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In Cylinder Pressure Curve and Combustion Parameters Variability with Ethanol Addition

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Introduction

- ✓ Spark-ignition engines stability depends on different factors such as misfires, fuel type, operating condition, engine project and others.

- ✓ Ensuring engine combustion stability for each operating condition is very important to maintain the mechanical engine output with minimal fluctuation.

- ✓ Some papers (Ex.: SAMUEL et al., 2010; CHOI et al., 2009; ZERVAS, 2004; BALL et al., 2000) report that engine combustion instability can reduce engine power, increase fuel consumption and cause problems on vehicle driveability.

- ✓ It was not found studies related to Flex-Fuel engine combustion variability.

- ✓ It was decided to study a Flex-Fuel engine operating with different ethanol contents on gasoline in order to analyze its influence on the combustion variability.

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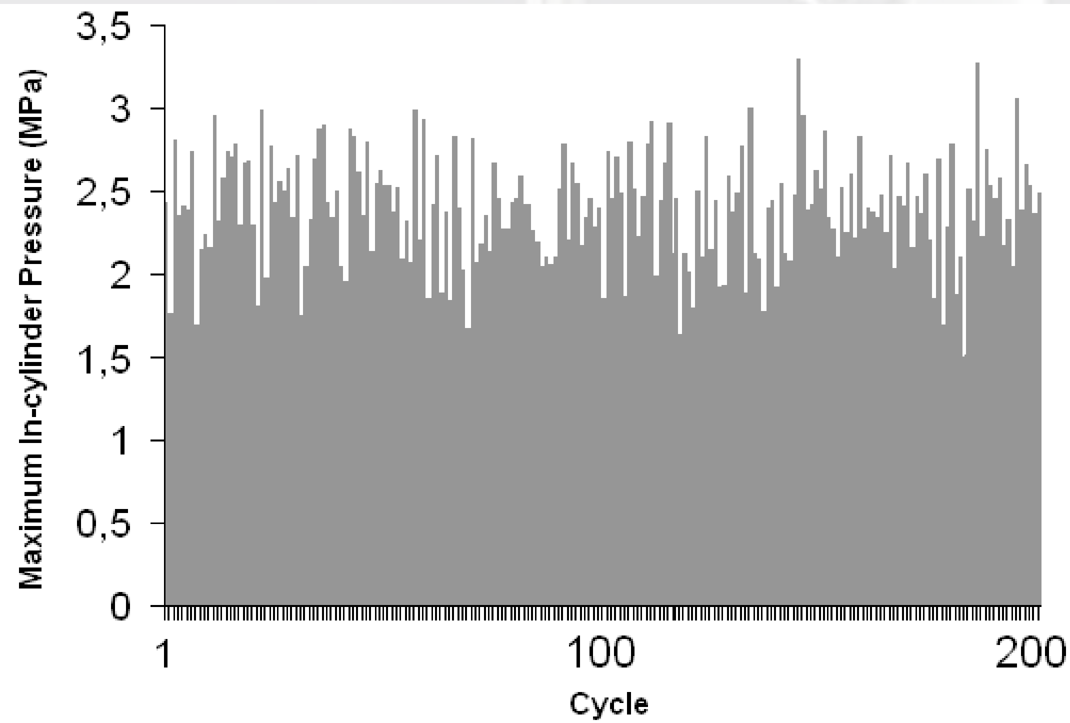
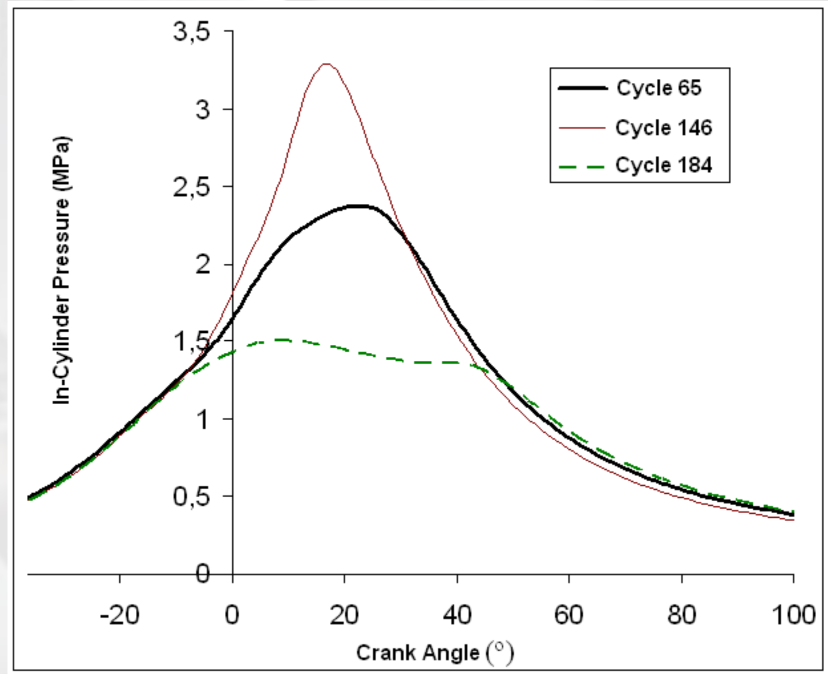
Introduction

- Maximum pressure cycle to cycle variability – GASOLINE E22
- Stability calculated by the Coefficient of Variation (CoV)
- CoV = Standard deviation/average value (%)





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Experimental Test Setup

- Engine FIAT Fire 1.4L Tetrafuel
- Fuels: H0 (E25); H30; H50; H80; H100 with 105 Nm at 2250, 3875 and 4500 rpm.

