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The influence of ethanol blends on mixture preparation and PM emissions of a GDI engine

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Jaguar Cars

Overview

- Introduction
- Experimental Apparatus and Test Method
- Results and Discussion
- Conclusions

Introduction

The motivation and regulations for blending ethanol with gasoline

- Octane enhancement → better combustion, lower CO_2 emissions;
- EU promotes bio-fuel use establishing targets of 5.75% by 2010 and 10% by 2020;
- Global ethanol trade is forecast to increase 25-fold by 2020 to fulfill biofuel demand.

Advantages and Challenges of Gasoline Direct Injection Engines

- Key enabler for reducing CO_2 emissions;
- GDI engines with high PN in the nucleation mode (<100nm) may not pass future number-based regulations as readily as they would mass-based regulations.

Objectives

- Effects of ethanol blends on mixture preparation and PM emissions using:

1. DMS 500 to obtain size resolved PM number concentration and mass concentration;
2. high speed camera to capture spray and combustion images;
3. Fast FID to assess the variation of in-cylinder pre-flame HC concentration.

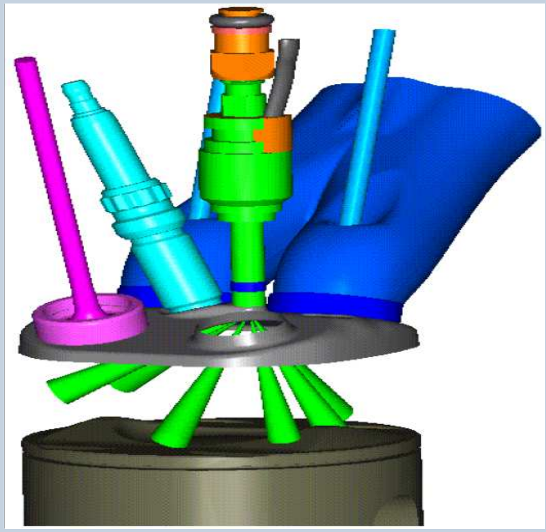
- Influence on combustion performances such as IMEP and MFB.

Experimental Apparatus and Test Method – Engine

Jaguar single-cylinder optical access engine

- The injector is mounted in the centre of the pent roof whilst the spark plug is mounted at a small angle inclined to the longitudinal axis;
- The multi-hole injector produced six spray plumes.

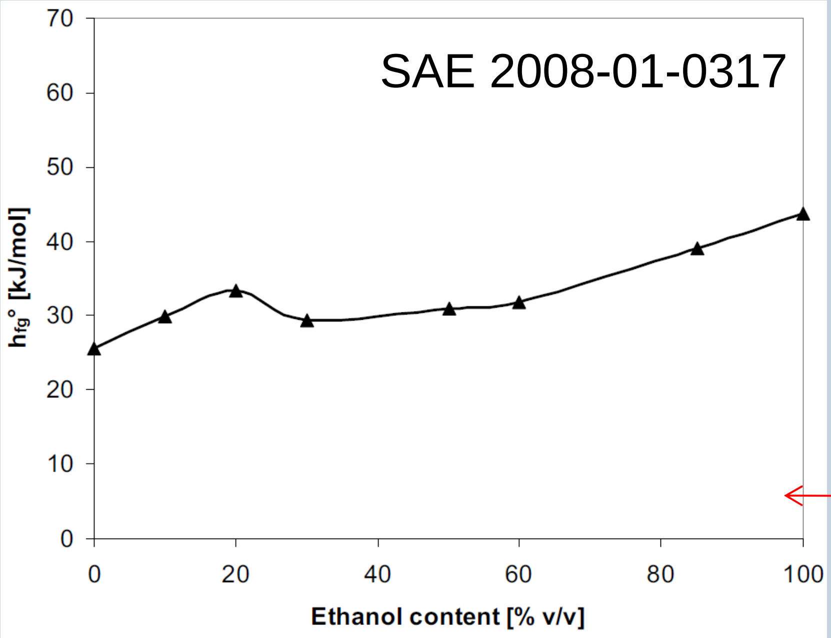
Bore × Stroke	89 × 90.3 mm
Displacement	562 cm^3
Valves per Cylinder	2 intake, 2 exhaust
Compression Ratio	11.1
Fuel Pressure	150 bar
Injector	Multi-hole Nozzle
Valve Timing	IVO 33º, IVC 243º, EVO 509º, EVC 39º



SAE 2009-01-1060

Experimental Apparatus and Test Method – Fuels

- The base fuel is PURA (Shell) and it has a low aromatic content of approx. 22% and a higher iso-paraffine content of 64%;
- Tests were conducted with E0, E10, E20, E50, E70 and E85.



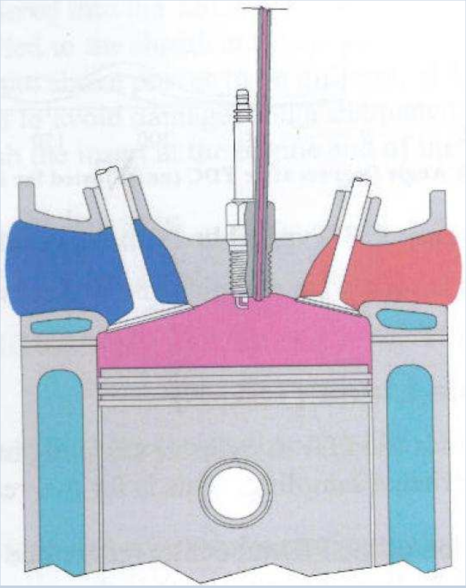
	PURA	Ethanol
Density @ 15ºC (kg/L)	**0.724**	**0.794**
Reid Vapour Pressure (mbar)	**574**	**159**
Research Octane Number	**95.7**	**107**
Final Boiling Point (ºC)	**168.8**	**78.5**
Stoichiometric AFR	**14.74**	**9.0**
Enthalpy of Combustion (MJ/kg, Liq.)	**-43.55**	**-26.8**
Heat of Vap. (MJ/kg)	**0.357**	**0.925**
H/C	**1.99**	**3**

