EURENCO
IGNITE YOUR AMBITIONS

How to give a chemical push to ammonia in a compression ignition engine?

The storyboard

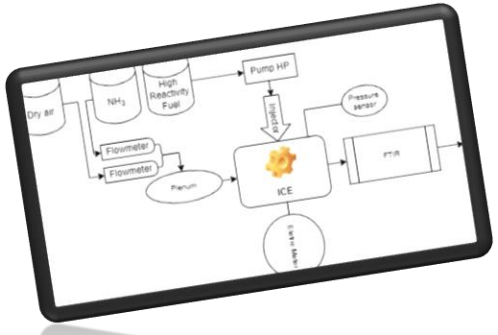
Our expertise in combustion led us to examine the possibilities to help Ammonia in a compressive Ignition

➔ the Additives

Start of our project: tests on Rapid Compression Machine

➔ Conclusive!

Move to tests on Research engine with additive in pilot (and ammonia at admission)



➔ Additive in pilot makes combustion happens where it would otherwise misfire

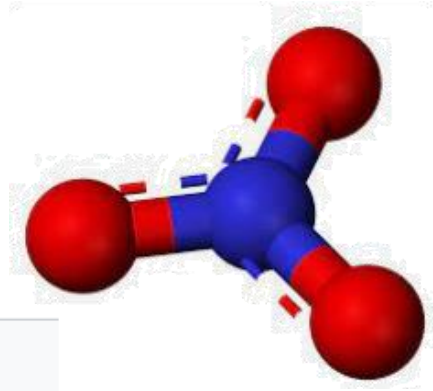
➔ Additive in pilot improves pressure & Heat release in cylinder

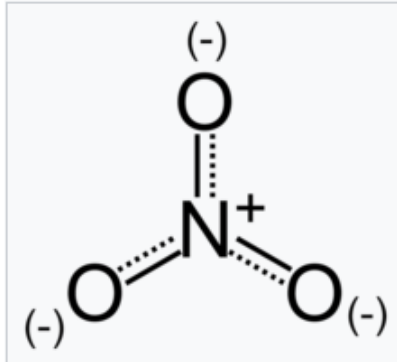
➔ Additive in pilot improves energetic efficiency during combustion cycle

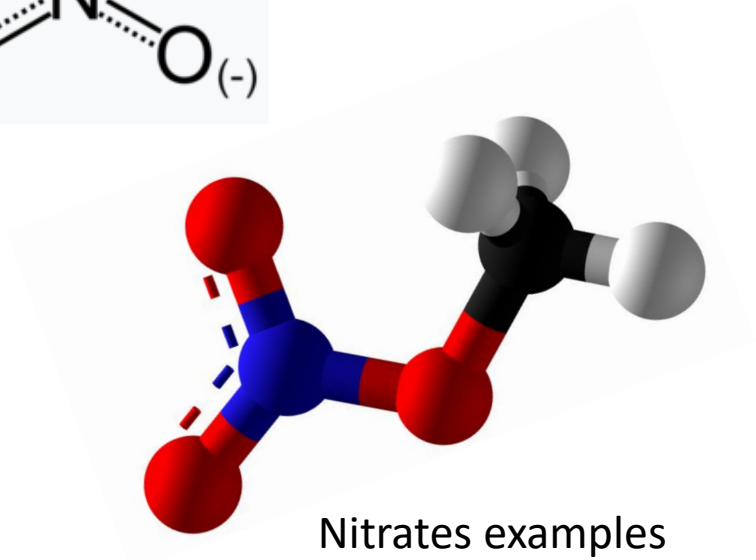
The additives

- **One of our company's expertise is nitration**
- **Biggest maker of a 2-Ethylhexyl nitrate used to improve Diesel fuels ignition**
  - we have technical understanding of mechanisms this type of additives have with HC based fuels
- **Developed nitrates based products to enhance combustion of emerging renewable fuels:**
  - Bio-sourced
  - Was first targeting MeOH
  - Called "CEN" for Combustion Enhancer Nitrate
- **Have a working partnership with the Prisme Lab in Orléans developing expertise on ammonia engine**
  - We tried the developed product on Ammonia « just to try »