SAE 2012-36-0486

Experimental Settings - Engine

- The original Engine Control Unit (ECU) was replaced by a programmable one (MoTeC M800) in order to allow engine optimization for each fuel.
- The original engine lambda sensor was replaced by a linear wide-band one with lambda measurements done by ETAs.
- Operational conditions were adjusted for torque 105 Nm, lambda=0,9 and engine speeds of 2250, 3875 and 4500 rpm with sparking time adjusted at MBT (Maximum Break Torque).

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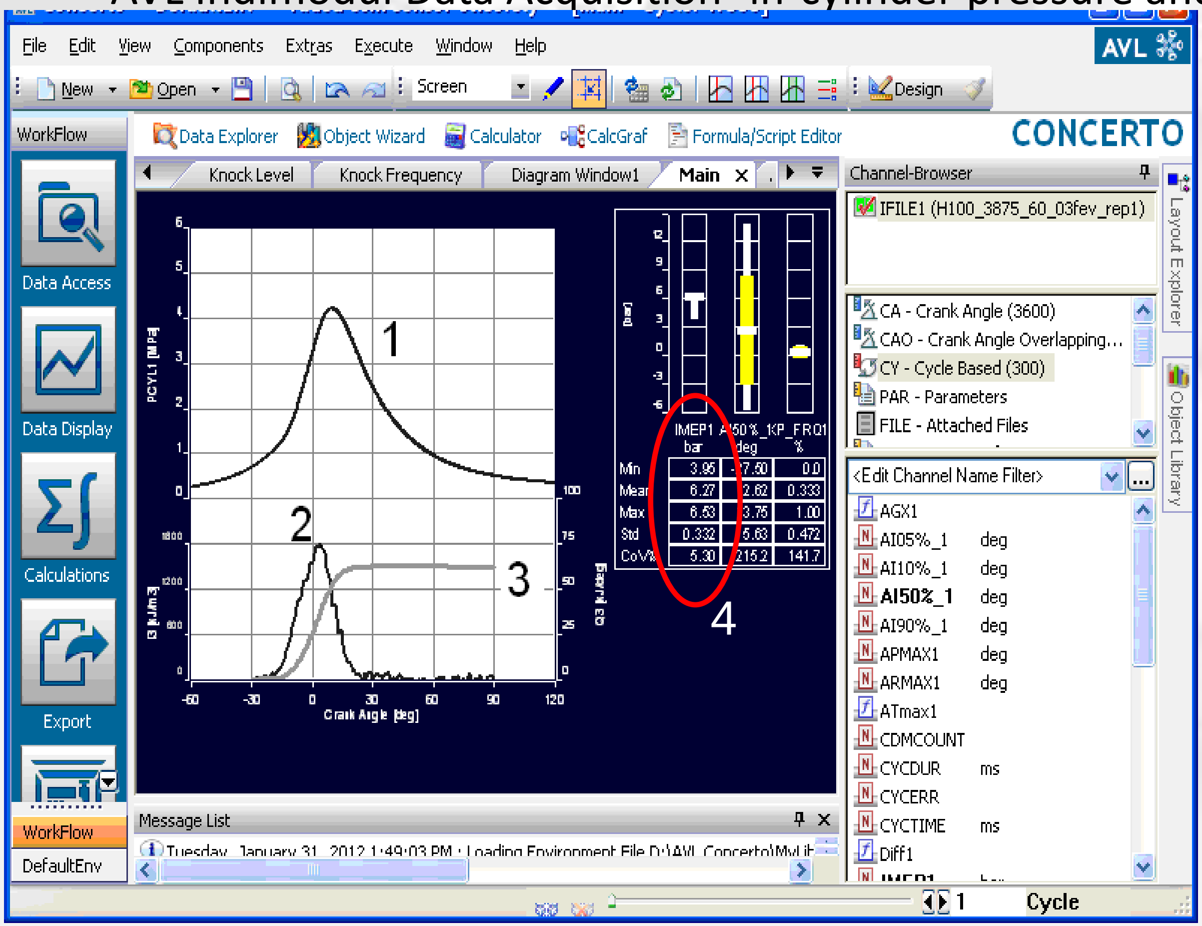
Experimental Setting - Combustion Parameters

- AVL Indimodul Data Acquisition- in-cylinder pressure and combustion analysis.



