

# HYDROCARBON BURNING VELOCITY DETERMINATION USING MODIFIED CFR ENGINE

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## ABSTRACT

Hydrocarbon burning velocities have been investigated for a long time, as they affect internal combustion engine performance. Burning velocities depend on temperature, pressure and mixture composition, and can be evaluated by open pipe or constant volume vessel techniques. Farrell [2] published experimental data on combustion velocities for pure compounds measured in a constant volume vessel under typical conditions of temperature and pressure found at the end of an Otto engine compression stroke. Dalavia [1] proposed a method of assessing overall burning time in an Otto cycle CFR engine, measuring the time elapsed from the mixture ignition to the flame front arrival at the opposite cylinder wall, as detected by an ionization sensor. Our work compared flame travel times measured in a modified CFR engine to burning velocity data published by Farrell [2] for pure hydrocarbons, checking the correlation between them. The mean combustion speeds of ten pure hydrocarbons were evaluated at stoichiometric conditions, keeping the compression ratio constant as the ignition advance was changed. The results were validated and the modified CFR engine was found to be an effective tool to determine burning velocities.

## INTRODUCTION

Hydrocarbon burning velocities have been investigated for a long time, as they affect internal combustion engine performance. Burning velocities depend on temperature, pressure and mixture composition, and can be evaluated by open pipe or constant

volume vessel techniques. Dalavia [1] introduced a method of measuring burning time directly in a CFR SI engine. This work presents the burning times of several hydrocarbons, as measured by Dalavia's method, and compares them to burning velocity data published by Farrell [2].

The combustion process in any SI engine is a function of several interlinked variables. Fuel evaporation is a function of atmospheric air temperature, moisture, pressure [2, 4, 5] and intake manifold fuel droplet size, which is a function of either injection pressure and phase in a EFI, or venturi vacuum in a carburetor engine [5]. As SI engine combustion nature is turbulent, its flame speed depends on both fuel qualities like chemical composition and air-fuel relative ratio, and engine characteristics like cylinder pressure and temperature, which depend on compression ratio and spark advance [3, 4] .

In a conventional SI engine the fuel and air are mixed in the intake system, drawn through the intake valve into the cylinder, where mixing with residual gas takes place, and then compressed. Under normal operating conditions, an electric discharge at the spark plug starts combustion just before the end of the compression stroke. A turbulent flame then develops and propagates through the premixed fuel, air, and burned gas until it reaches the vessel walls, where heat transfer and destruction of active species extinguish the flame. Combustion in a conventional SI engine thus results from the expansion of a premixed, unsteady and turbulent flame. [4].

Typically, open pipe techniques can measure laminar burning speed at ambient temperature and atmospheric pressure, while constant volume vessel techniques make it possible to evaluate burning speed at the higher temperature and pressure levels found in spark ignition engines. Most of the published data on hydrocarbon burning velocities were measured at room temperature and atmospheric pressure, while data for higher pressures and temperatures is scarcer.

Farrell [2] published experimental data on combustion velocities for 45 pure hydrocarbons measured in a constant volume vessel at 304 kPa and 450 K, over the fuel equivalence ratios from 0.55 to 1.3. Burning velocities data were derived from thermodynamic analysis of the pressure rise following ignition.

Dalavia [1] proposed a method of assessing burning velocities in an Otto cycle CFR engine, measuring the time elapsed from the mixture ignition to the flame front arrival at the opposite cylinder wall, as detected by an ionization sensor. This method has the merit of evaluating the burning velocities in the engine itself, avoiding the need of correction factors for temperature, pressure, and turbulence

## **EXPERIMENTAL**

Our work compared flame travel times as measured in a modified CFR engine for several hydrocarbons with burning velocities data published by Farrell [2], checking the correlation between them.

Flame travel times of ten pure hydrocarbons were evaluated at stoichiometric conditions, keeping the compression ratio constant as the ignition advance was changed. The results were validated and the modified CFR engine was found to be an effective tool to determine burning velocities.