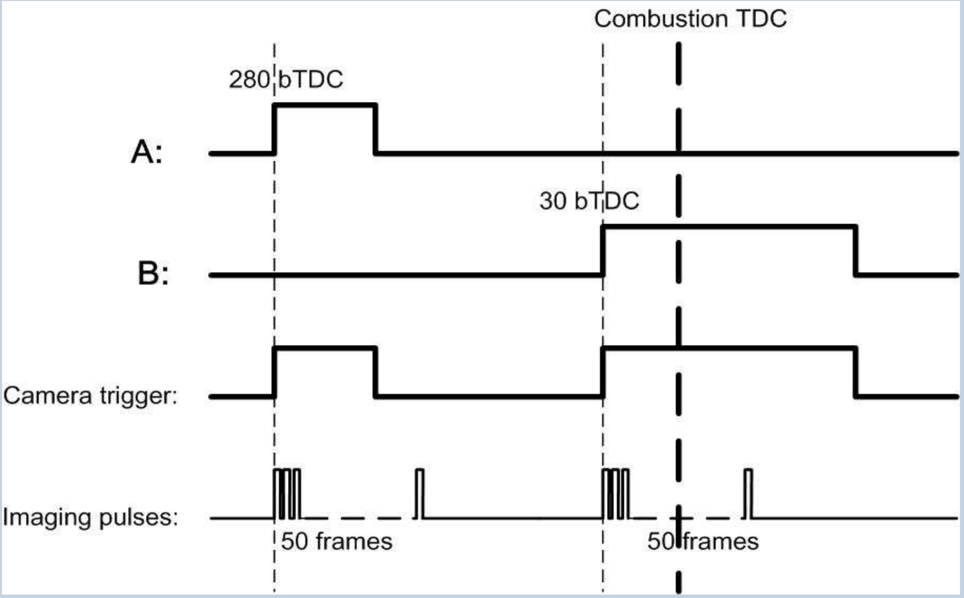
Experimental Apparatus and Test Method – Instruments

- DMS500 – PM size distribution
- Fast FID – Variation of in-cylinder pre-flame HC concentration
- Photron camera and synchronized LED – Spray and combustion images

  6000 fps (1.5 CA/frame at 1500 rpm); 512*256 spatial resolution;

  LED illuminates spray images while combustion images were visualized by chemiluminescence.

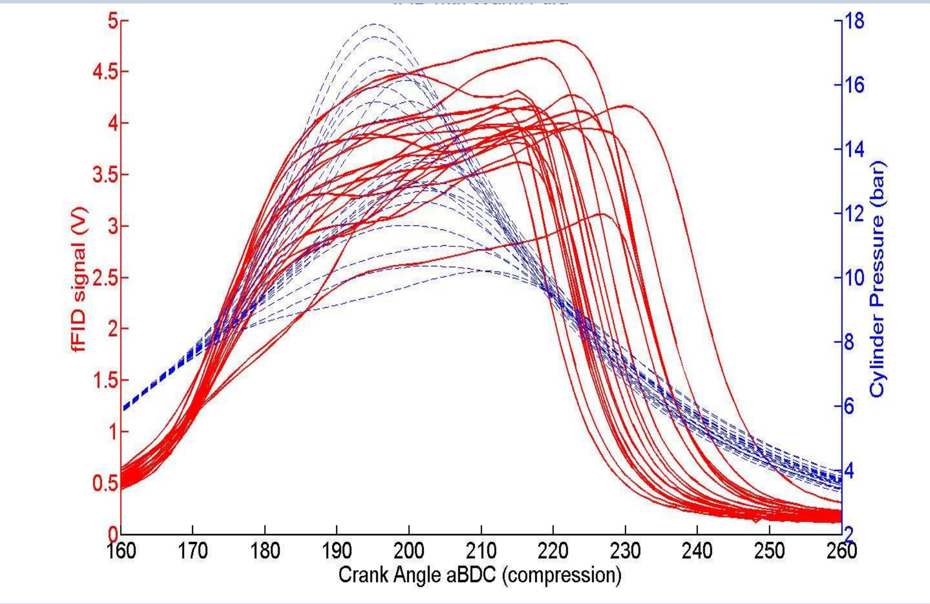




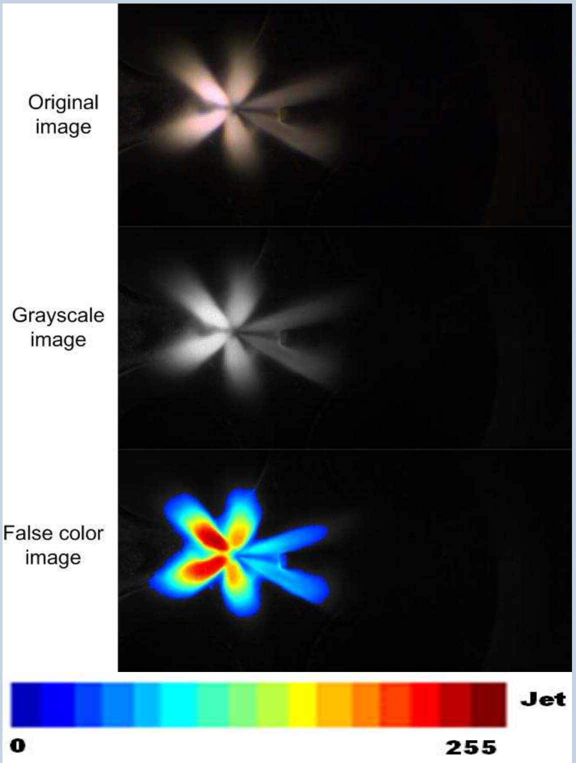
Experimental Apparatus and Test Method – Data Interpretation

- DMS500 – convert PM size distribution to mass distribution using a PM density model:

$M = 1.72\times10^{-24}\times D_p^{2.65}$ (Symonds *et al*, 2008)



- Local maximum values were taken as the indicator of the pre-flame mixture [HC];
- Ensemble COV represents the cyclic variability of the pre-flame [HC].