1 – In-Cylinder Pressure

2 – Heat Release Rate (HRR)

$$HRR = \frac{k(\theta)}{k(\theta)-1} \times P(\theta) \times \frac{dV(\theta)}{d\theta} + \frac{1}{k(\theta)-1} \times V(\theta) \times \frac{dV(\theta)}{d\theta}$$

3 – Mass Fraction Burned (MFB)

$$MFB = \int HRR/Qt$$

4 – Indicated Mean Effective Pressure (IMEP)

$$IMEP = \oint pdV/V$$

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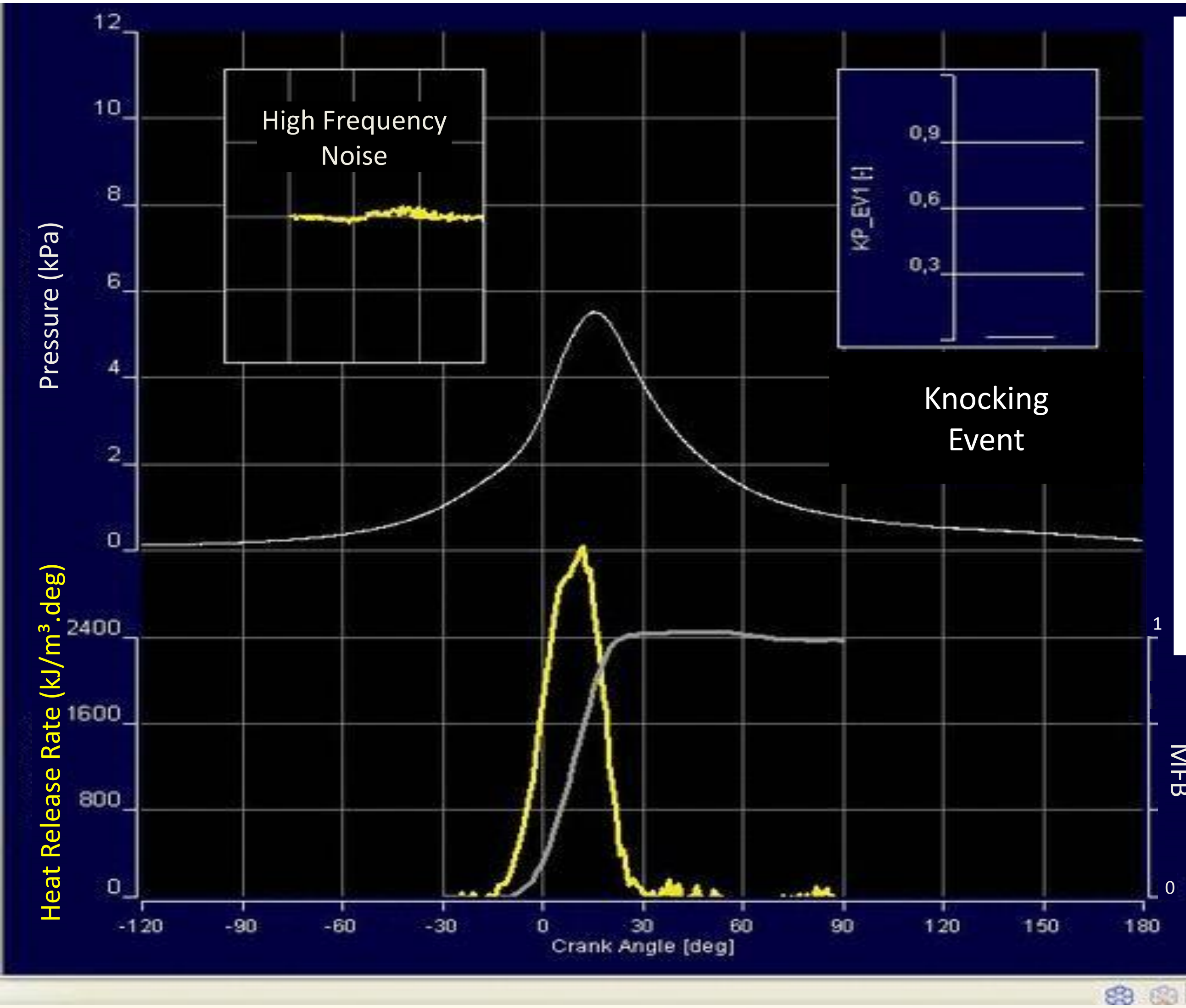
Experimental settings: Pressure and Knocking Detection



Indimodul New Sub-Routine Implemented

- Pressure curve: Measurement of the high frequency noise
- By-pass filter and mathematical equations to calculate knocking event.
- Knocking Limit: 5 knocking events over 100 engine cycles

Experimental Settings – Fuels Properties

	H0 (E25)	H30	H50	H80	H100
Specific Mass (kg/m³)	748,2	764,9	779,2	797,7	808,7
MON	85,1	88	89,7	91,6	91,8
RON	97,3	>100	>100	>100	>100
Carbon (% w/w)	73,3	64,3	59,5	53,9	50,7
Hydrogen (% w/w)	13,7	13,4	13,3	13,1	13,0
Oxygen (%w/w)	13,0	22,3	27,2	33,0	36,3
Ethanol (% v/v)	25,0	46,3	60,3	81,6	95,7
Gasoline (% v/v)	75,0	52,5	37,5	15,0	0,0
Water (% v/v)	0,0	1,2	2,2	3,4	4,3
A/F_{Stoich}	12,7	11,1	10,3	9,3	8,8
LHV (MJ/kg)	38,92	34,68	31,84	27,59	24,76
PVR (kPa)	55,9	52,5	47,2	33,0	15,4