Flame travel times were found to be a function of compression ratio, ignition advance, and mixture composition. A second degree polynomial function (1) of ignition advance was found to fit the experimental data.

$$t_i = ax^2 + bx + c_i(r, \phi) \quad (1)$$

Where  $t_i$  is the  $i_{th}$  hydrocarbon flame travel time,  $x$  is the ignition advance [degrees BTDC], and  $c_i$  is a function of the hydrocarbon chemistry, fuel equivalence ratio  $\Phi$  and compression ratio  $r$ .

The data acquisition system is comprised by a modified CFR engine as described by Dalavia [1], an electronic timer, and a digital storage oscilloscope. The Figure 1 shows the data acquisition system.

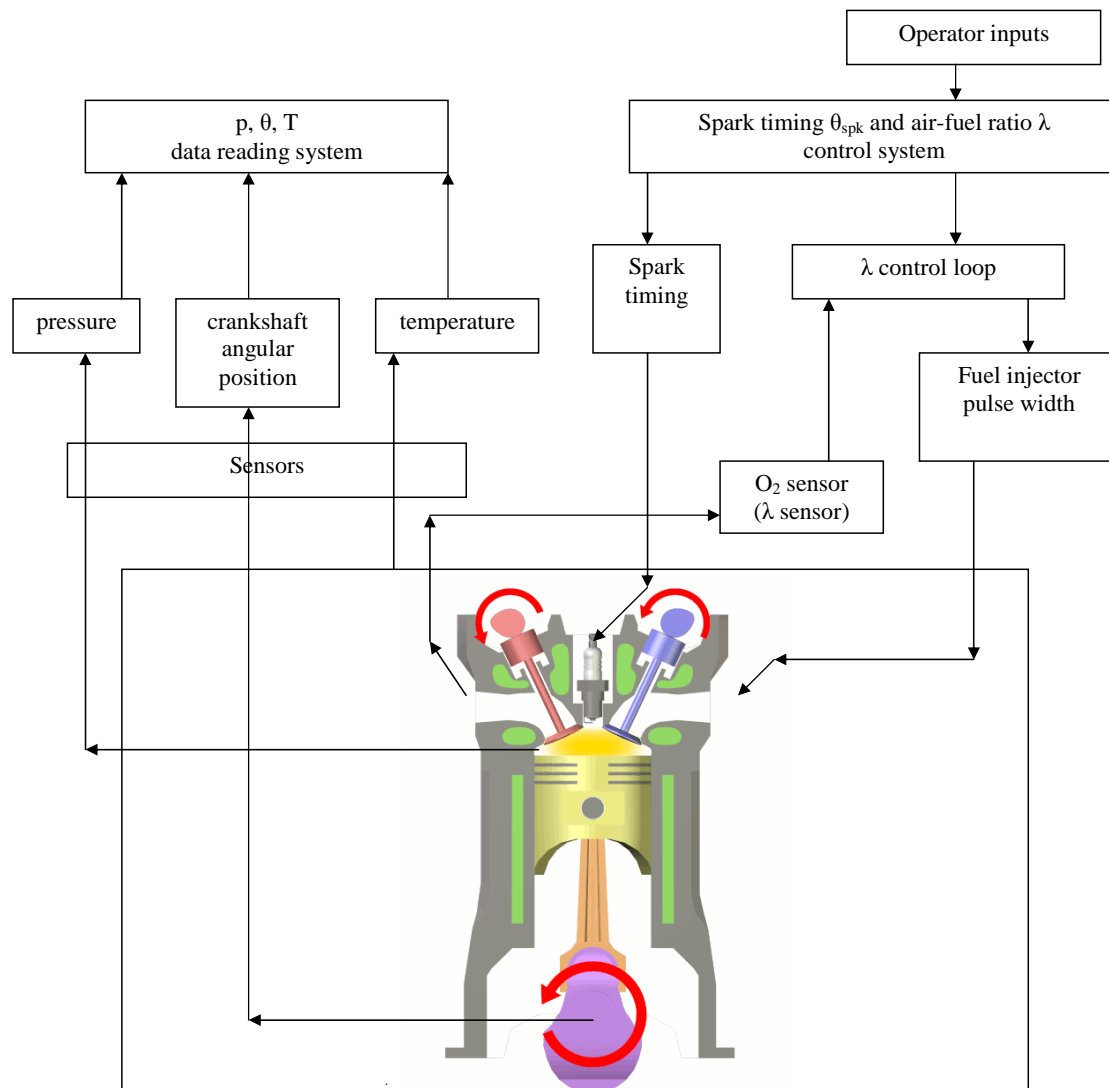


Figure 1: CFR data acquisition system.

