ANALYSIS OF SPEED FLAME PROPAGATION IN INTERNAL COMBUSTION ENGINE

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Abstract. *The flame speed propagation in Otto cycles engine is a conclusive fuel feature, whose knowledge has a fundamental importance for a better accuracy of the pair engine/fuel. The higher flame speed propagation enables a greater cylinder filling, which can also increase power with gain in engine's rotation, as a result holding back the ignition advance, with, it will be necessary a lower negative work to compress the mixture already in combustion before the top dead center, then resulting a greater efficiency cycle. The flame speed propagation is highly influenced by the compression rate, mixture's condition and ignition advance. This work proposes is to investigate the influence of these operational parameters over the flame speed propagation in a CFR engine [Cooperative Fuel Research]. In this way, the angle measure experimental results are introduced between the fuel ignition moment and the flame detection over the opposite edge of combustion chamber by a ionization sensor in a CFR engine, as well as the diagram work pressure versus volume, which allows the liquid work evaluation produced by cycles and available the high pressure value, the angle with this occurs, the mean effective pressure and the curve of mass fraction burned for each tease condition. Introduces the analysis of combustion angle variation as much MTBE as the isooctane and hydratated ethanol in 5 distinct ignition advance for the testing are introduced analysi. This parameters values studies incorporates typical operational ratios of commercial engines. The results indicated a low angle of combustion for the elevated ignition advance.*

***Keywords**: Combustion, CFR, Hydrated Ethanol, MTBE, Isooctane*

1. INTRODUCTION

The objective of this work is the development of a research tool that it makes possible to analyze the influence of the main parameters of operation in the angle of development of the combustion in internal combustion engines. Had to the constructive characteristics and of the simplicity of the geometry of the combustion chamber, a ASTM CFR standard engine is used for the analysis of the combustion parameters, , which has adapted to an electronic system for managing both fuel and spark, as well as a system for the determination of the angular position of the crank angle. Moreover, one used a sensor for the measurement of the pressure inside of the combustion chamber and a sensor of ionization in set with a sounding lead of oxygen wide band for the monitoring of the mixture condition. For the accomplishment of this work it will be analyzed the variation of combustion angle of the fuels for distinct spark advances. For the fuels hydrated ethanol MTBE and isooctano it became analysis of the dependence of the angle of combustion with the variation of the ignition advance. The values of the compression rate, ignition advance and relations of mixture enclose the typical bands of operation of commercial engines.

2. ENGINE AND TECHNIQUES

2.1 Mass fraction burned

The characteristics of heat release and mass fraction burnt for engines natural aspired with ignition for spark generally are gotten through the analysis of Wiebe from experimental data [Blair, 1999]. Through this method it is possible to analyze the curve of mass fraction burnt and to adjust a mathematical expression to the experimental data. The mathematical adjustment is exponential, for the mass fraction analyzes a particular angle of the crank angle, from data of heat release and the combustion happens all during the angle of $\Delta b°$ combustion.

From tests of lower speed, it can be observed that the ignition angle increases gradually with the increment of the engine speed. To optimize the localization of the combustion around the top dead center (to reach the greater imep), the ignition delay increases with the increment of the speed of the engine and the duration of the combustion is relatively constant with the increase of the engine speed, but the coefficients of Wiebe reduces [Blair, 1999].

The analysis of the heat release is a tool of great importance for the study of the phenomenon of the combustion in engines [Martins, 2007]. The amount of heat necessary to produce a variation of pressure capable to be observed can on the basis of be calculated the first law of the thermodynamics applied to the existing gases in the cylinder (Equation 1). The content of the cylinder is treated as a simple zone and, with this, the reagents and products are considered a homogeneous mixture. Therefore, it is assumed that difference does not exist enters the properties of the reagents and of the products. The corresponding equations are express for:

$$\delta Q_{hr} = dU + \delta W \tag{1}$$

Were δQ_{hr} it is the heat release due to combustion.

$$\delta W = p dV \tag{2}$$

$$dU = m c_v dT \tag{3}$$

$$mdT = \frac{(pdV + VdP)}{R} \tag{4}$$

Combining Equations 2 and 3, substituting in Equation 4 and writing the function in relation to the angular variation we have:

$$\frac{dQ_n}{d\theta} = \frac{dQ_{hr}}{d\theta} - \frac{dQ_{ht}}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dP}{d\theta} \tag{4}$$

The energy heat release net in function of the crank angle of winches $dQ_n/d\theta$, it is gotten from the measured values of pressure, of the calculated values of volume, a estimate of the average value of the specific heats during the periods of compression and expansion and of the data that define the variation of pressure and volume with regard to the crank angle.