False Colour Imaging

Experimental Apparatus and Test Method – Test Matrix

Fuel	**Pura, E10, E20, E50, E70, E85**
Speed (rpm)	**1500**
Manifold pressure (bar)	**0.5**
Fuel Pressure (bar)	**150**
Injection Timing	**280 ºbTDC (Combustion)**
Ignition Timing	**30 ºbTDC (Combustion)**
Relative AFR	**1**
Coolant Temperature (ºC)	**20, 80**
IVO	**33 ºaTDC (Intake)**
IVC	**243 ºaTDC (Intake)**
EVO	**509 ºaTDC (Intake)**
EVC	**39 ºaTDC (Intake)**

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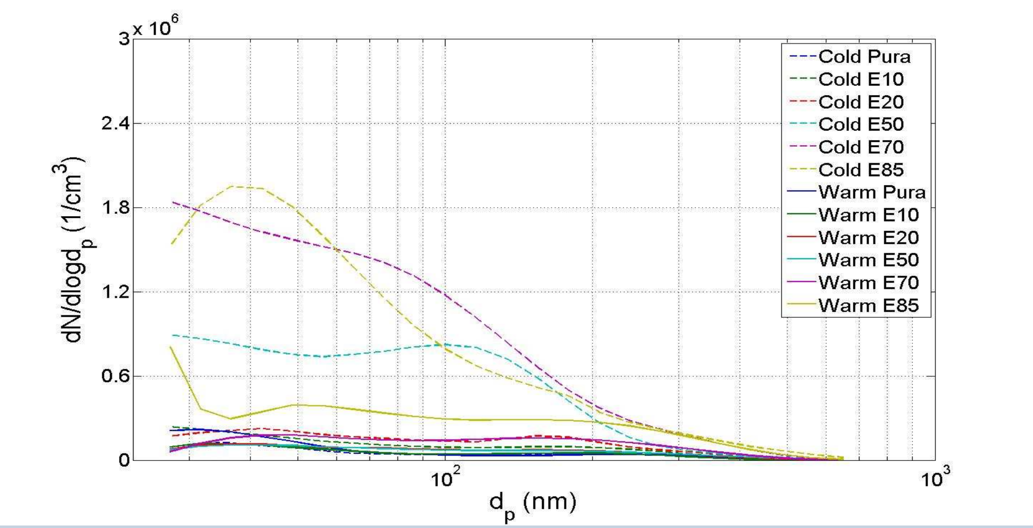
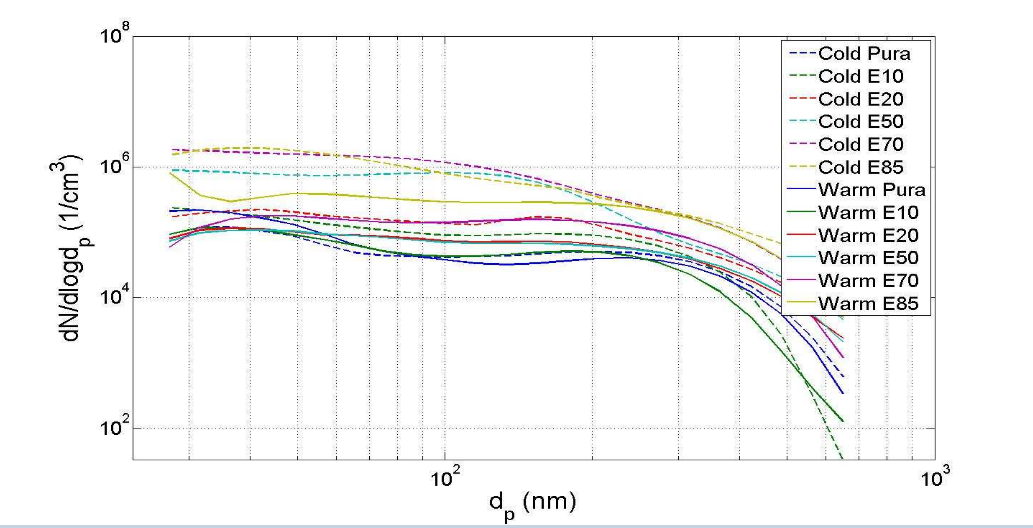
Results and Discussion – PM emissions

- Truncated data for 23-700 nm particles;
- A cold engine always produces a higher particulate number concentration than a warm engine;
- The increase in ethanol content results in the increase in particulate number;
- This trend for the 20 ºC operating point is stronger than that for the 80 ºC point.