The CFR spark plug is located at one end of the cylinder wall, while the ionization sensor is located at the opposite end, so the flame must travel a distance, which is essentially equal to the piston diameter from the spark plug to the ionization sensor, and the flame travel time is thus a function of burning velocity.

The Figure 2 shows ionization sensor installed in CFR engine.



Figure 2: Modified CFR engine, showing the ionization sensor position.

Compression ratio was chosen as the highest possible while avoiding knock for the lowest octane fuel evaluated. Stoichiometric conditions were chosen for all the fuels evaluated, so the  $c_i(r, \phi)$  term in eq. (1) was affected by the fuel composition only.

CFR speed was fixed at 600 rpm, as this speed is convenient to set by the existing pulley and belt assembly and was found to yield more consistent results than 900 rpm, which was the other option available.

Ignition advance was swept from the minimum of 15 degrees BTDC to the value causing the peak pressure to be at 15 degrees ATDC, which is close to operation at MBT [4].

Flame travel times were measured 128 times by an electronic timer set by the ECU ignition spark command and reset by ionization sensor output to the flame front arrival

at the opposite cylinder wall, and the average was recorded for each fuel and ignition advance value.

The records thus obtained were tabulated and compared to the data published by Farrell [2], and a correlation between the constants  $c_i$  and the peak burning velocities measured by the constant volume vessel was found to exist. The mean combustion speed is obtained by dividing the distance between plugs, which is 82 mm, by the parameter  $c_i$ .

## RESULTS

In the table 1, it shows both these records and Farrell [2] experimental data.

Table 1: Flame travel times, mean combustion speeds (MCS) and peak burning velocities (PBV) [2] for several fuels

i	Fuel	$c_i$	std err	Stat t	P-value	MCS	PBV
1	cyclopentane	9,74	0,23	41,8	4,4E-68	8,42	0,78
2	mesitylene	12,00	0,22	53,7	3,5E-79	6,83	0,56
3	cumene	10,03	0,24	41,7	5,0E-68	8,17	0,77
4	ethylbenzene	10,11	0,23	43,6	5,4E-70	8,11	0,77
5	toluene	10,22	0,24	42,7	4,6E-69	8,02	0,68
6	1-hexeno	9,22	0,24	38,3	2,5E-64	8,89	0,84
7	isooctane	10,56	0,23	45,9	3,3E-72	7,76	0,68
8	2,3-dimethylbutane	10,16	0,23	43,6	5,9E-70	8,07	
9	methylcyclohexane	10,25	0,25	40,3	1,7E-66	8,00	0,71
10	ethanol	9,89	0,24	41,1	2,1E-67	8,29	0,87

The standard deviations of the  $c_i$  values for each hydrocarbon evaluated in this work are one order of magnitude lower than their average value, thus  $c_i$  is a statistically significant parameter that represents the amount of flame travel time attributable to the fuel chemical properties.

The Figure 3 shows the results in graphical form.