It is standard out despite the relation enters the specific heat at constant pressure and the specific heat at constant volume γ used for the accomplishment of this work is based on the experimental results comparing and numerical simulation developed in an engine CFR the 200 RPM, where this relation is equal the 1,33 [Rech, 2010, Heywood, 1988].

Combining it Equation 5 in relation to the crank angle of winches gets it function of accumulated heat release, of which the normalized curve of mass fraction burnt (MFB) can be gotten, and the angles of 10%, 50% and 90% of burnt mass can be calculated. The curves of mass fraction burnt are important to quantify the dwell time and the duration of the combustion.

As already it was commented, it is possible to analyze the curve of mass fraction burnt and to adjust a mathematical expression to the experimental data (Wiebe method). The mathematical adjustment is exponential, with numerical coefficients, and the *m*, for the mass fraction forest fire x(θ) for a particular angle of the crank angle. From data of heat release, the combustion occurs all during the angle of $\Delta\theta_b$ combustion. The mass fraction forest fire, for data angle covered for the axle of $\Delta\theta_b$ winches is, therefore, express for:

$$x_b = 1 - \exp\left(-a \left(\frac{\theta - \theta_{ign}}{\Delta\theta_b} \right)^{m+1} \right) \tag{6}$$

The coefficient *a* is called efficiency parameter and coefficient m of form factor [Melo, 2007].

How much greater the value of *a*, faster is the change in the fraction that occurs around the average point of the total duration of the combustion. The rate of maximum heat release dislocates the first half of the period of the combustion. For a fixed parameter of efficiency, a greater value of *m* makes with that the second half of the period of the combustion has a greater heat release.

3. METHODOLOGY

From standard motor CFR in functioning the data of crank angle position had been collected, signal of the ignition, signal of the ionization sensor, signal of the oxygen sounding lead, signal of the ignition coil and pressure inside of the combustion chamber during 30 consecutive cycles.

3.1. Determination of the flame detection angle

The detection of the flame is carried through with the use of ionization sensor installed in a diametrical opposing position to the spark plug, thus the flame covers all the extension of the combustion chamber. The signal of this sensor continuously is acquired by the system of data acquisition to each pulse emitted for encoder. When the flame front is detected by the ionization sensor, occurs the electric chain conduction enters the electrodes of the sensor, unloading the circuit and generating a discontinuity in the curve of reply of this sensor. The point that characterizes the detection of the flame in the opposing wall the spark plug, as well as the point of beginning of the spark ignition, is represented in Figure 1.

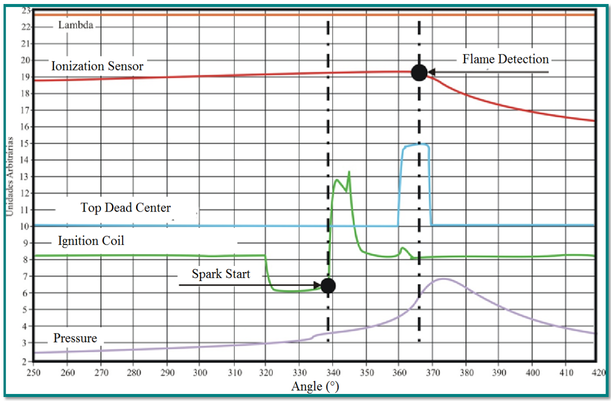


Figure 1: Signals of flame detection and spark start.

3.2. Obtaining pressure versus volume diagram and calculation working by cycle

The diagram pressure versus volume was traced during the accomplishment of each test. In the applicatory developed in LabView it was implemented equation of calculation of the volume contained in the interior of the cylinder in function of the compression rate, of the relation connecting rod/winch, the dislocated volume, and the angular position of the crank angle. Also the acquired values of pressure in relation to each angular position of the crank angle are presented.