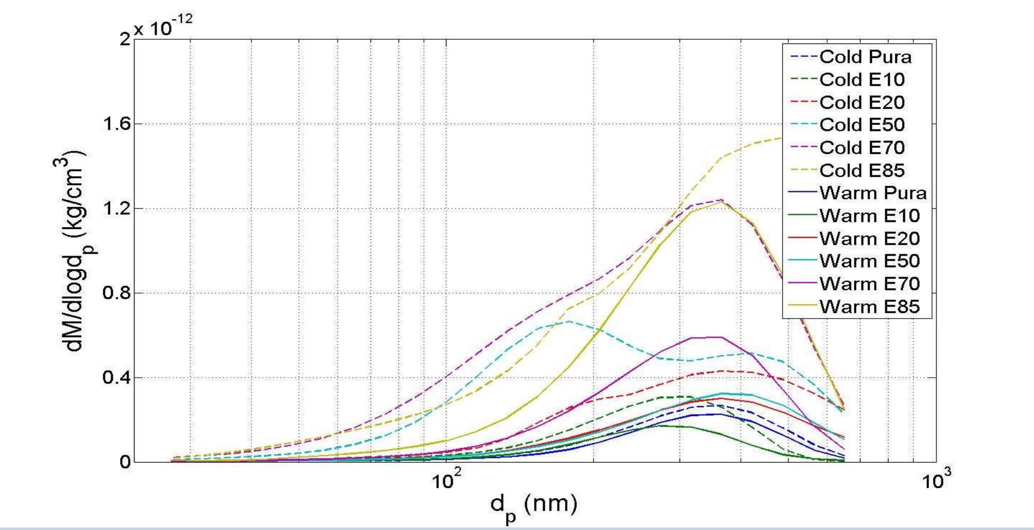
Results and Discussion – PM emissions

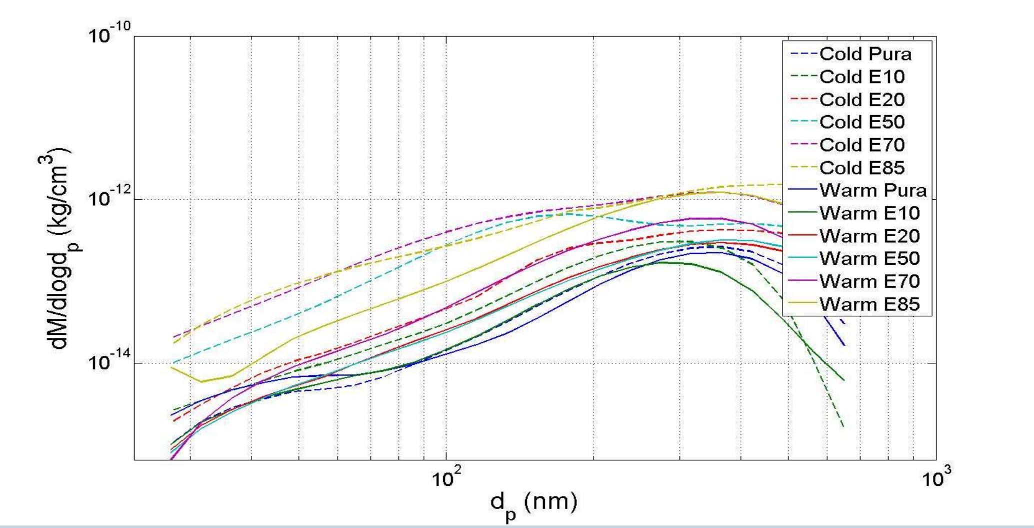
•Accumulation PM mode (>100 nm) dominates the mass spectra;

•A cold engine always produces a higher particulate mass concentration than a warm engine;

•An increase in ethanol content results in an increase in particulate mass;

•This trend for the 20 ºC operating point is stronger than that for the 80 ºC point.

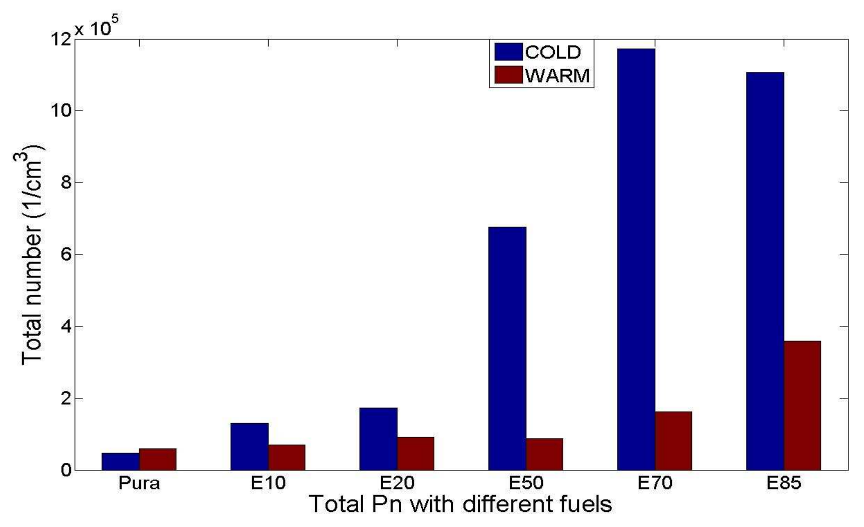


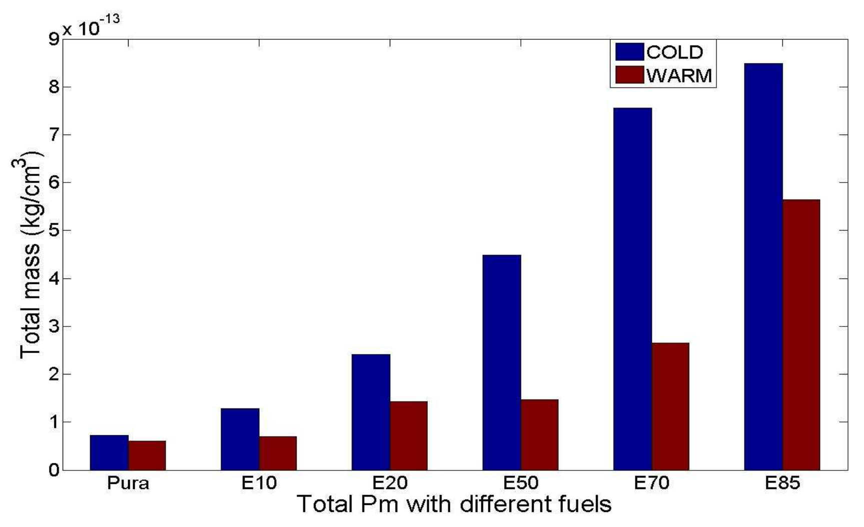


Results and Discussion – PM emissions

In general:

- Adding ethanol increases both total PM number and total PM mass;
- E85 produces 15 times higher total Pn than PURA under cold condition but only 6 times higher under warm condition;
- E85 produces 11 times higher total Pm than PURA under cold condition whilst 8 times higher under warm condition.