➔ Results started this whole project for us

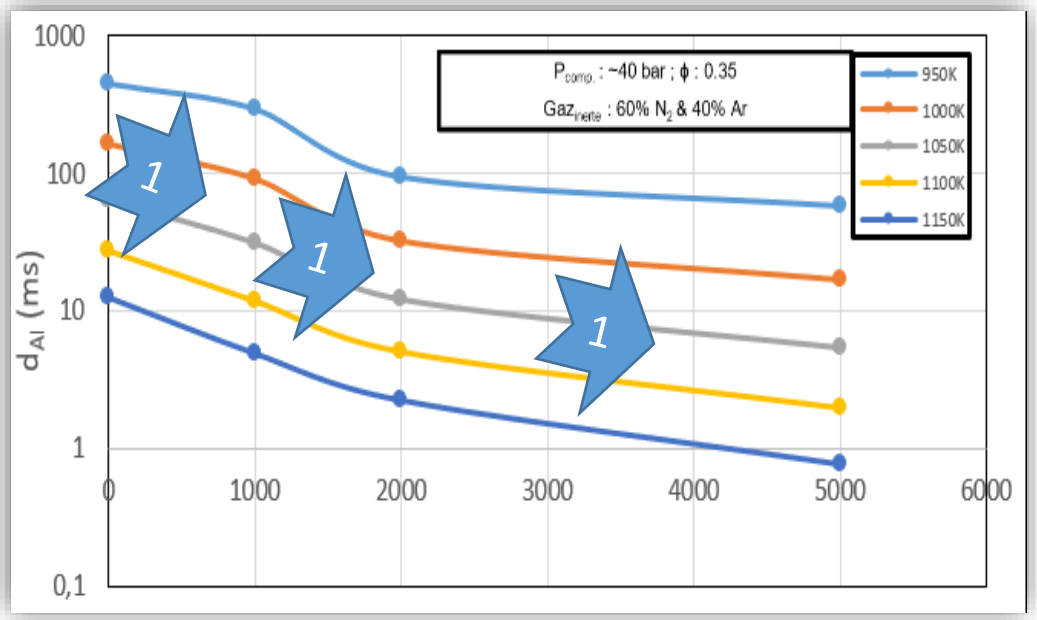


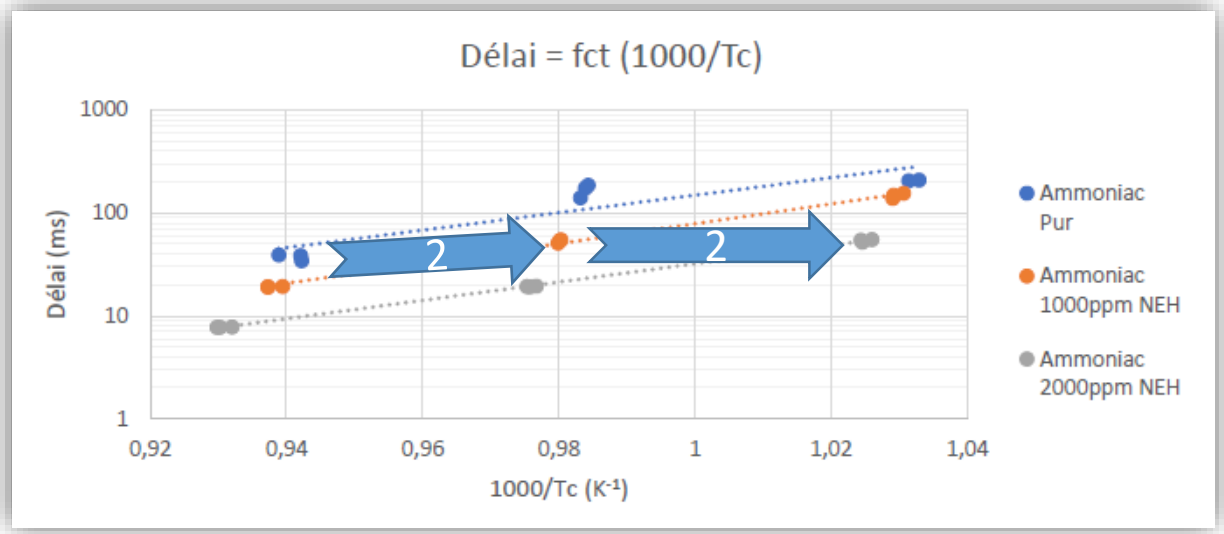




Nitrates examples

Initial results: Rapid Compression Machine





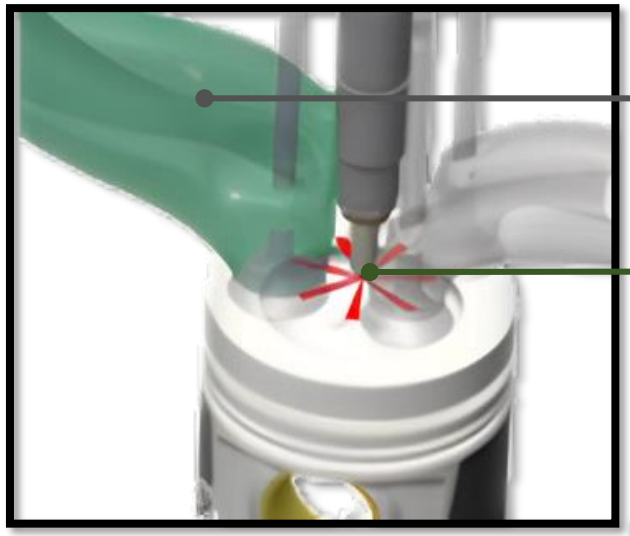
1. With additive reduction of ignition delay regardless of ignition temperature

2. With additive decrease of ignition temperatures

- Measures ignition delay of a combustible mixture
- Additive is mixed directly to NH_3
- Left: X axis ➔additive in ppm (weight)
- Right: X axis reverse intake temperature
- Pressure is at 40 bars to have ignition of ammonia w/out additive at any temperature

CEN on DICI : Ammonia

- **Gaseous admission of Ammonia through intake**
- **Injection of a two types of pilot fuels with or without additives**



Low Reactivity Fuel : NH_3 (+ Air) — 98% energetic

Reactivity Fuel : $C_{12}H_{26}$ or HVO **+ CEN**
CEN : 0 – 1 – 10% volume fraction of HRF — 2% energetic

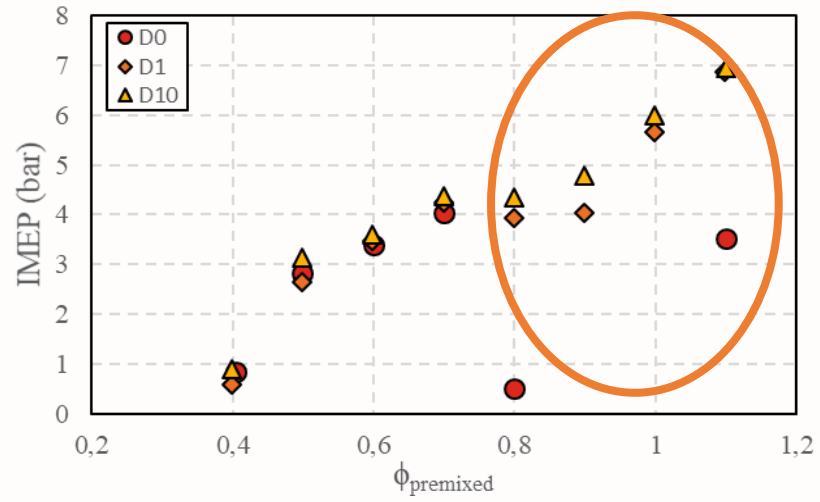
Fuels properties

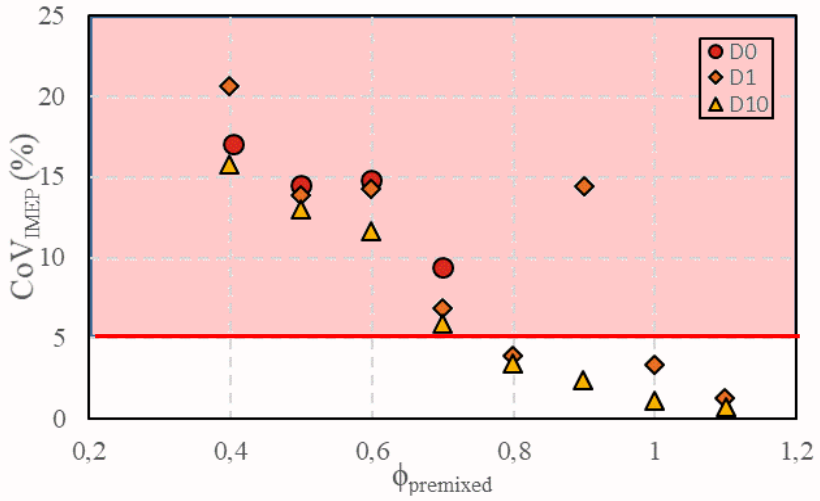
	Ammonia	Dodecane	HVO	CEN
Chemical Formula	NH_3	$C_{12}H_{26}$	~ $C_{12}H_{26}$	-NO_3*
Density *(g/L) – Std conditions*	0.730_{gas}	750_{liquid}	785_{liquid}	~950_{liquid}
Molar mass *(g/mol)*	17	170	~ 170	-*
Cetane number	<5	73	-	-
Lower Heating Value *(MJ/kg)*	19	45	44	~ 30*