On the basis of the diagrams pressure versus volume tracings, the value of the work can be calculated during each cycle acquired through integration the corresponding areas, considering the four stroke of the engine. This integration follows the distribution of the areas related by Heywood, 1988. After the attainment of the values of work of the thirty consecutive cycles, becomes fulfilled the calculation of the average value of the work by cycle of the thirty samples and determines the value of the shunting line standard. This task makes possible the determination of the average liquid work by cycle in each one of the assayed conditions. The calculation of the diagram is also become fulfilled pressure versus average volume through the average of the value of pressure gotten for each angle of the crank angle

3.3. Calculation of energy rate release and mass fraction burned

The values of the energy heat release in relation to the crank angle are gotten through the calculation of the present volume in the combustion chamber from the data of position of the crank angle. These data are gotten through the signals generated for encoder that it uses as reference position the signal emitted for the optic key (that marks the position of the top dead center), and related with the values gotten for the measurement of pressure in the interior of the combustion chamber to each signal of increment of encoder. Of ownership of these data, together with an estimate of the average value of the values of the specific heats during the periods of compression and expansion, it can, through the use of Equation 5, to get the value of the energy heat release in relation to the crank angle.

This analysis is carried through in a preset interval of the crank angle. In the case of this work, from the angle where the spark occurs until crank angle to cover 90° after the spark, interval this sufficient so that the combustion process occurs. One typical curve that describes the energy heat release for degree of the crank angle (J/°) gotten during the assays is presented in Figure 2.

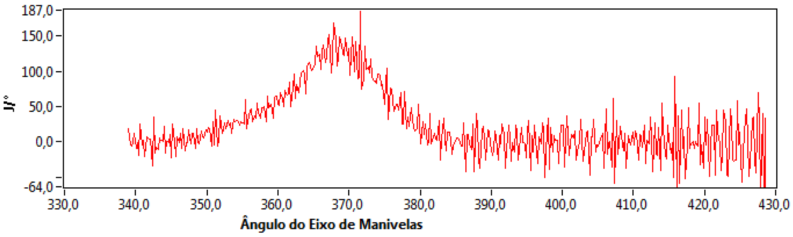


Figure 2. Typical curve of energy rate release

Combining this curve in relation to the crank angle, it gets the energy heat release of accumulated. Normalizing this curve, it of mass fraction burnt is gotten arched (MFB). The gotten results can be compared with the results calculated for the Wiebe equation. In the development of this work, the gotten experimental results had been calculated the values of the coefficients of Wiebe equation on the basis of, having been adopted 1% MFB as the angle of beginning of the combustion. The delay of the combustion is calculated by the difference enters the angle of ignition advance and the angle of 1% MFB. Also the angle of the crank angle covered for the consumption of 10% to 90% of the fuel mass is adopted as criterion of combustion development.

4. EXPERIMENTAL PROCEDURE

In this chapter the characteristics of standard engine ASTM CFR are presented (cooperative fuel research), as well as the modifications implemented in this engine for the accomplishment of the tests of verification of the variation of the development angle of combustion. Moreover, the materials used for the data acquisition for the development of the present work are presented.

4.1. Features of CFR engine

The Cooperative Fuel Research engine (CFR) posses mechanical systems that allow to the variation of the compression rate of 4:1 to 16:1 without affecting the valves regulation or the basic configuration of the combustion chamber is, probably, what it made with that this project prevailed on the competitors. CFR Engine is connected by a V belt to a synchronous engine, that has the function to stabilize the speed and, thus, to agreement constant speed, functioning however as brake however as a motor. Table 1 presents the main mechanical characteristics of CFR engine.

Table 1. Features of ASTM-CFR engine [ASTM, 1964]

ASTM-CFR engine	
cylinder	monocylinder
bore	82,55 mm
stroke	114,3 mm
displacement	611,3 cm3
intake valve open	30° APMS
intake valve close	214° APMS
exhaust valve open	160° APMS
exhaust valve close	355° APMS

The choice of CFR engine for the fuel research is justified therefore, for being a standardized engine with simple geometry, it guarantees the repeatability of the tests of the present work in any another research center. Moreover, this engine posses all the main constant parameters of functioning, allowing that in an experiment it is modified only the interest variable that, in the case of this work, are the fuel+air relation, the compression rate and the spark ignition angle.

4.2. Retrofitting of ASTM CFR engine.

For the development of this work some alterations had been carried through in CFR engine so that it was possible the implementation of an electronic management system of ignition and fuel injection, beyond the use of sensors for the measurement and monitoring of the interest parameters. To follow the main alterations carried through in CFR engine are described.