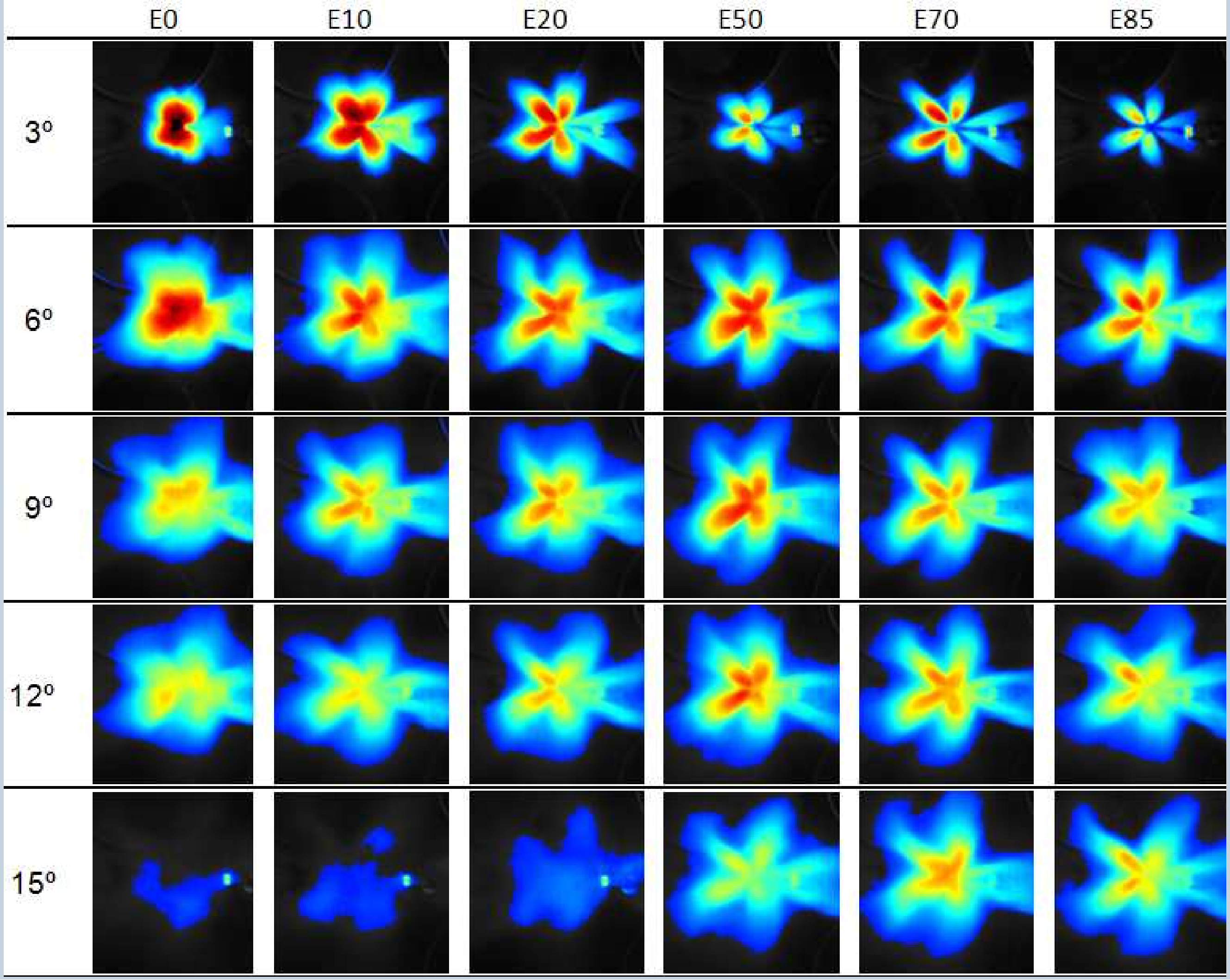


Results and Discussion – Spray Images

Results and Discussion – Spray Images (20ºC)

•Variation of the spray area at 3º after SOI is due to shot-to-shot variations in injection;

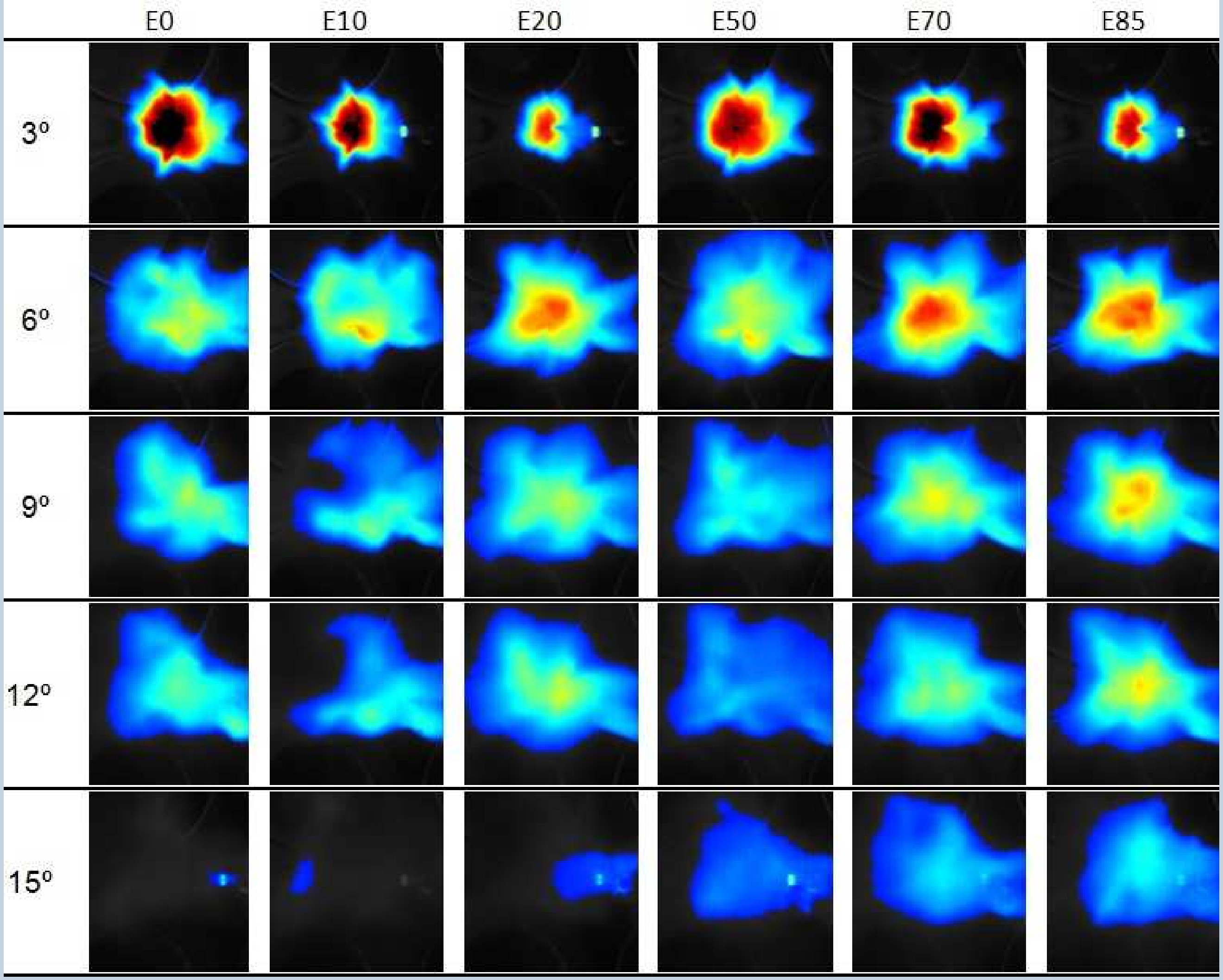
•Spray area and evaporation duration increase as the ethanol content increases.