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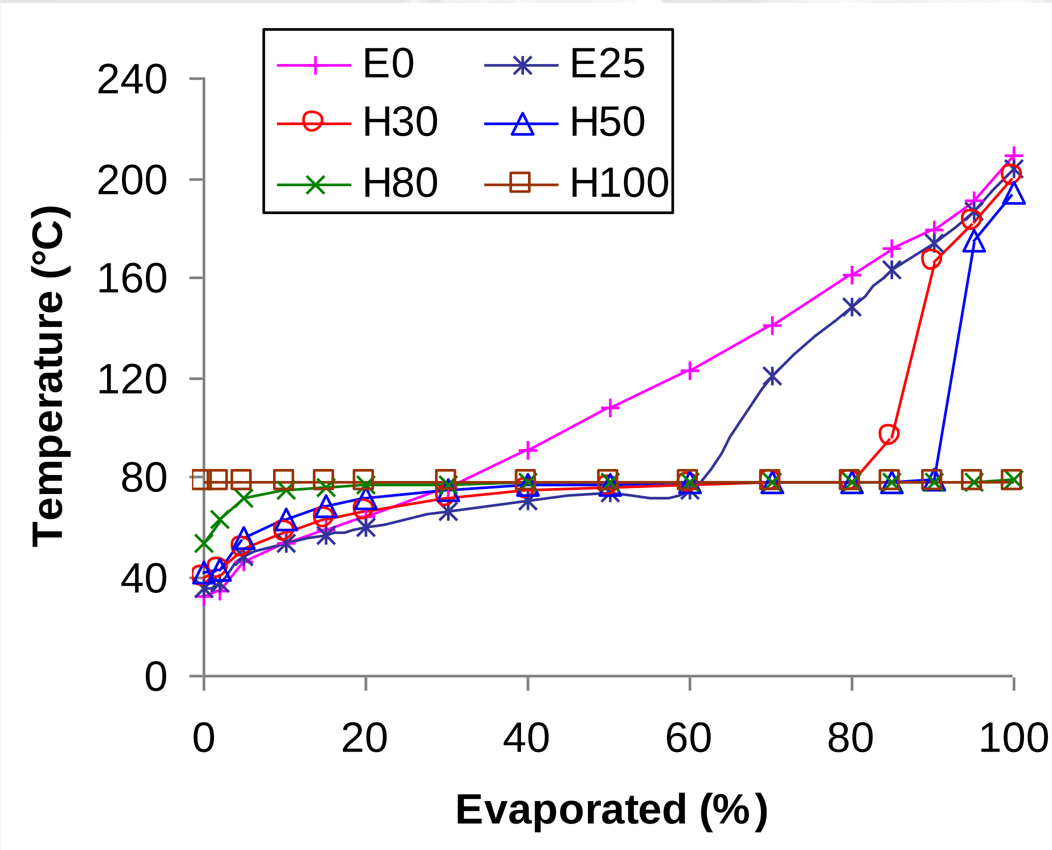
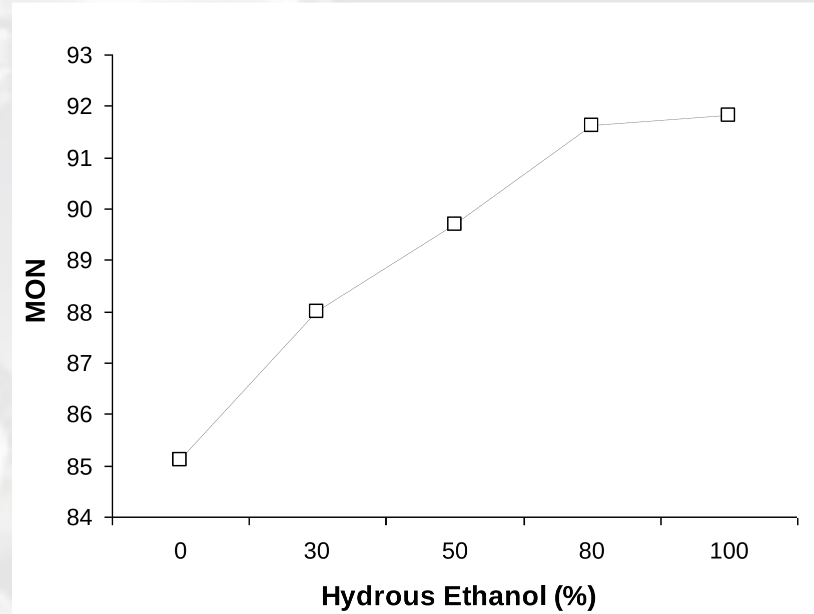
Experimental Settings – Fuels Properties