Blends (vol%)

	Dod.	HVO	CEN
D0	100		0
D1	99		1
D10	90		10
H0		100	0
H1		99	1
H10		90	10

Fuel/air ratios & IMEP



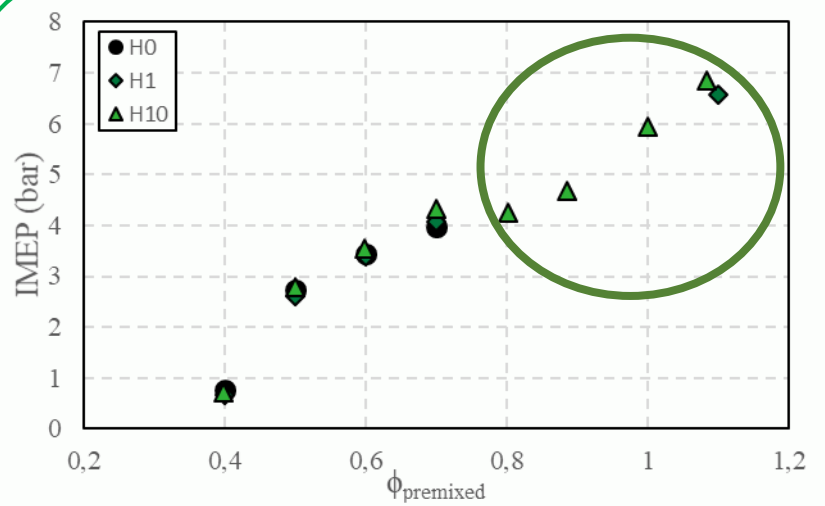


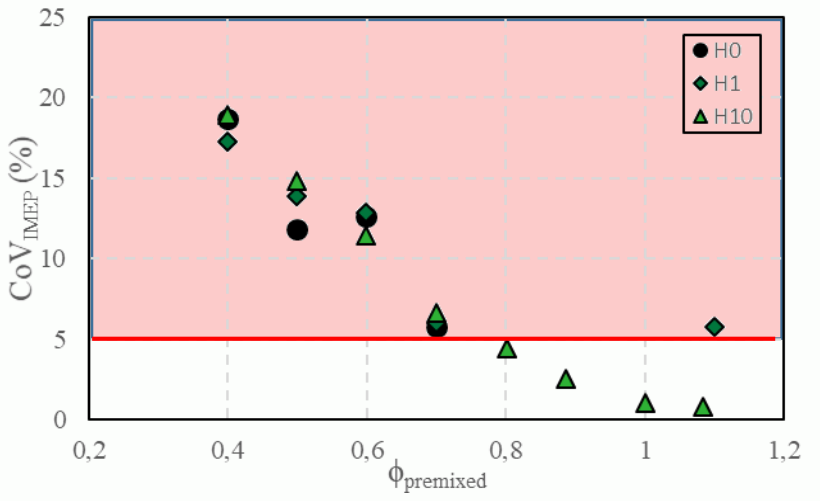
Dodecane

Unstable combustion at low F/A Ratio

Blends (vol%)	Dod.	HVO	CEN
D0	100		0
D1	99		1
D10	90		10
H0		100	0
H1		99	1
H10		90	10

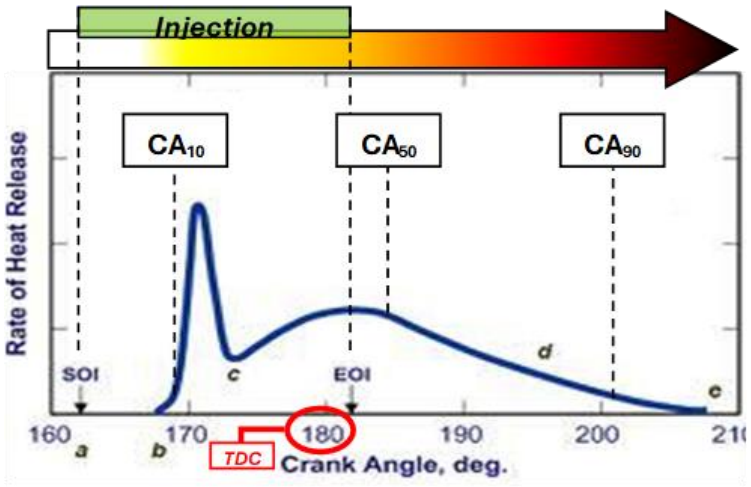
Stability (CoV<5%) gained with F/A ratio > than 0,7