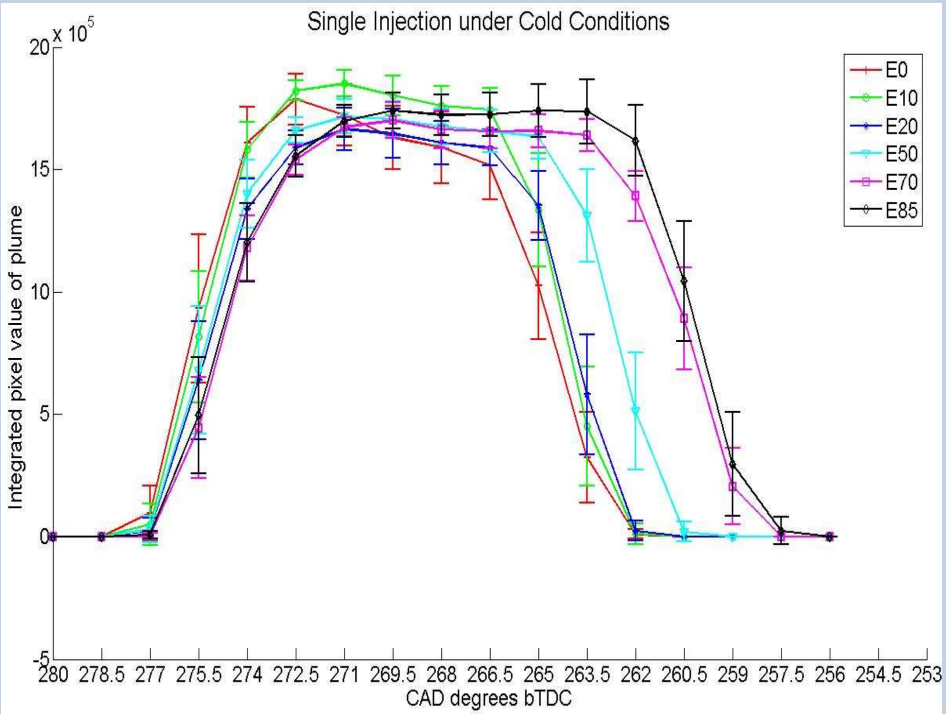
Results and Discussion – Spray Images (80ºC)

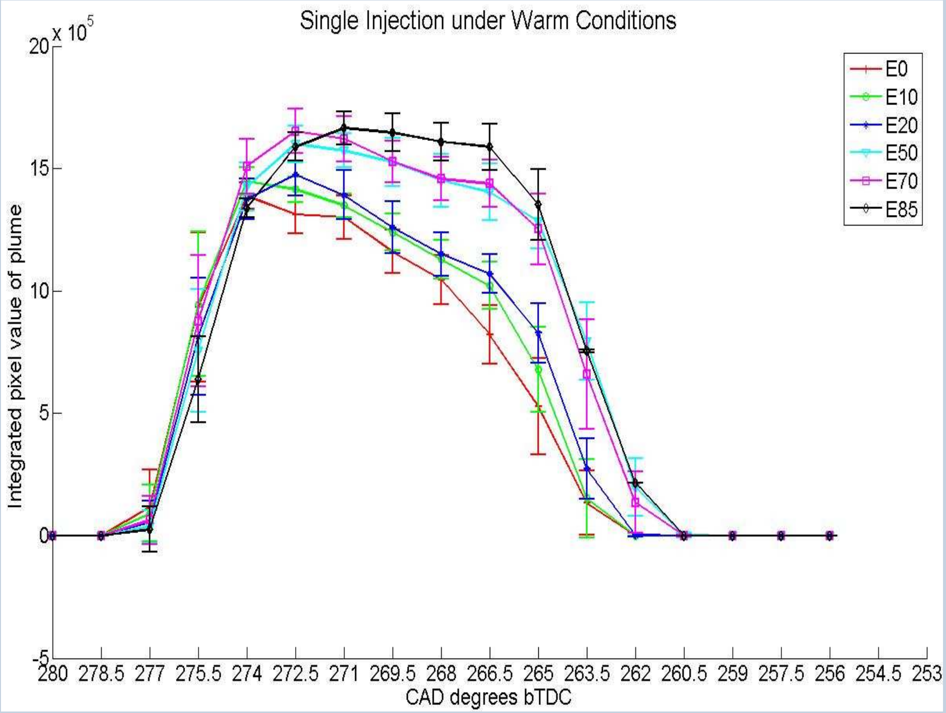
- Compared with 20ºC plumes, 80ºC plumes are less defined and have lower pixel intensity values;

- Spray area and evaporation duration increase as the ethanol content increases.