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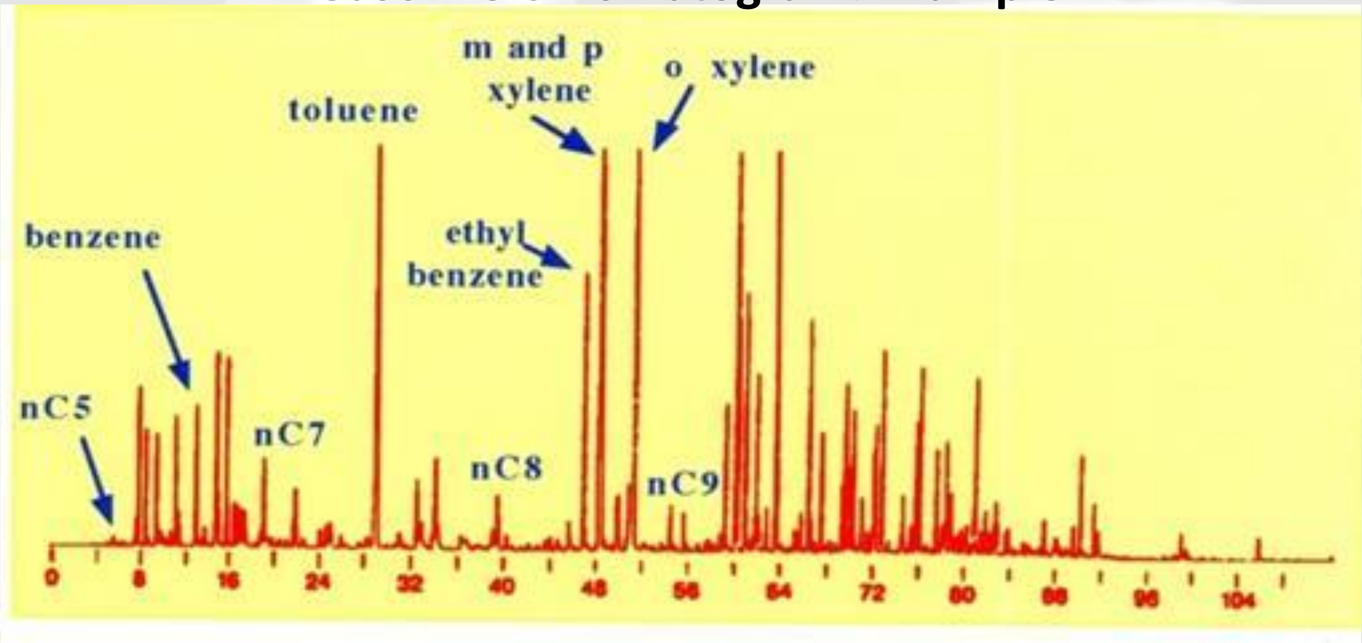
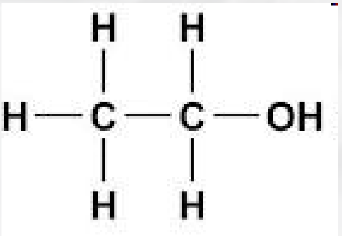
Experimental Settings – Fuels Properties