4.2.1. Intake system

In the experimental group, for the accomplishment of the tests a modified intake manifold in CFR engine, that allows the installation of fuel injectors for the use a programmable electronic system of fuel management (electromotive TEC II). Figure 3 shows the intake system adapted in the group of benches of fuel tests.

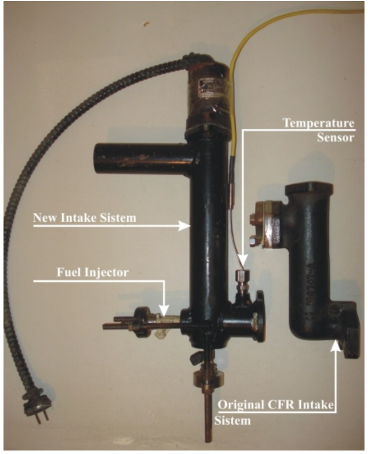


Figure 3. Intake system adapted bench test the fuel and the original intake manifold of CFR engine.

4.2.2. Management system of fuel and spark

The original system of ignition was substituted by a programmable electronic system of ignition and fuel injection called Total Engine Control II - TEC-II, manufactured for the Electromotive company Incorporation. This system on the basis of allows to the programming injection and ignition advance maps of the data of load applied to the engine, speed, temperature and mixture ratio. That is possible in reason of its constitution to understand two basic aspects: the electronic ignition and the electronic fuel injection. Thus, this system allows the complete control of the engine. The intention of this exchange inhabits in the necessity to make use a more homogeneous and constant air + fuel mixture, in order to minimize its oscillations, making possible the accomplishment of the tests.

Moreover, TEC II manages the fuel valve injector and is through this system that is established the ignition advance and the air-fuel relation (changeable during the assays).

4.3. Instrumentation system implemented

For the accomplishment of the tests, an instrumentation system was mounted, having been the used components described to follow.

4.3.1. Combustion chamber pressure sensor

The pressure in relation to the position of the crank angle is measured by means of a sensory mark optrand incorporated and model D32292Q installed in the combustion chamber. It posses frequency of reply of 30 kHz and range of measurement the 0 to 20 MPa, with error of ± 1% of the scale under combustion conditions. The signal of this sensor is related with the pressure by means of a calibration curve predetermined for the manufacturer.

4.3.2. Spark sensor

The ignition angle is registered from the coil keying, carried through for the electronic injection control system.

4.3.3. Air/fuel ratio

The air/fuel rate was measured during the accomplishment of the tests for a wide band oxygen sensor. The conditioning and reading of the wide band oxygen sensor had been carried through with equipment WB-02 Datalogger, manufactured by the company FuelTech Ltda. EPP. This measures the Lambda value (reason of the air+fuel mixture) for an ample band of mixtures and still presents an isolated analogical exit, of proportional value to λ measured. This proportionality is defined by the equation $\lambda = 0{,}141V + 0.621$, where λ is the reason of mixture and V the electric tension of the signal of exit of the equipment.

4.3.4. Crack angle position sensor

The used system to measure the crank angle position is constituted by an incremental encoder manufactured for Danaher Sensors & Controls, model BA 3022 of 1000 pulses for revolution, on to the front part of the crank angle through synchronization belt strap and a pair of pulleys. The pulleys connected to the crank angle have 26 teeth and the pulley connected to the axle of encoder have 15 teeth, totalizing to each revolution of the crank angle 1733,33 pulses for revolution, what it corresponds to a resolution of 0,20769 degrees for each pulse of encoder. This instrument allowed, to each reading, the attainment of all the parameters searched for thirty consecutive cycles. Figure 4 shows the instrument that was installed in the engine.

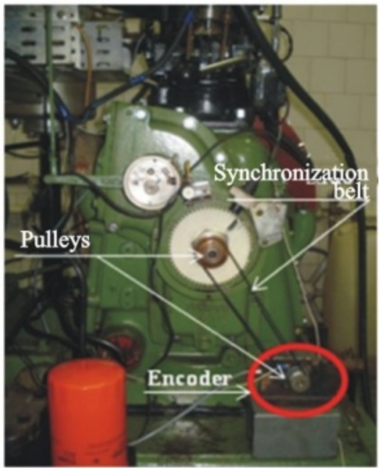


Figure 4. Encoder model BA 3022 used in tests.