Results and Discussion – Spray Images



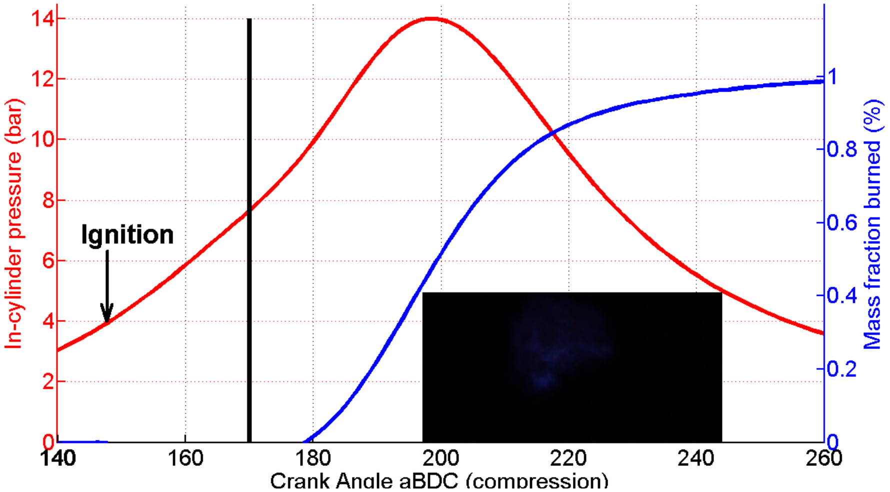


- In general, warm fuel plumes exhibit smaller integrated pixel values than cold plumes;
- The evaporation duration of warm plumes is shorter than for cold plumes;
- The spray duration increases as the ethanol content increases;
- Standard deviations in the ‘plateau’ region are always smaller than at both ends.

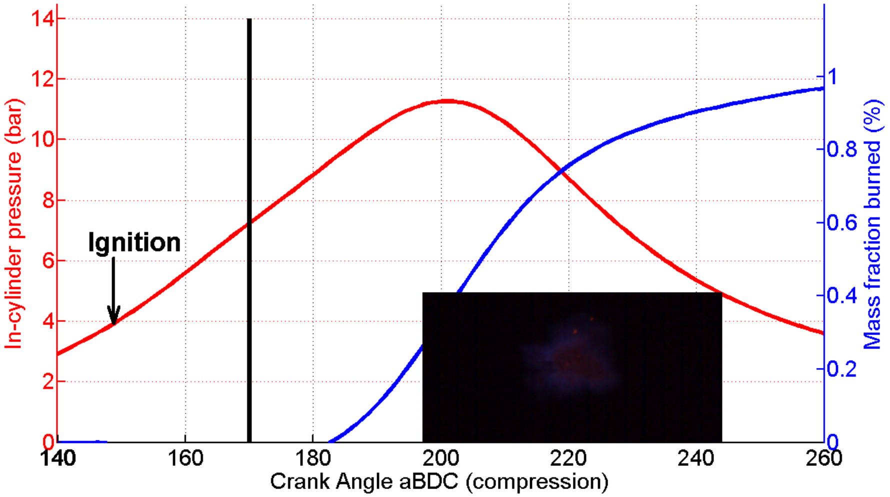
Results and Discussion – Combustion Images

- Chemiluminescence images from 170-222.5°aBDC in steps of 7.5°CA ;
- E0 images are chemiluminescence-dominated whist E85 exhibits soot-dominated (red spots) images;
- The images suggest that E85 produced more in-cylinder PM than E0, which is consistent with the DMS500 results.