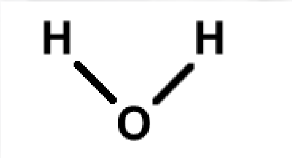
Gasoline Chromatogram: Example



Ethanol



Water



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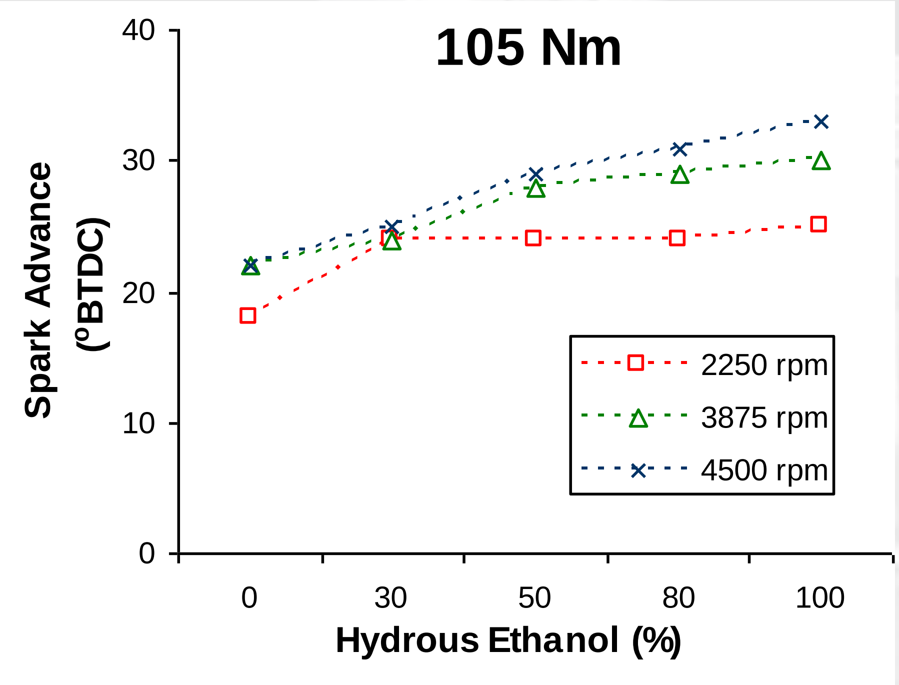
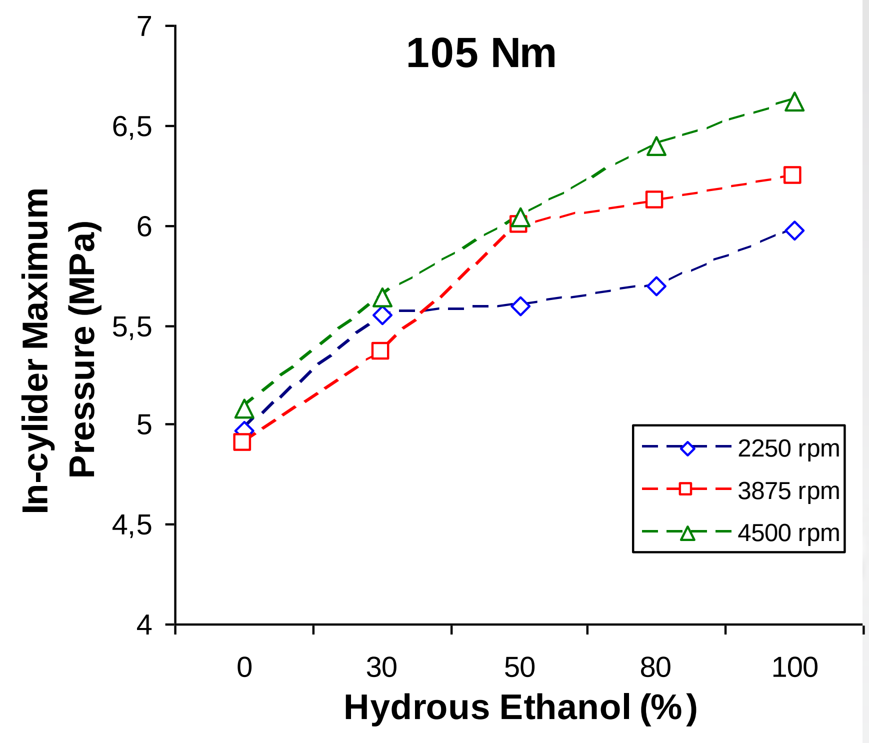
Combustion Results





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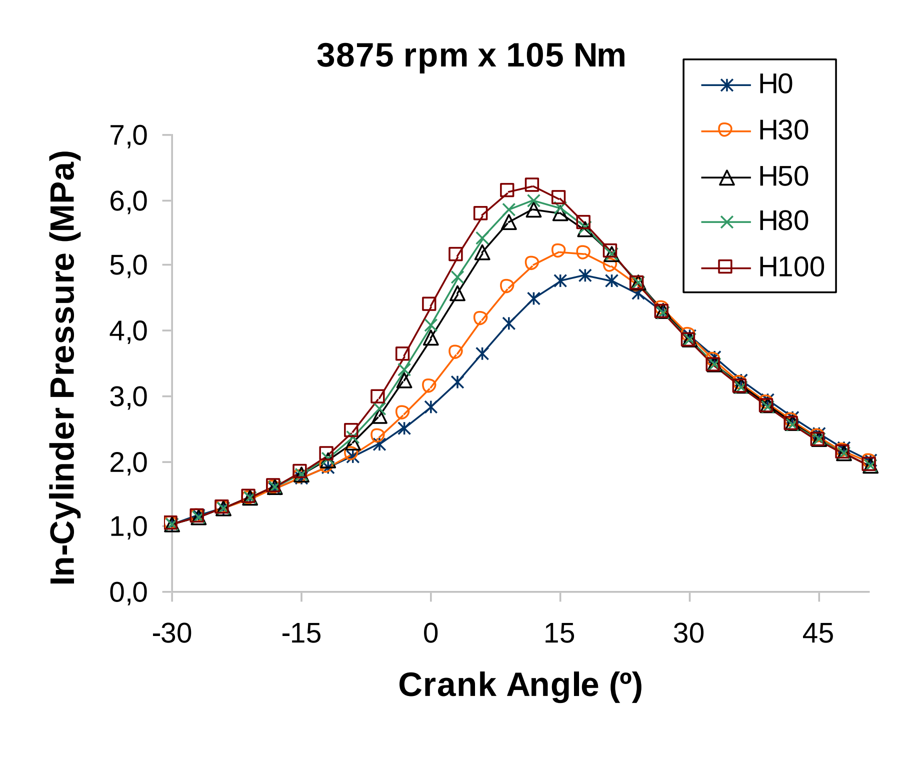
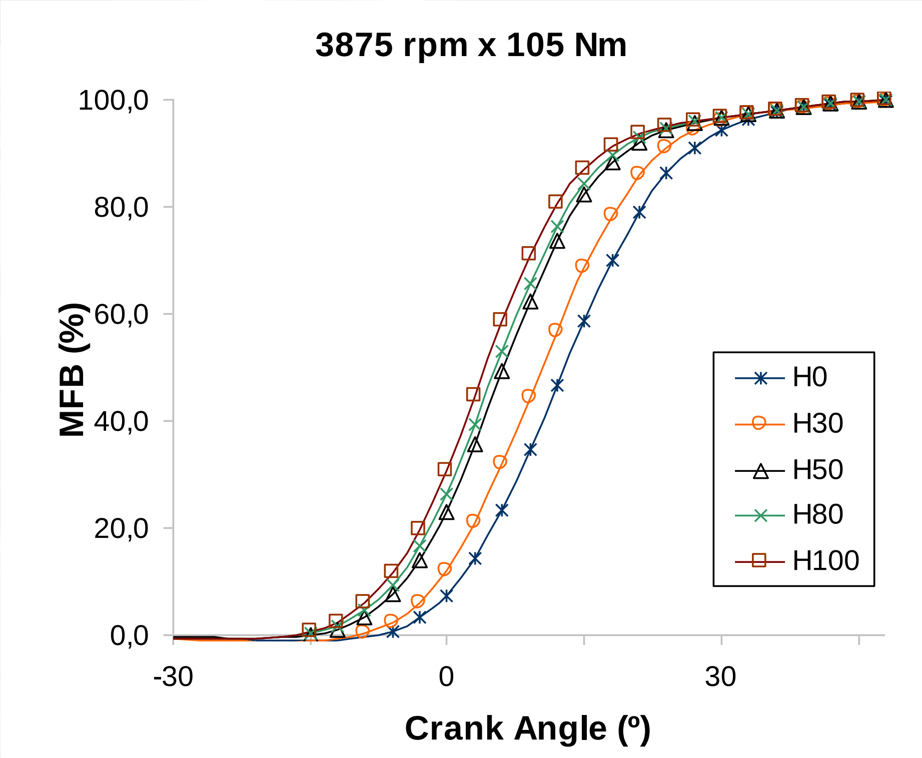
Combustion Results