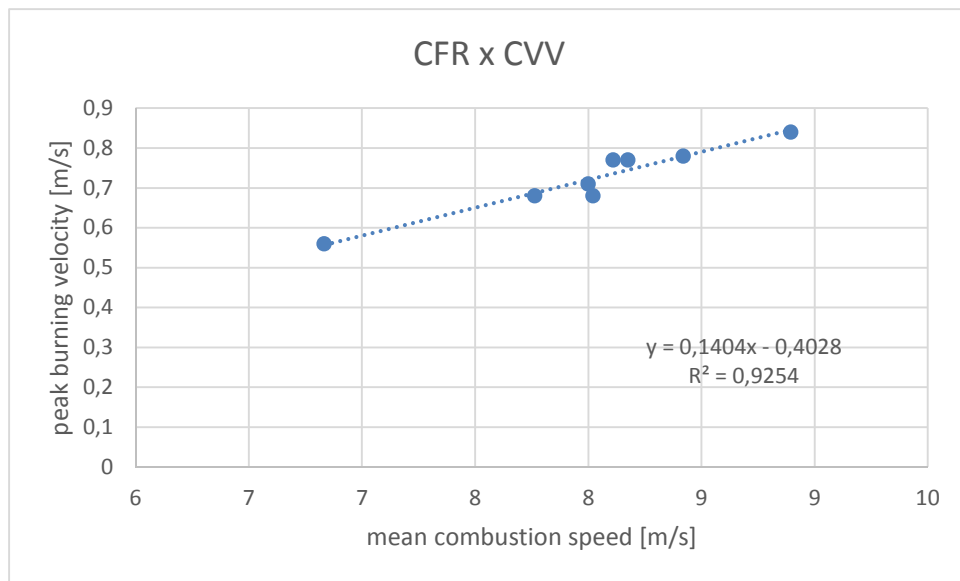


Figure 3: Mean combustion speed vs Peak burning velocities for several fuels.

Flame travel times measured by the CFR engine correlate to peak burning velocities measured by the constant volume vessel method, as shown by Fig. 3.

The Figure 4 compares mean combustion speed experimental data to the values predicted by eq. (1), showing the difference (dif) from both.

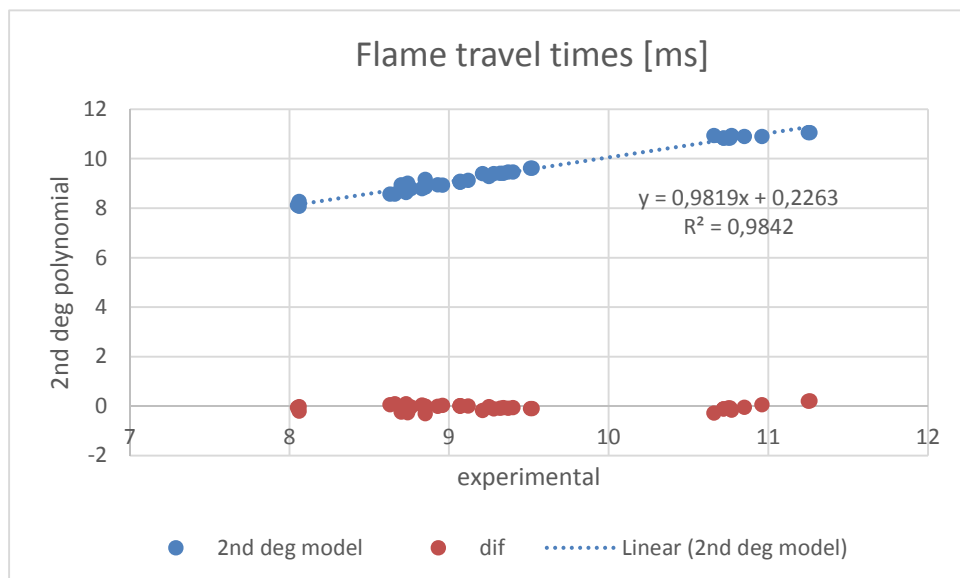


Figure 4: Flame travel times: Experimental data vs Values predicted by eq. (1).

## CONCLUSIONS

Flame travel times measured by Dalavia's method on the CFR engine were found to correlate to peak burning velocities measured by Farrell [2] using the constant volume vessel method for ten hydrocarbons tested in this work. The modified CFR engine was found to be an effective tool to determine burning velocities.

It was not possible to evaluate all the hydrocarbons studied by Farrell [2], due to availability issues. Limitations in CFR operation time and sample volumes did not allow evaluation of hydrocarbon flame speeds at different compression and air fuel ratios. A more extensive study would yield a larger amount of data, making it possible to fit a more complex equation than (1) to the experimental results.

Some scatter was found in flame travel times data, which may be attributed to the ionization sensor failing to detect all the flame fronts arriving at the cylinder wall, and the timer design, which lacked means to cope with this situation. A more elaborated timer should improve data accuracy.

## REFERENCES

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