The reference determination of the angular position of crank angle engine is fixed in the back part of the engine. The set is constituted by a fixed optic sensor in the back part of the engine and a bulkhead necessarily located of form to interrupt the ticket of blinking in the TDC of the crank angle. The signals are sent to a analogical-digital converter to be treat, interpreted and analyzed.

4.3.5. Flame detector system

For the accomplishment of the measurement of flame propagation a spark plug was used located diametrical opposing to the original CFR engine spark plug. In the electrode of this an ionization detector circuit was connected. This circuit was developed in partnership with the Laboratório de Mecatrônica e Controle (LAMECC - UFRGS), in the scope of CONTROLGÁS/FINEP project, and has the capacity to detect the flame presence through the electric conductivity difference between the sensors electrodes, that, in this experiment, are represented by the ground electrode and the central electrode of the spark plug.

The flame sensor operation can be described by the following points:

- It applies a voltage in a conductor placed directly in the flame;
- When there is no presence of flame current in the conductor, the circuit behaves like an open circuit;
- When the flame is present, power is a way to close the circuit, because the plasma is a electricity conductor, therefore, there is a current that passes through the flame and goes to the ground electrode;
- A comparator circuit, which behaves as a resistor (between 10 MΩ and 100MΩ), identifies the potential difference resulting from the presence of flame.

A schematic diagram of the instrumentation system used for the tests is shown in Figure 5.

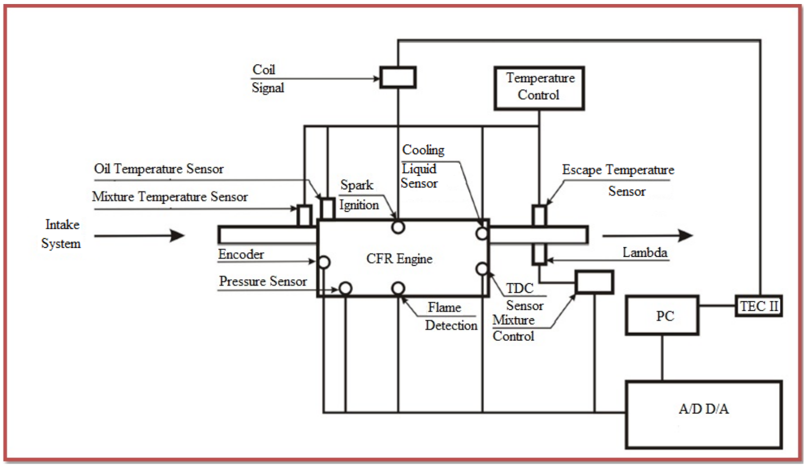


Figure 5. Instrumentation system implemented.

4.4. Supervisory and control program

For the accomplishment of this work a program for the acquisition and treatment of the data gotten during the carried through assays was developed. The data are acquired on the basis of the pulses supplied for connected encoder to the crank angle, in way that to each pulse detected in entrance the digital data acquisition board (NI PCI-6221 - 16 bit, 250 kS/s, 16 analogical entrances, 02 analogical exits of 16 bit, 833 kS/s, 24 I/O digital, counting of 32 bit), is carried through the reading and storage of the data of all the used analogical canals, guaranteeing as soon as all the measured signals correspond to data crank angle of winches.

The program was designed in blocks to facilitate their future adaptation to other jobs.

The block "Peak Detector" aims to identify the start of data acquisition. For this he receives the input signal into two channels: the channel of the TDC sensor and the channel pressure sensor. The channel signal of the TDC sensor is derived in relation to the angle and its peak is located. Monitors the number of pulses sent by the encoder concurrently with the value of the pressure signal. If after a given angle, the value of the pressure signal does not reach a minimum value, it is known that the motor cycle is dead. Is expected then a new sensor signal TDC, thus beginning the acquisition of data.

The block "Characteristics of the Cycle" which determines the peak start and end of acquisition of the sprocket will be analyzed.

The block "Split Channel" is used to select the desired channel, and separate the desired interval (each cycle).

Based on the TDC sensor and the pulses generated by the encoder, the block "position in the Vector Generator Volume Combustion Chamber With position adjustment" creates the array of displacement to generate the pressure versus volume diagram. In this block there is the constant determination of geometrical parameters of the CFR engine, as the relation connecting rod / crank, compression ratio and volume displaced.