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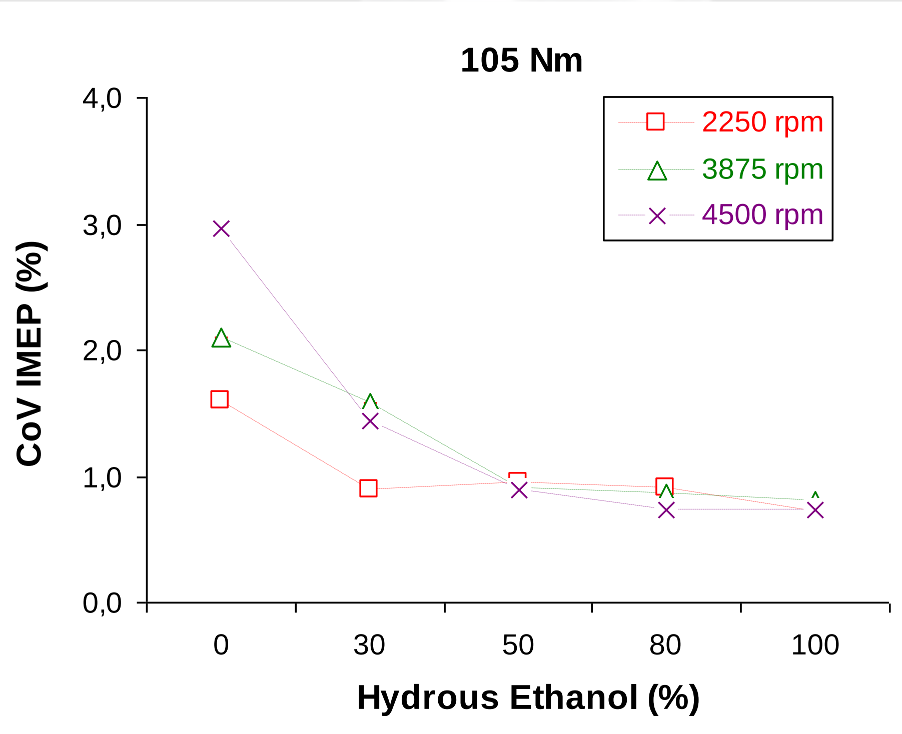
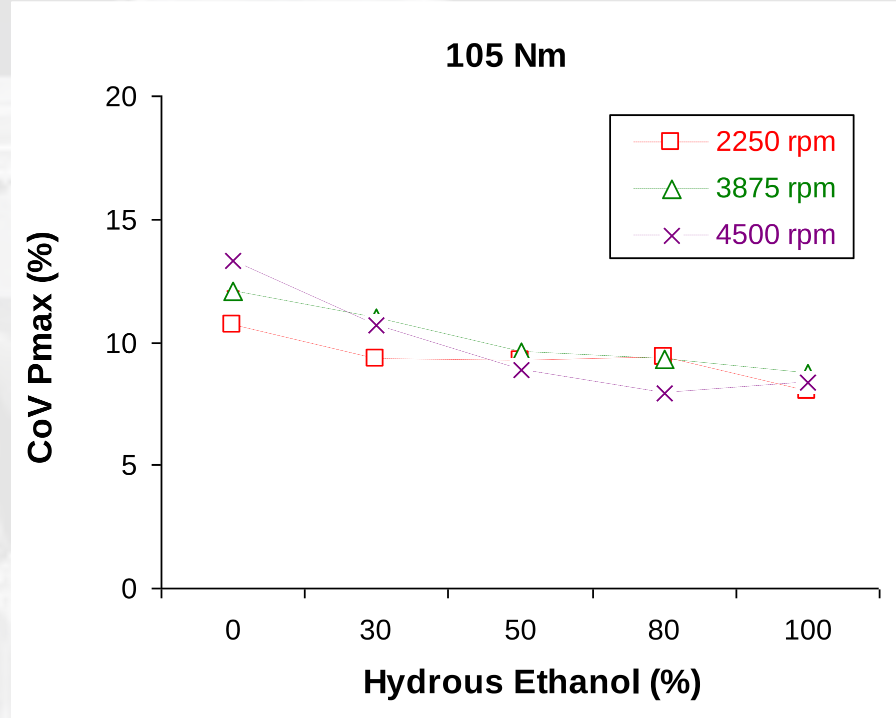
Combustion Results – CoV (Coefficient of Variation)