HVO

Misfiring zones: F/A >0,7



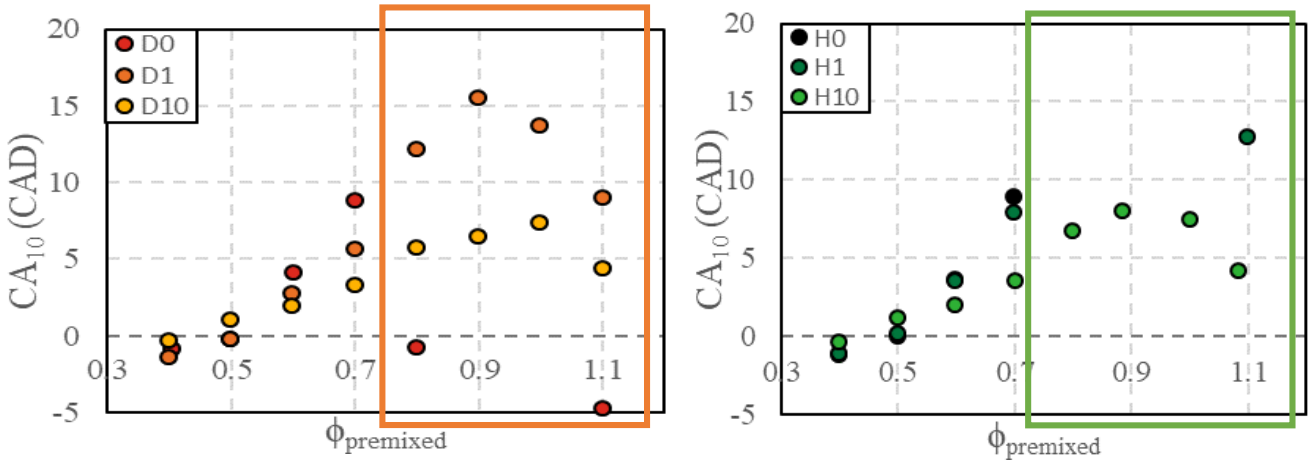
At F/A ratio above 0,7

No combustion with pilot fuels not containing the additive

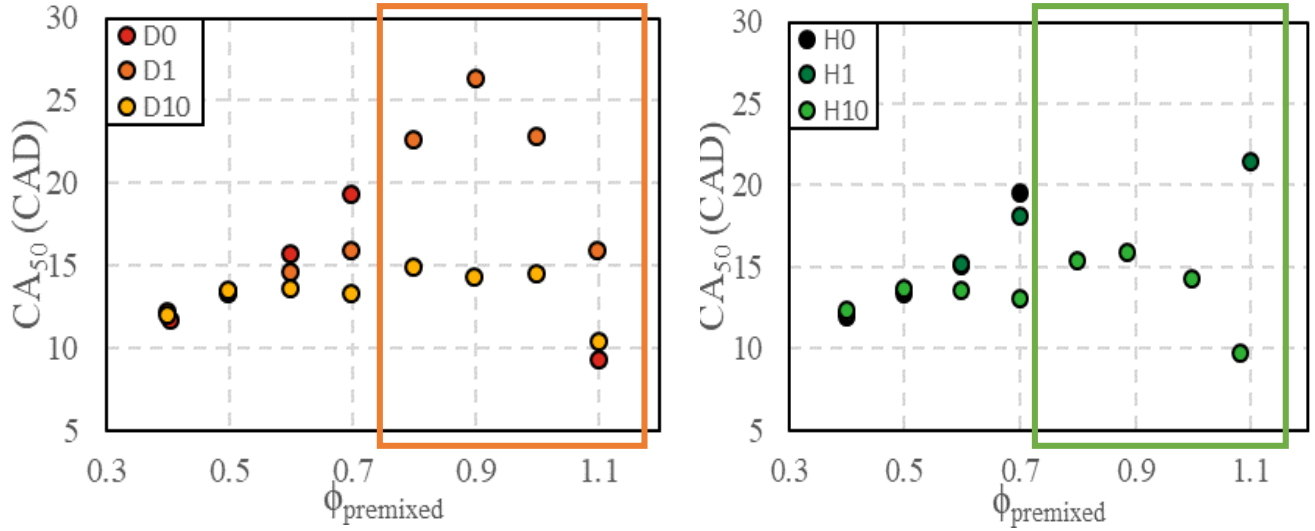
For HVO even requires 10% additive

➔ The additive effect does not pertain to ignition enhancement of the pilot fuel

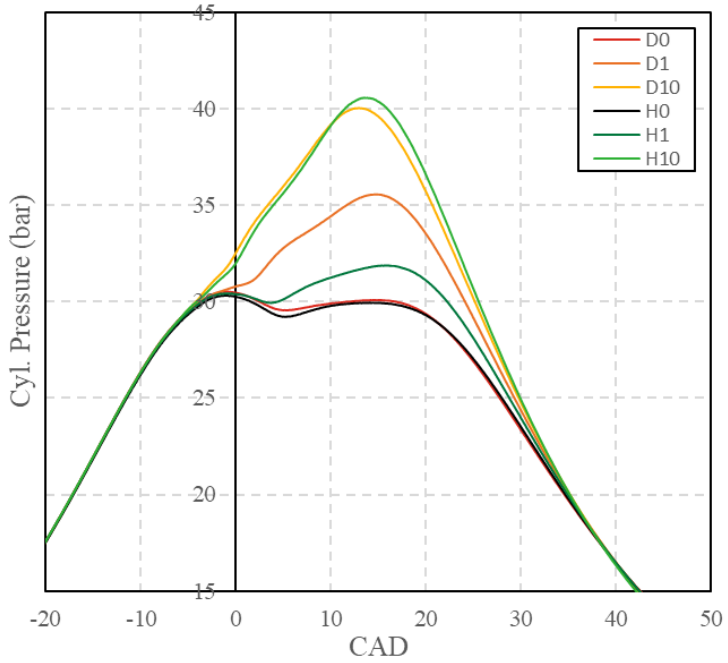
CA_{10}

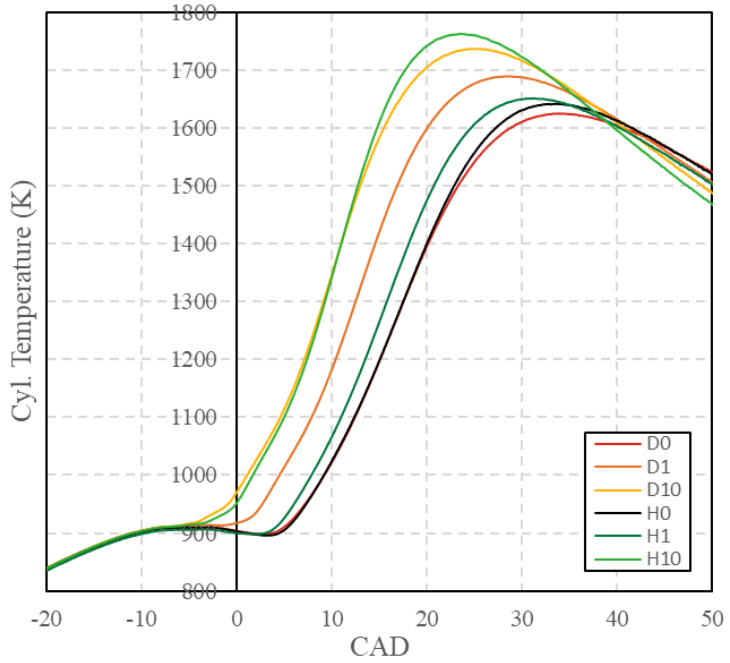


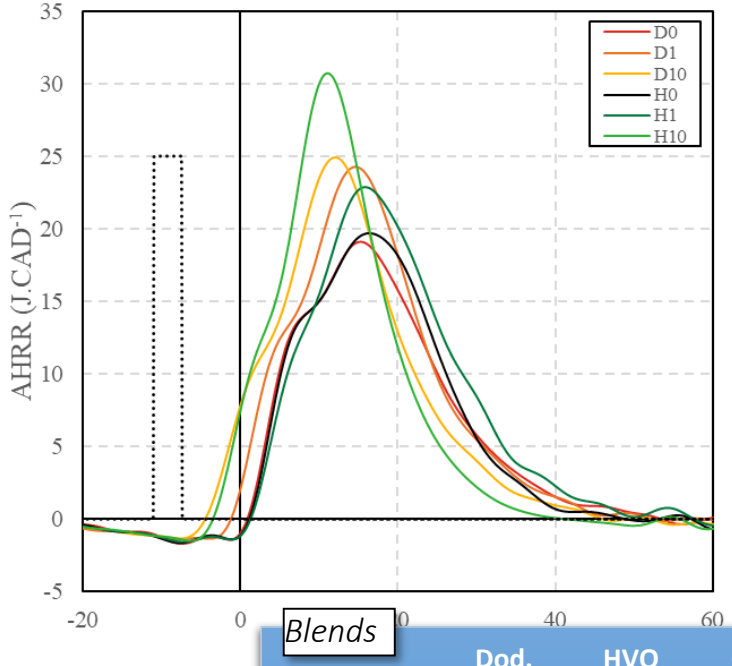
CA_{50}



Cycles IMEP 4 bar- F/AR 0,7







Very visible different behavior of NH_3 in the combustion chamber when the pilot contains the additive:

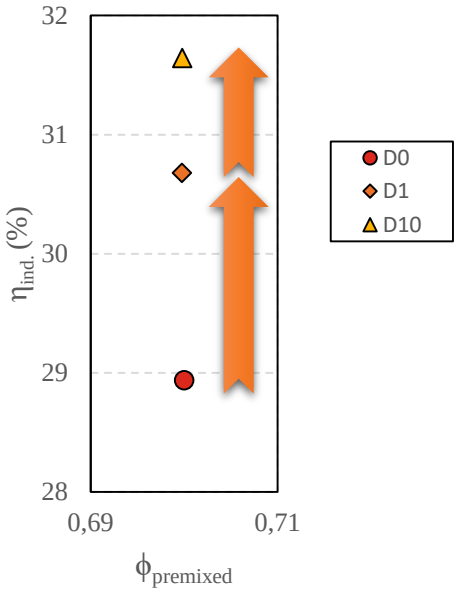
- ➔ Higher $P_{cylinder}$
- ➔ Higher $T_{cylinder}$
- ➔ Better AHRR (for slightly longer combustion event)

Blends

	Dod.	HVO	CEN
D0	100		0
D1	99		1
D10	90		10
H0		100	0
H1		99	1
H10		90	10

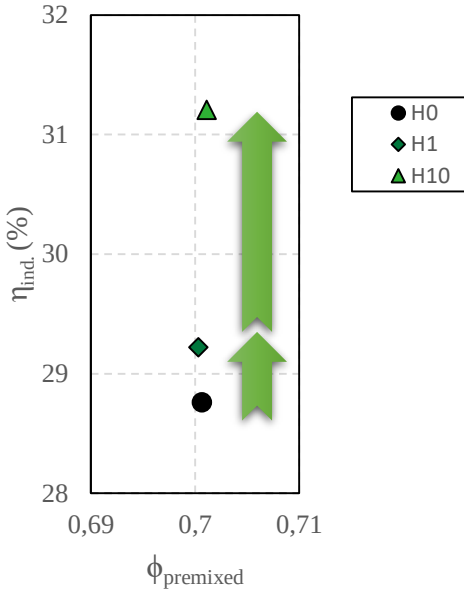
Indicated Thermal Efficiency

2,9% ITE gain with additive in pilot fuel



Increased ITE with usage of additive in both pilot fuels

Activity is different from one pilot to other



2,5% ITE gain witha additive in pilot

