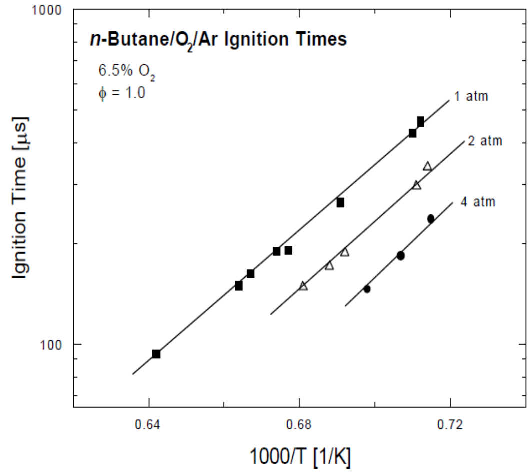

Figure 8 - Effect of pressure on the ignition delay time of n-butane.
Source: Honning (2011).

Figures 9 show the effect of pressure on the ignition delay time for n-heptane with 4.4% of O_2 and equivalence ratio 1.

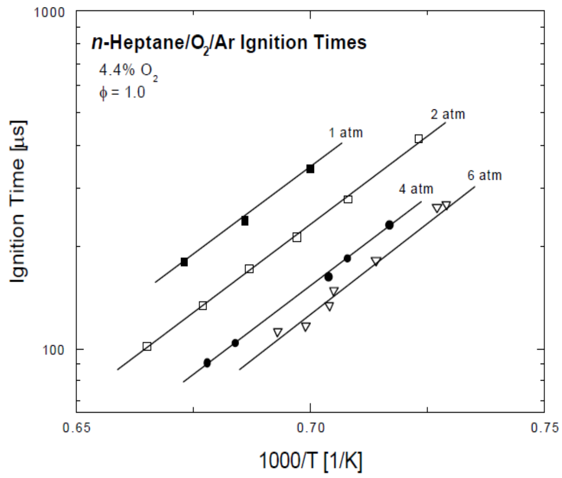

Figure 9 - Effect of pressure on the ignition delay time of n-heptano.
Source: Honning (2011).

Richard Hanson conducted test to measure the ignition time of the Jet-A fuel, JP-8, n-Dodecane and Diesel high pressure and low temperature retardation. The tests were performed in Shock Tube of the department of mechanical engineering at Stanford University from 2004 to 2007. The tests were performed under the following initial conditions: temperature of air-fuel mixture 715-1229 K, pressure of the reflected shock 17-51 ATM ratio of equivalence of 0.5 to 1.0 and oxygen concentration ranging from 10 to 21% synthetic air. The figure 10 compares the time delays ignition of the fuel Jet-A and JP-8 Stanford made with measurements by others authors.

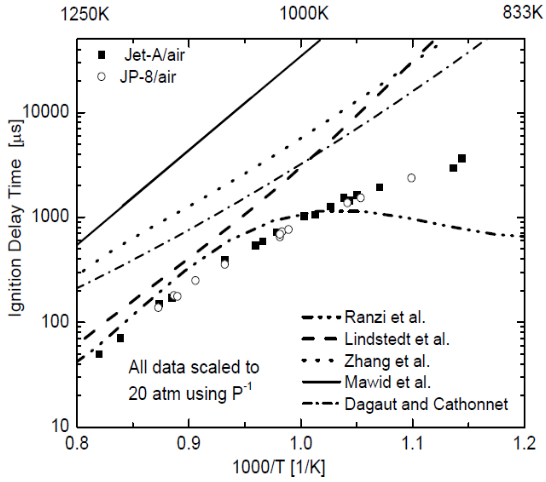

Figure 10 – Ignition delay time of the fuel Jet-A and JP-8 for φ = 1.
Source: Hanson (2007).

The figure 11 shows the ignition delays time of n-dodecane performed at Stanford.

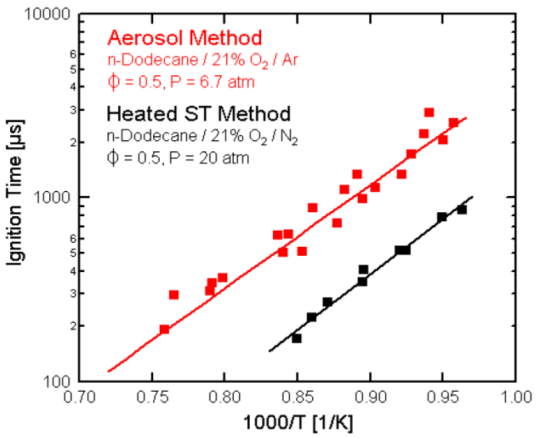

Figure 11- Ignition delay time of n-dodecane.
Source: Hanson (2007).