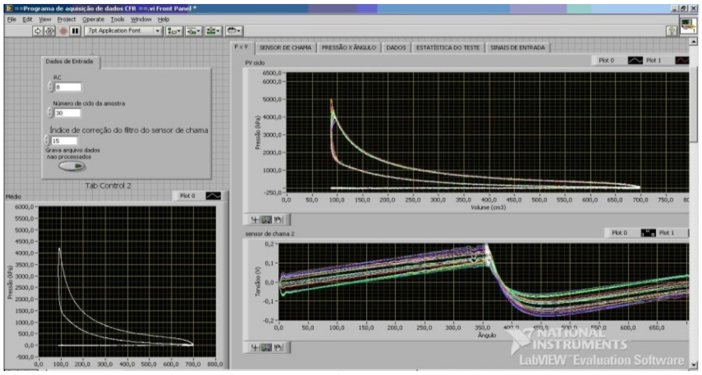
In the "Treatment Optrand " This is the calibration curve of the pressure sensor used so that the acquired signal in volts can be converted to pressure units (Pa). This block also removes the high frequency noise present and detects the location of peak pressure and the angle of the crankshaft where it occurs and its amplitude.

The treatment of the flame sensor is performed in block "Flame Sensor Processing" and consists of removing a fixed value due to the sensor power (remove DC), filter the high frequency noise that does not interfere with the derivative of the signal and locate in the signal derived from the corresponding point on the flame detection, along with the angle at which it occurs. It also serves to calculate the difference between the angle that occurs in the early spark and flame detection.

The block "Lambda Treatment" making the calibration of the λ curve supplied by the manufacturer.

The block "Calculation of Work" separates the cycle acquired in four segments and calculates the work in each of these segments.

The interface for using the program developed in LabVIEW 8.6 is presented in Figure 6. The top right should be filled with the test parameters such as number of cycles to be acquired, compression rate, recording or not the file filter and flame sensor. The remaining fields show the results obtained during the test, among which the pressure curves inside the cylinder to crank angle, curves of pressure versus volume response of the flame sensor, table with the average results of the test, average and standard deviation of the parameters monitored during the test and those signals coming directly from the data acquisition board, without treatment.



RC: 8
Número de ciclo da amostra: 30
Índice de correção do filtro do sensor de chama: 15

Figure 6. Interface of program for treatment and data acquisition.

4.5. Experimental methodology.

With the objective to minimize the involved variable in the tests, an only methodology for the accomplishment of all was adopted the assays carried through in this work. This methodology was developed in the scope of the LABMOT of the UFRGS and takes as base the described methodology in used norm ASTM D 357-64 in the assays for the determination of octanes number of a fuels below of 100 octanes. In this they are determined that the tests alone can after be carried through the stabilization of the temperature of the liquid of cooling in 80°C.

During the accomplishment of the tests, after the steady readinesses of the engine, it is made right condition of air/fuel rate, the spark angle and compression rate of the tests. The value of acquisition of 30 consecutive cycles of combustion as representative of the tests results was defined experimentally. All these signals are acquired to each pulse supplied for encooder to the data acquisition board, thus resulting in data related to the angular position of the crank angle, where the sensor of top dead center marks the beginning of the acquisition of each cycle synchronized with the top dead center of the engine, at the beginning of the admission phase. These data recorded and are visualized to the end of each developed assay in a applicatory one in LabView 8.6. Aiming at the validation through the statistics analysis the data are registered three times.

For the demonstration of the functionality of the system proposed considered in the fuel properties analysis, tests had been carried through using as fuel hydrated ethanol. The spark advance angle varied, in as tests objectified it analysis of the influence of the variation of the compression rate and, in third, the analysis of the influence of the variation of the air/fuel relation. During all tests the too much parameters of control had been kept fixed. The tests conditions are described to follow.

In this work, the tests was remained fixes the compression rate (rc 8:1) and the mixture condition ($\lambda = 1$), varying the ignition angle in the values of 17°, 19°, 21°, 23° and 25° BTDC.

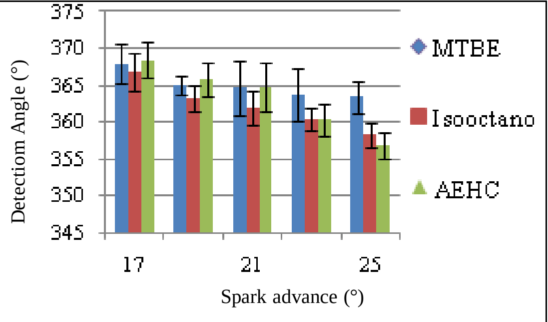
5. RESULTS

Based on data collected from the reply of the ionization sensor, implemented in CFR engine, it is presented Table 2 where the values of the angles are express where the presence of the flame is detected in the opposing extremity the spark plug, beyond the value of the shunting line standard gotten for each assayed condition. One notices, although the proximity of the measured values, a convergence for the result of a lesser angle covered for the crank angle with the increase of the ignition advance.