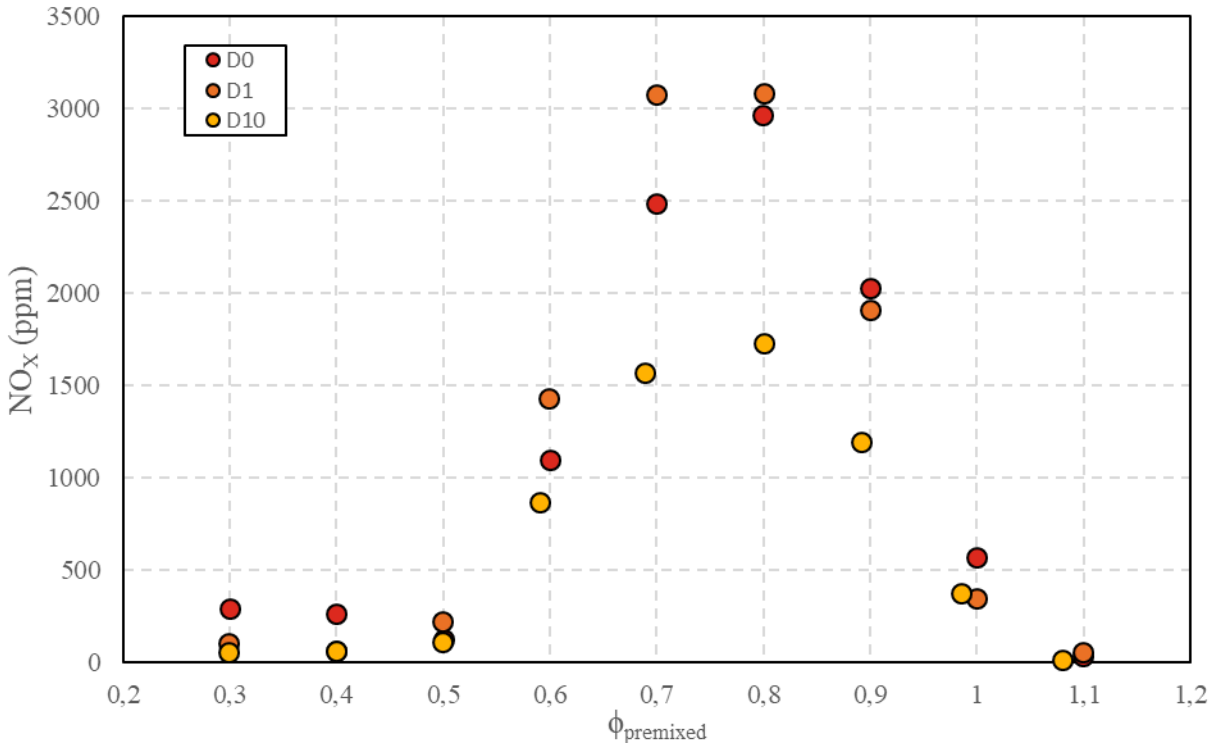
With Dodecane

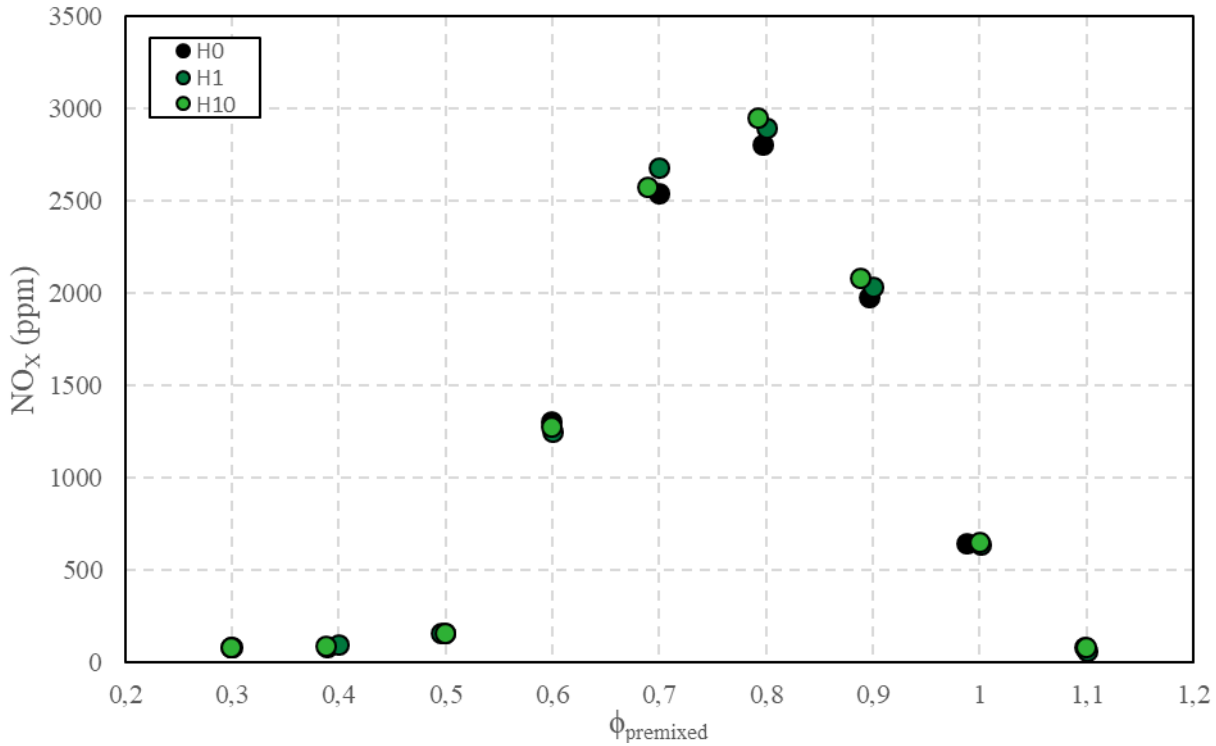
- **Gain of about 1,9% with 1% additive**
- **+ 1 more % with 10% additive**

With HVO

- **Gain of about 0,5%with 1% additive**
- **+ 2 more % with 10% additive**

Emissions: NOx 12 bar IMEP

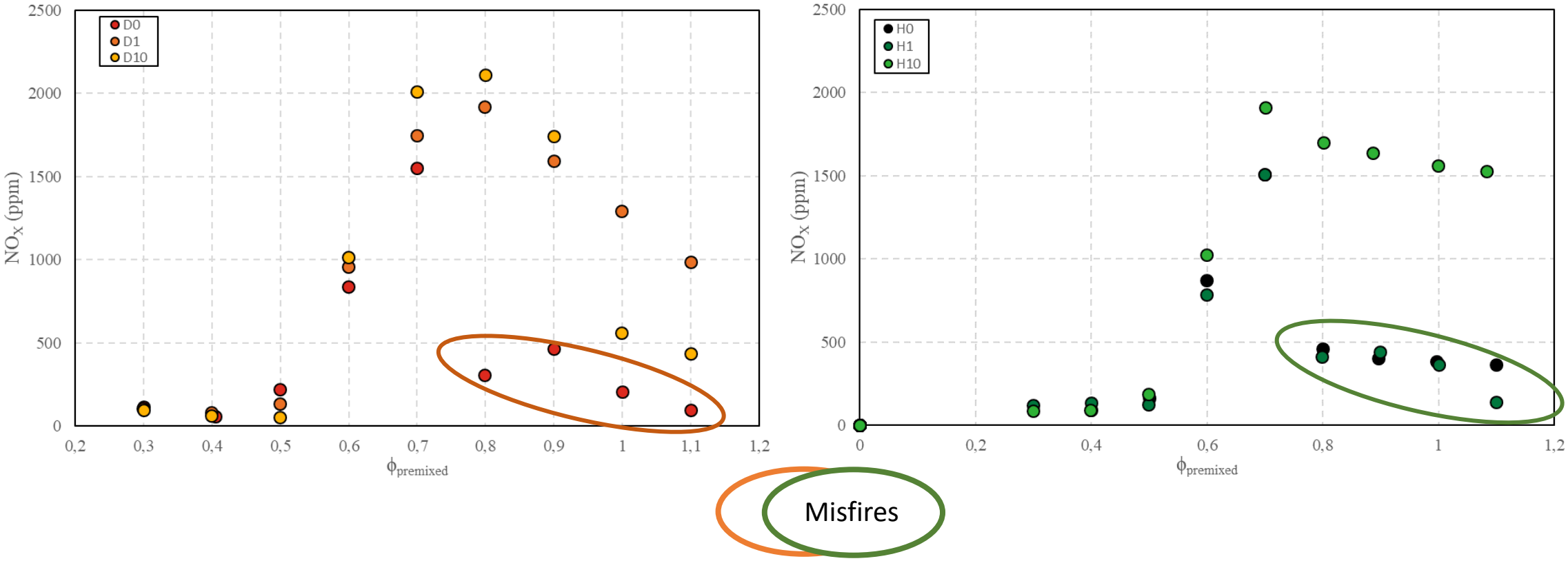




At high IMEP, no sign of help from the additive on NOx reduction for HVO

At high IMEP, in misfiring areas clear reduction of NOx emission, by having additive in dodecane