The objective of work Richard Hanson et.al was to measure the ignition delay times for methyl oleate ($C_{19}H_{36}O_2$) and methyl linoleate ($C_{19}H_{34}O_2$) using a shock tube. The tests were performed for the following initial conditions: temperature of the shock wave reflected 1100 - 1400 K, pressures from 3.5 to 7.0 ATM shock and ratio of equivalence from 0.6 to 2,4. The figure 12 shows the test with Methyl linoleate under the following conditions: temperature of the reflected shock 1222 K, pressure 6.7 atm and ratio of equivalence of 1.13. Ignition delay time measured 782 $m_{S.}$

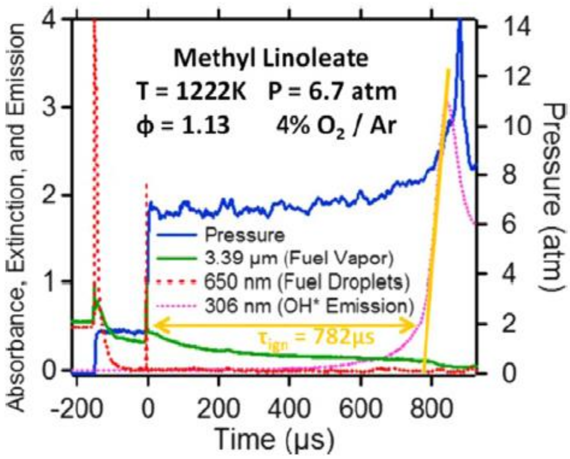

Figure 12- Ignition delay time of Methyl linolate.
Source: Hanson et.al (2012).

The figure 13 shows the measured ignition delays times of Methyl Oleate varied pressure and equivalence ratio.

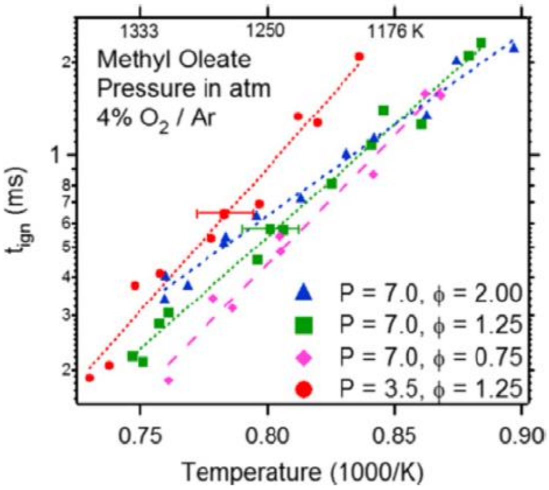

Figure 13- Ignition delay time of Methyl Olate.
Source: Hanson et.al (2012).

The figure 14 shows the measured ignition delays times of Methyl Linoleate varied pressure and equivalence ratio.

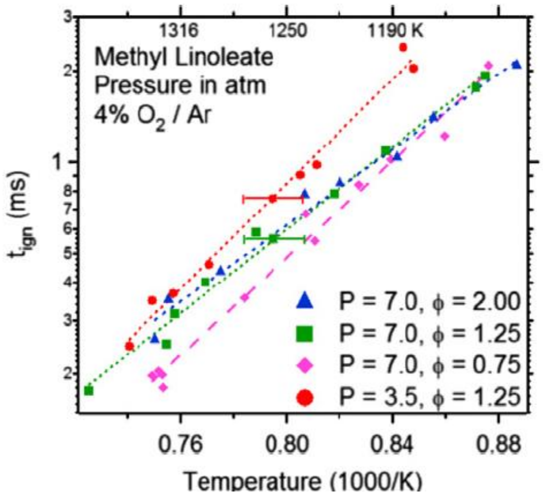

Figure 14 - Ignition delay time of Methyl Linolate.
Source: Hanson et.al (2012).

3. METHODOLOGY

The methodology involves the test with combustion in the shock tube. The tests with combustion were performed with an acquisition rate of 600, 16000 and 40000 Hz. The tests was realized with 8, 12 and 32 bar of pressure in section Driver (pressure rupture of diaphragm) and 25 °C of temperature in both section. These experiments were conducted with the tube ends closed. Four membranes used in order to increase the burst pressure, as in earlier tests with a single membrane were observed one burst pressure of approximately 4 Bar. The membranes were placed between the sections Driver (high pressure region) and Driven (low pressure region), this region separation of the sections is located in the middle of the tube. The tests were conducted whit Diesel S25, Diesel reference, biodiesel B100 and ethanol with additive. This tube was made of stainless steel, with total length of 7.00 meters divided into 7 modules with 1.00 meters each, inner diameter of 97.18 mm and thickness of 8.56 mm sidewalls. One of the modules has six windows for optics and instrumentation holes 14 for installing pressure sensors and temperature. As for the other six modules only have 4 holes for installation of sensors. These holes can also be used for installation of fuel injector valves and spark plugs. The figure 15 shows the schematic of the shock tube, the single modules of shock tube and location position of sensor temperature and pressure.