According to the results, note that for the test that is used in lower ignition advances, there is less difference in the value of the angle detection calls between the three fuels tested, and with increasing advance ignition, the difference between fuels is more pronounced, especially when comparing the response of the MTBE fuel with others, where it showed a variation in flame detection of 4.48° between the conditions of the ignition advance of 17 and 25° BTDC, compared to ethanol, which provides for the same variation of the ignition advance angle of a change in flame detection of 11.6° and isooctane fuel remaining between these two figures, presented a change in flame detection angle of 8.52° for these test conditions.

Table 2:Flame detection angle with spark advance variation

Spark Advance (°)	MTBE Flame Detection angle (°)		ISOOCTANO Flame Detection angle (°)		AEHC Flame Detection angle (°)	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
17	367,89	2,68	366,80	2,56	368,41	2,41
19	364,91	1,26	363,31	1,77	365,78	2,22
21	364,70	3,67	361,94	2,22	364,75	3,22
23	363,73	3,67	360,45	1,53	360,29	2,06
25	363,41	2,20	358,29	1,67	356,78	1,78



The following are the average results of the mass fraction burned curves obtained from the five conditions tested, where one can see that for the test condition is used where the spark timing 17 ° BTDC is a great similarity in the way that energy available in the fuel is delivered from fuel isooctane and MTBE fuel to the condition of the ignition advance of 19 ° BTDC realizes that the isooctane fuel and fuel MTBE present a pattern quite similar to the condition of mass consumption of fuel reaches 10 % of total mass, from this point, isooctane has its energy rate release increased. To test the condition using the ignition advance of 21 ° BTDC the isooctane and ethanol have very similar behavior, especially after consuming 40% of the mass contained in the cylinder to be consumed. When the use of ignition advance higher in the case of ignition advances tested 23 and 25 ° BTDC, the fuel ethanol has a higher of energy rate release, especially after consuming 50% of the mass contained in the cylinder. The evolution of mass fuel consumption of the three fuels mentioned in the five conditions described is shown in Figure 7.

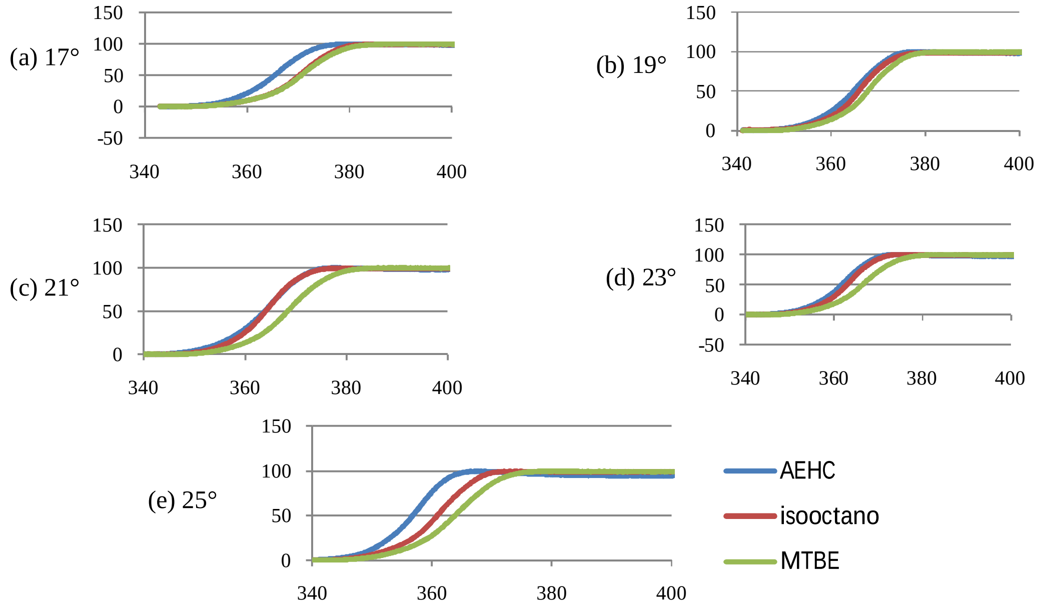
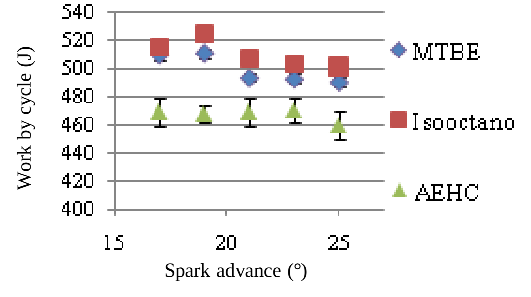