Emissions NOx
4 bar IMEP



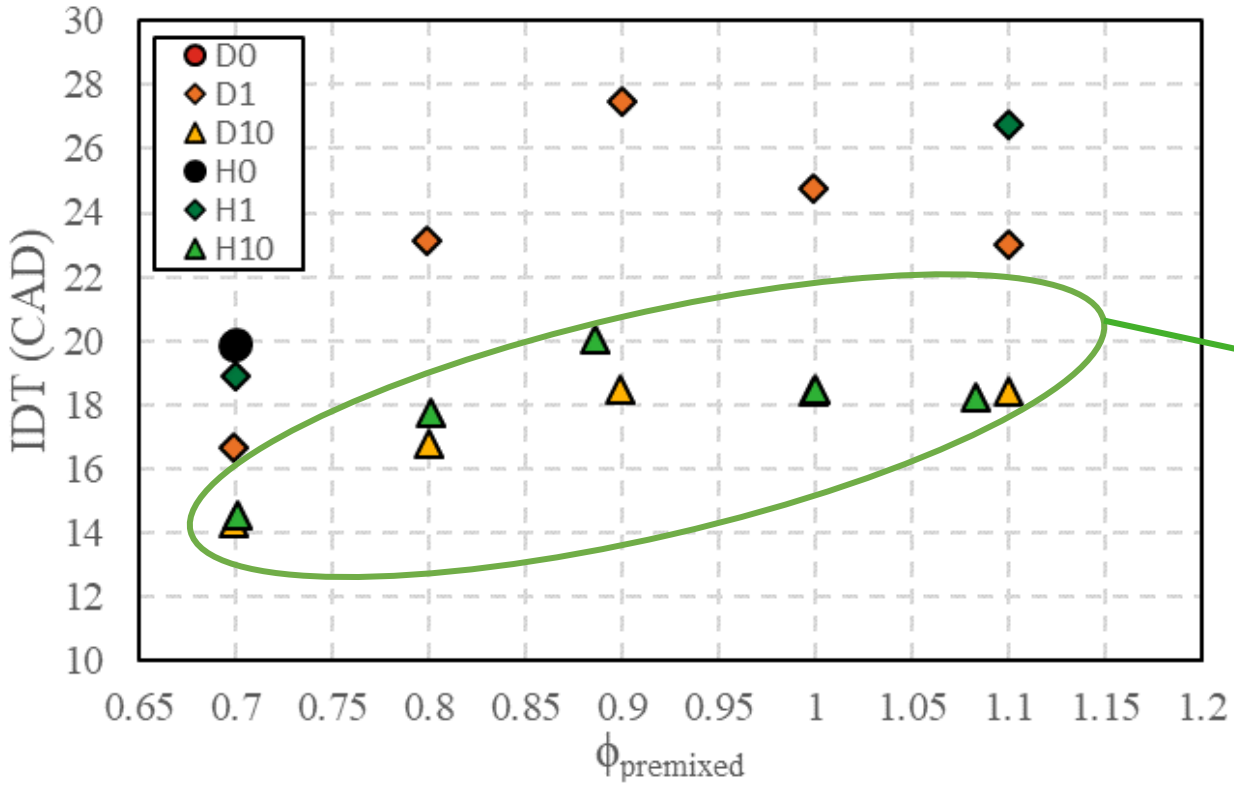
At Low IMEP, clear help from the additive on NOx reduction for HVO at higher F/A

At Low IMEP, slight Increase of NOx with the additive for Dodecane at higher A/F

Impossible to directly conclude on impact of additive on NOx emissions

Conclusion 1: Ignition

CEN addition in the pilot fuel promotes the inflammation and the combustion (CA_{10} → IDT).

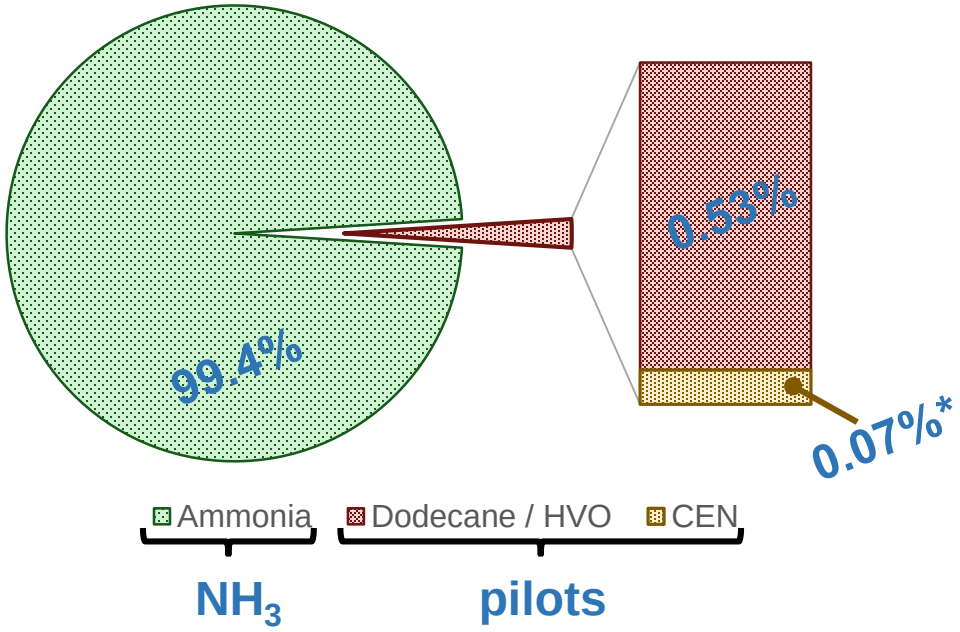


10 vol % additive in pilot= <0,1% of total mass of fuels

Usage of additive

Less than 0,1 mass % of CEN give a significant chemical push to ammonia in a Compression Ignition situation

Fuel mass ratios

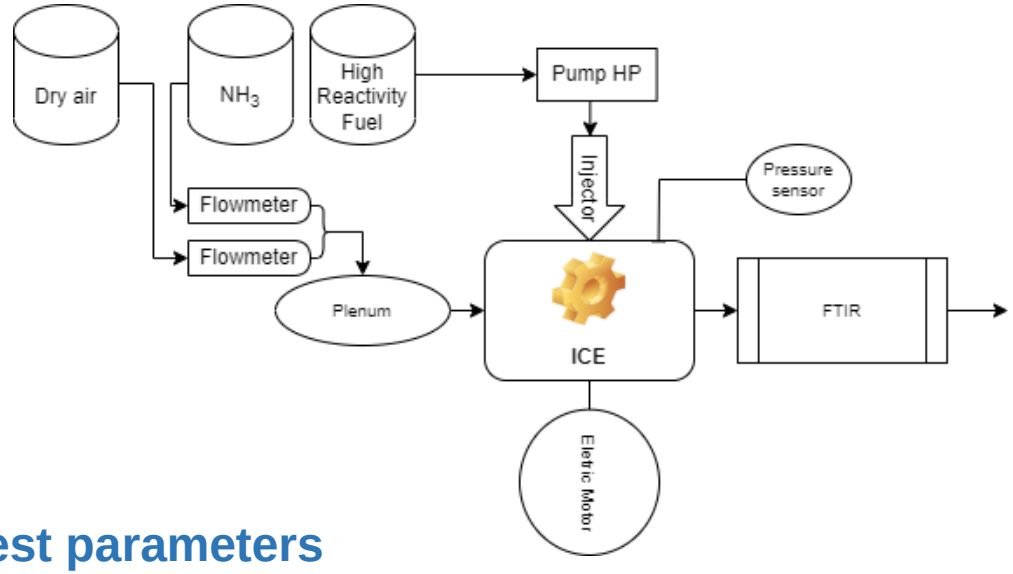


*10%$_{vol.}$ in pilot(s).