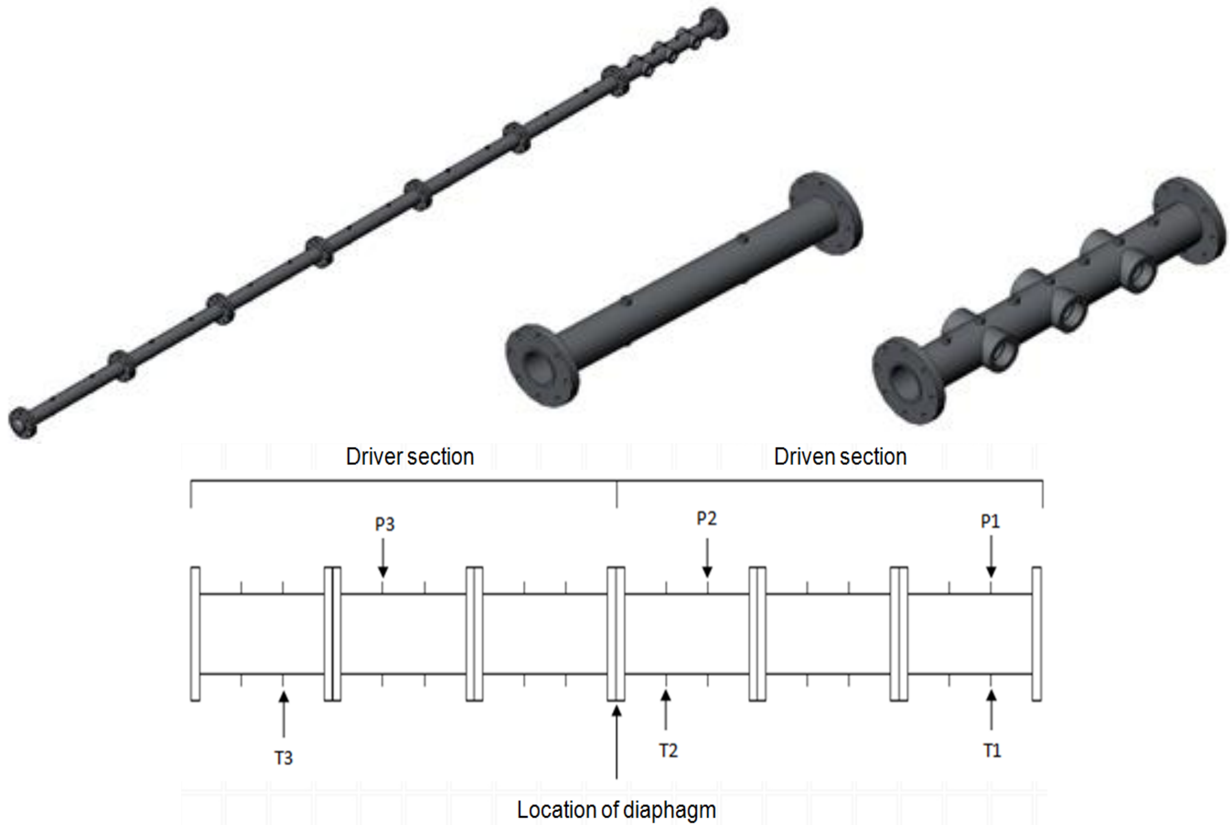

Figure 15 - Schematic of the shock tube and location position of sensors temperature and pressure.
Source: Combustion Laboratory, UFMG (2010).

Following the results and analysis of tests conducted with combustion in shock tube. The tests were conducted whit diesel S25. Was performed pressure of 32 bar in section Driver (pressure rupture of diaphragm) and 25 °C of temperature in the section Driven and 110 °C in the section Driver. The condition of the first shock was temperature 1229 K, pressure 12 bar, ϕ=0.94 for diesel. The figure 16 shows the test with Diesel S25 combustion an acquisition rate of 16000 Hz and your respective ignition delay time.