Figure 7. Variation of mass fraction burned versus spark timing

Based on the data obtained from pressure and volume of the combustion chamber is calculated the values of the average work done per cycle for each test condition performed, which are presented in Table 3, where we obtained the largest amount of work per cycle isooctane for fuel, provided the test with the ignition advance of 19 ° BTDC and obtained the smallest amount of work per cycle for fuel ethanol in the test condition of 25 ° BTDC. The following is a graphical representation of results obtained for the parameter of work per cycle, where it is noticed that the fuel isooctane has the highest value of work done per cycle, followed by MTBE fuel and the fuel with ethanol has less work for the conditions tested. Also, note that the fuel isooctane and MTBE behave quite similar, with values of maximum work value for the test condition of 19 ° BTDC, with a marked reduction in this value after this condition, however the fuel ethanol has a maximum work value in progress condition of 23° BTDC.

Table 3. average work done by cicle

Spark Advance (°)	MTBE		ISOOCTANO		AEHC	
	Work by cycle (J)		Work by cycle (J)		Work by cycle (J)	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
17	510,03	4,49	515,08	2,53	469,74	10,07
19	511,18	3,22	524,88	2,80	468,15	6,13
21	493,64	2,41	507,08	4,12	469,62	10,13
23	492,80	3,43	503,11	4,37	470,90	8,69
25	490,53	3,56	501,34	4,73	459,64	9,95

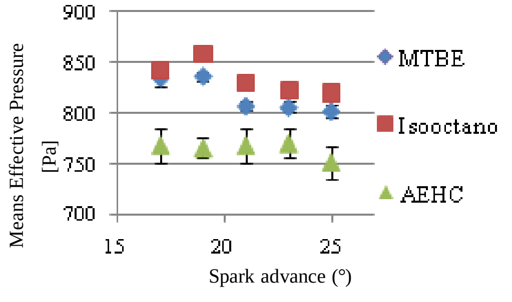


The values obtained indicated mean effective pressure, calculated from the values of work per cycle, are presented in Table 4, where it is noticed once again that the highest value is presented on condition that the ignition advance of 19° BTDC for fuel isooctane, and the lowest value corresponds to the test with fuel ethanol, with the use of an ignition advance of 25° BTDC.

Making the comparison of results based on experimental data of pressure and volume of the combustion chamber, one gets the values indicated mean effective pressure, where again it is clear that MTBE and isooctane fuels have a fairly similar, showing a maximum value for the test condition with the use of an ignition advance of 19° APMS and fuel ethanol presents a maximum indicated mean effective pressure in the test condition with the use of an ignition advance of 23° BTDC.

Table 4. Variation of IMEP with the spark angle

Spark Advance (°)	AEHC		Isooctano		MTBE	
	IMEP (kPa)		IMEP (kPa)		IMEP (kPa)	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
17	768,80	16,48	843,01	4,13	834,75	7,35
19	766,19	10,02	859,05	4,58	836,63	5,26
21	768,61	16,57	829,91	6,74	807,91	3,94
23	770,69	14,22	823,42	7,15	806,54	5,61
25	752,28	16,27	820,51	7,74	802,83	5,82



6. CONCLUSIONS

The test bench was made with a fuel adjustment of the CFR engine along with the proposed instrumentation system has demonstrated full capability to reproduce and monitor the combustion phenomena, taking control of individual parameters such as ignition advance.

The variation of ignition advance has great influence on the flame development. Insofar as the ignition is advanced, there is a significant increase in pressure due to higher mass fraction burned inside the cylinder before the piston reaches the top dead center, leading to an increase in temperature, with consequent increase in flame speed propagation.

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8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.