- Ethanol Addition – Reduced the coefficient of variation values meaning a more stable combustion.
- IMEP – Indicated Mean Effective Pressure
- CoV IMEP < 5% - Satisfactory Driveability

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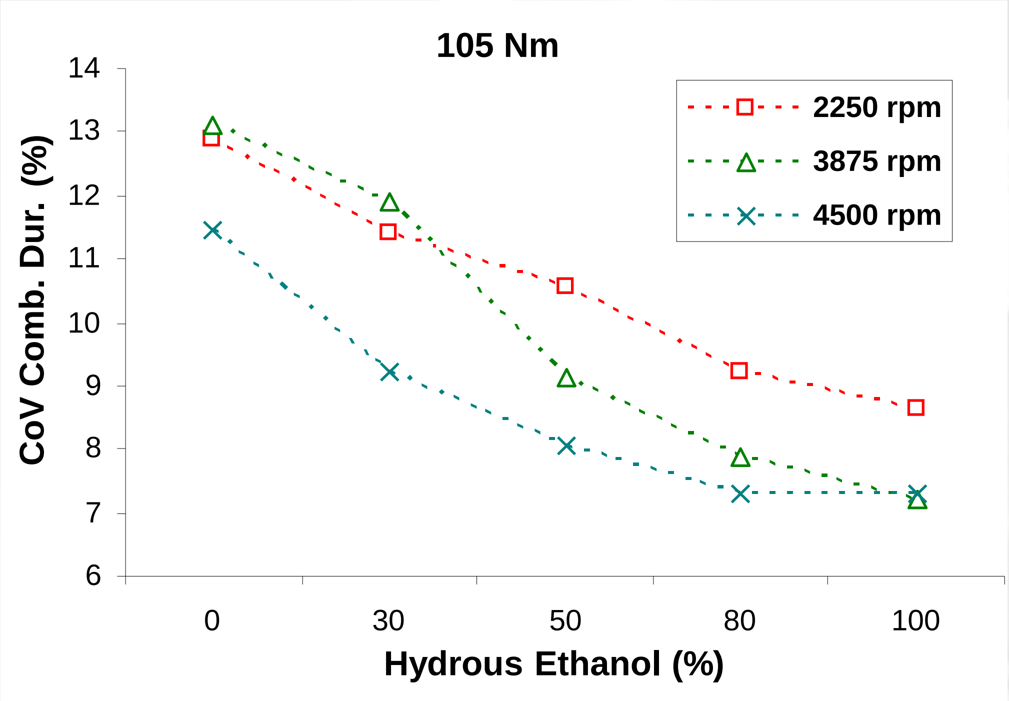
Combustion Results - CoV



Fuel	10% MFB (ºTDC)	90% MFB (ºTDC)	Combustion duration (º)
H0	1	26	25
H30	-1	23	24
H50	-5	19	24
H80	-6	18	24
H100	-7	17	24

TDC – Top Dead Center

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Conclusions

- For most of engine speeds and tested fuels ethanol addition reduced the cycle-to-cycle variability (CoV) of pressure, IMEP and combustion duration.

- For all tested fuels, CoV of IMEP was lower than 5%, meaning a satisfactory driveability for the final user.

- CoV reduction can be related to the fact that Hydrous ethanol has only two substances (ethanol and water), while gasoline is a complex mixture of hydrocarbons, including components with high vaporization temperatures, which can impact on fuel mixture formation with different combustion behavior.

- Combustion variability control is an important subject nowadays. Some OEM started to implement real time combustion variability reduction on some new vehicle models.

- Next steps of this work includes evaluation of different fuel properties (Octane number, Aromatics, Olefins and others) on the combustion variability

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