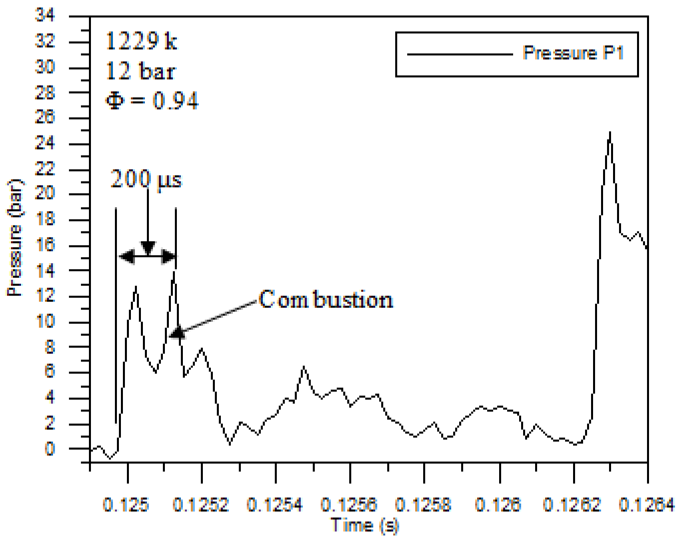

Figure 16 - Test of membrane disruption in the range of 0.0015 seconds.
Source: Combustion Laboratory, UFMG (2013).

4. RESULTS AND DISCUSSION

The table 3 shows the test realized with combustion and acquisition rates of 600 and 16.000 Hz.

Tests with fuel injection with an acquisition rate of 600 Hz				
Fuel	ϕ	P_2 (bar)	T_2 (K)	τ_{ing} (μs)
Diesel S25	0.94	12	1229	EC
Tests with fuel injection with an acquisition rate of 16.000 Hz				
Fuel	ϕ	P_2 (bar)	T_2 (K)	τ_{ing} (μs)
Diesel S25	0.94	5	750	NC
Diesel S25	0.94	5	750	NC
Diesel S25	0.94	12	1229	EC
Diesel S25	0.94	12	1229	EC
NC - Nonoccurrence of combustion / EC - Evidence combustion				

Table 3 - Test with combustion and acquisition rates of 600 and 16.000 Hz.
Source: Combustion Laboratory, UFMG (2013).

The table above show the need for increased acquisition rate, since these tests there was evidence of combustion, the presence of soot on the end of the tests, but it has not been possible to identify the combustion process.

The table 4 shows the test realized with combustion and acquisition rates of 40.000 Hz.

Tests with fuel injection with an acquisition rate of 40.000 Hz				
Fuel	ϕ	P_2 (bar)	T_2 (K)	τ_{ing} (μs)
Diesel S25	0.94	12	920	NC
Diesel S25	0.94	12	920	NC
Diesel S25	0.94	5	750	NC
Diesel S25	0.94	5	750	NC
Diesel S25	0.94	12	1229	200
Diesel S25	0.94	12	1229	225
Diesel S25	0.94	12	1260	200
Diesel S25	0.94	12	1292	200
Diesel S25	0.94	12	1292	225
Ethanol additives	1.00	12	1229	500
Ethanol additives	1.00	12	1229	525
Ethanol additives	1.00	12	1260	575
Biodiesel B100	0.92	12	1234	975
Biodiesel B100	0.92	12	1260	900
Biodiesel B100	0.92	12	1260	1225
Biodiesel B100	0.92	12	1292	1025
Biodiesel B100	0.92	12	1292	1125
Diesel reference	0.94	12	1229	150
Diesel reference	0.94	12	1260	175
Diesel reference	0.94	12	1292	150
Diesel reference	0.94	8	990	700
Diesel reference	0.94	8	1014	600
NC - Nonoccurrence of combustion / EC - Evidence combustion				

Table 4 - Test with combustion and acquisition rates of 40.000 Hz.
Source: Combustion Laboratory, UFMG (2013).

5. CONCLUSIONS.

Measured the ignition delay time of Diesel S25 and Diesel reference, the values were respectively (200-225 ms) and (150-175 ms to 12 bar pressure and 600 to 700 ms to a pressure of 8 bar). The measured values are consistent since reference Diesel has the highest cetane number of the diesel S25. The cetane number is inversely proportional to the duration of the ignition delay time, ie the greater the number of cetane lower ignition delay time.

If the measured ignition delay time of ethanol with 5 % additive, the values found are in the range 500-575 ms.

If the measured time of ignition retardation B100 biodiesel, the values found are in the range 900-1225 ms.

Should not use the fuel additive ethanol and B100 biodiesel as substitutes for diesel compression ignition engines without any major changes in engines. The ignition delays times of these fuels are at least three to four times larger than the time delay of the diesel reference. This could cause serious malfunctions of engines, such as clogging of nozzles and hard starting engine. Being necessary to make changes in the construction of them, for example, increased compression ratio.

6. ACKNOWLEDGEMENTS

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CENTRO UNIVERSITÁRIO UNA.

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8. AUTHORIAL RESPONSIBILITY

"The authors are the unique responsible for the content of this work."