E0, Warm

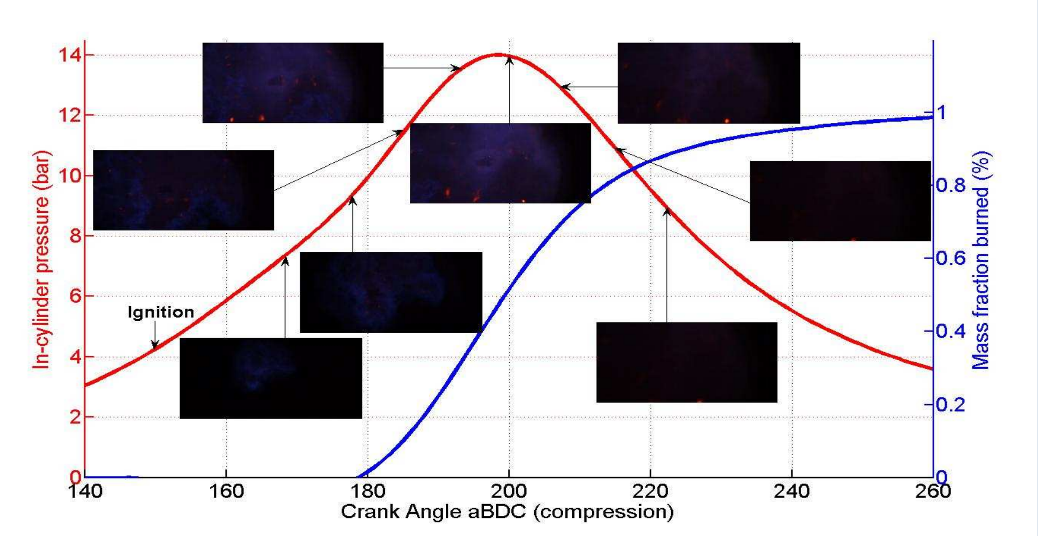


E85, Warm

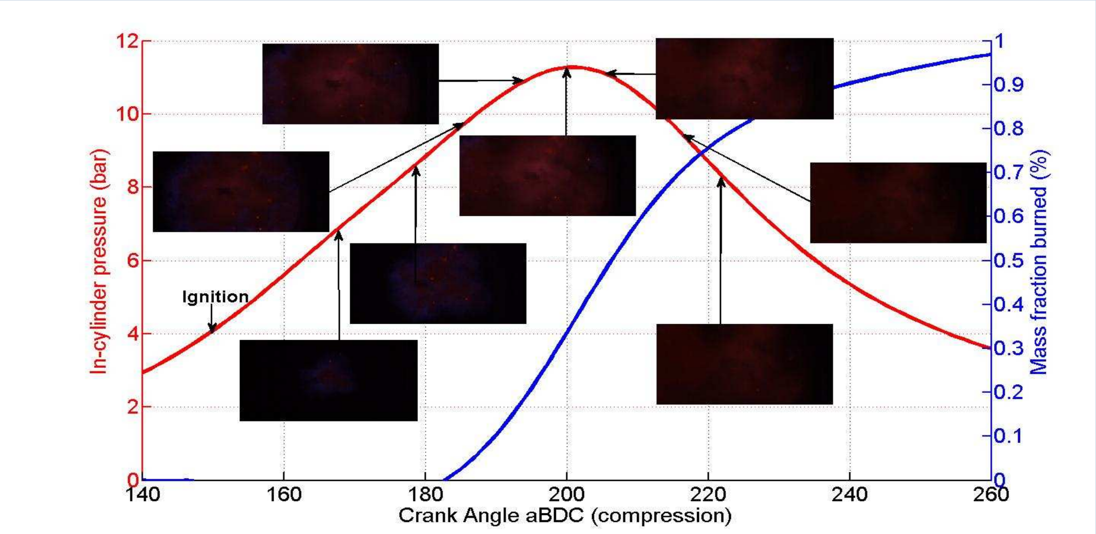


Results and Discussion – Combustion Images

E0, Warm



E85, Warm



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Results and Discussion – Mixture In-homogeneity

	Pura	E10	E20	E50	E70	E85
Cold	11.3%	12.1%	9.5%	13.0%	18.7%	34.9%
Warm	9.2%	11.2%	10.0%	9.7%	12.6%	20.7%

- The CoV of pre-flame fFID signals reflects the variability of pre-flame HC concentration;
- For E50-E85, increasing ethanol proportion led to an increase in [HC] variability; the trend is less clear with fuels with low ethanol proportions;
- In general, the cold engine exhibits higher [HC] variability than the warm one.

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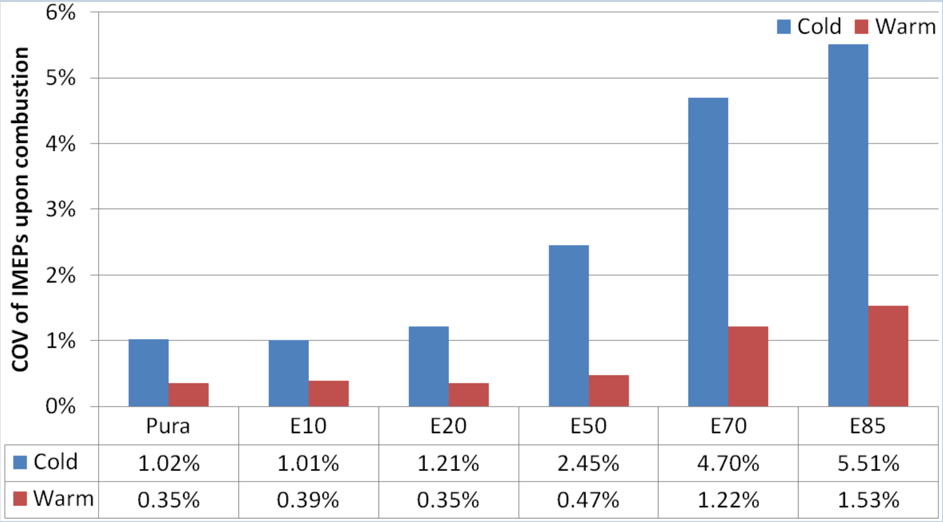
Results and Discussion – Combustion performance

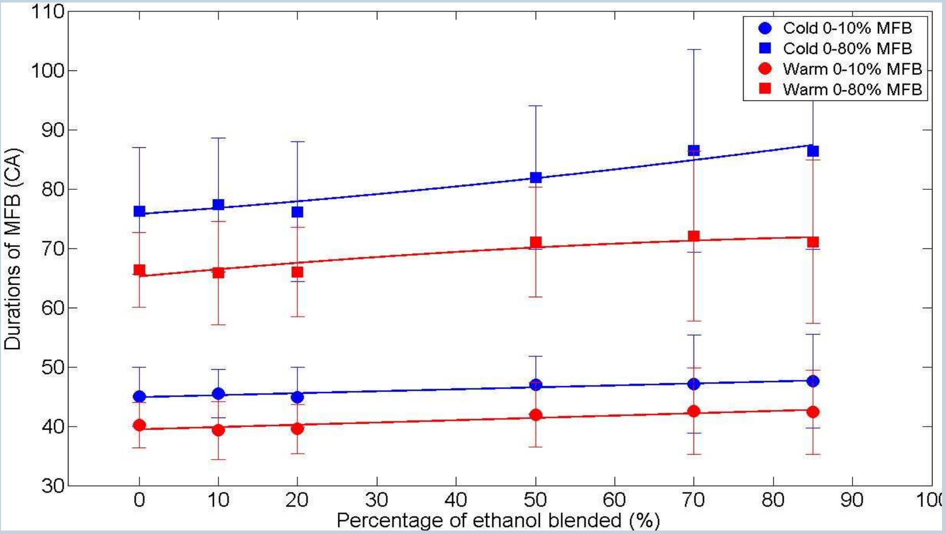
- The cold engine had a larger COV of IMEP than the warm engine by 3-4 times;

- In general, adding ethanol reduces combustion stability, especially for a cold engine;

- Adding ethanol slowed down the combustion process slightly and this trend is more clear for 80% MFB curves than for 10% MFB ones.



	Pura	E10	E20	E50	E70	E85
🟦 Cold	1.02%	1.01%	1.21%	2.45%	4.70%	5.51%
🟥 Warm	0.35%	0.39%	0.35%	0.47%	1.22%	1.53%



Summary

	Increasing coolant temperature (20 to 80ºC)	Increasing ethanol content (E0 to E85)
PM emissions	2-5 times lower for Pn and 2-3 times lower for Pm	6-15 times higher for Pn and 8-11 times higher for Pm
Spray characteristics	Faster evaporation and stronger break-up	Slower evaporation and less spray break-up
Mixture homogeneity	Increased mixture homogeneity	Decreased mixture homogeneity
CoV of IMEP	Decreased	Increased, especially with a cold engine

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