Annex

Description of engine

Engine installation



Engine configuration

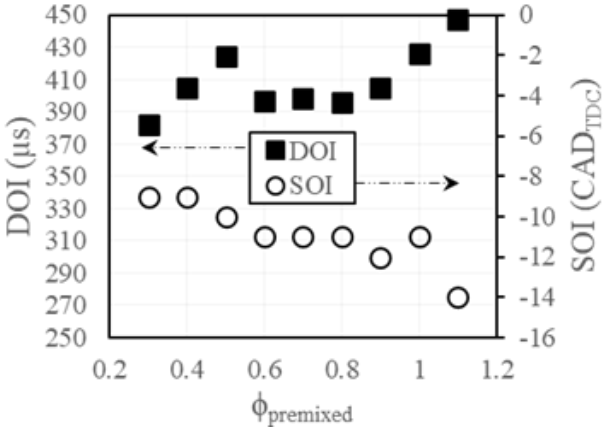
Engine (single-cylinder)	DW10F
Displaced Volume (cc)	499
Stroke (mm)	88
Bore (mm)	85
Compression Ratio	16.4 : 1
Number of Valves	4
Speed (rpm)	1500
Number of nozzle holes (Injector)	7

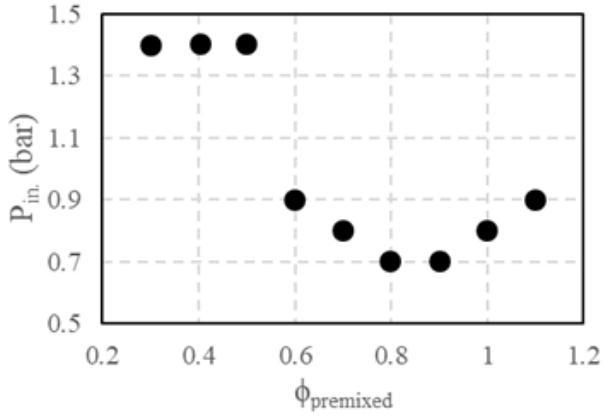
Test parameters

Parameters	Value
$P_{in.}$ (bar)	Variable
$T_{in.}$ (°C)	80
$P_{inj.}$ (bar)	200
DOI (µs)	Fct of $\frac{e_{LRF}}{(e_{LRF}+e_{HRF})} = 0.98$
SOI (CAD)	Copied from previous tests [4]

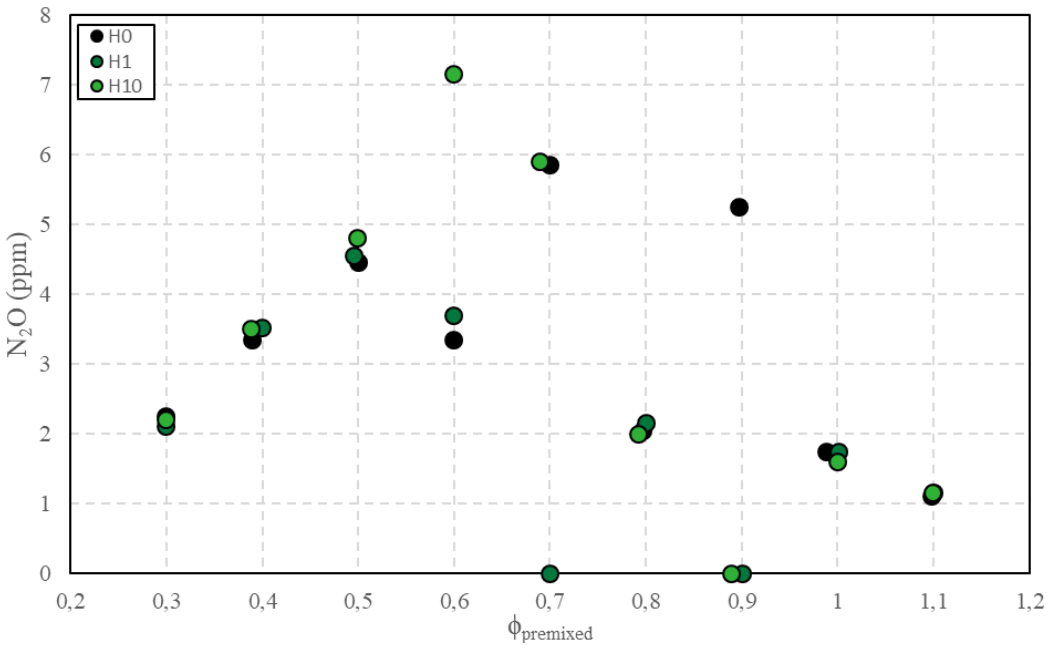
[4] : *Experimental study of RCCI engine – Ammonia combustion with diesel pilot injection, A. Dupuy et al., 2023*

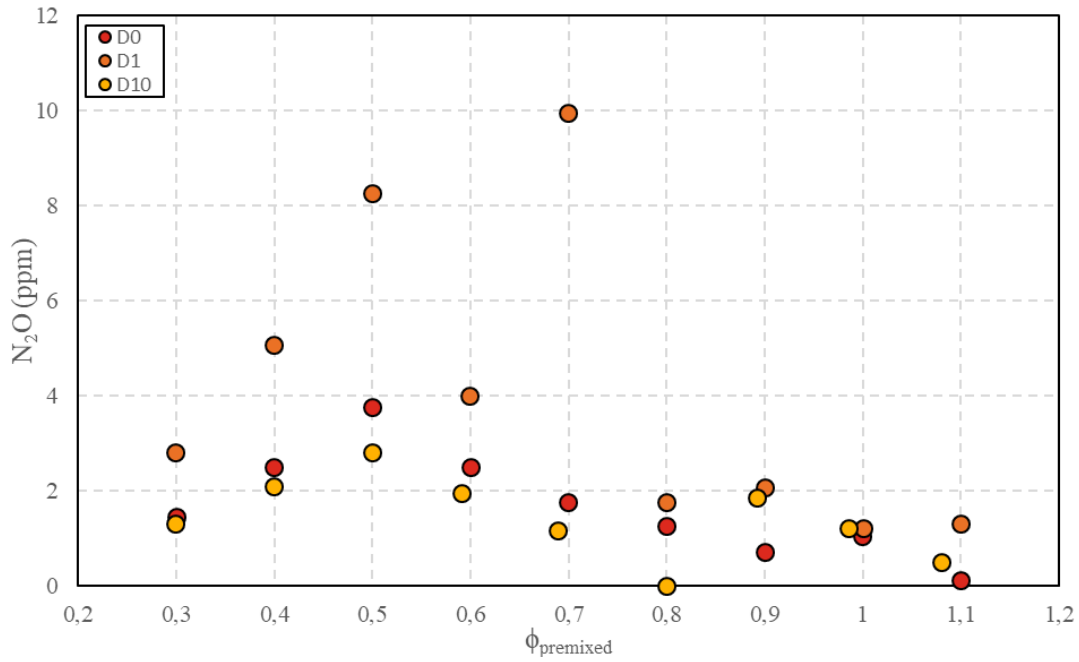
Injection and intake port parameters (IMEP : 4bar)





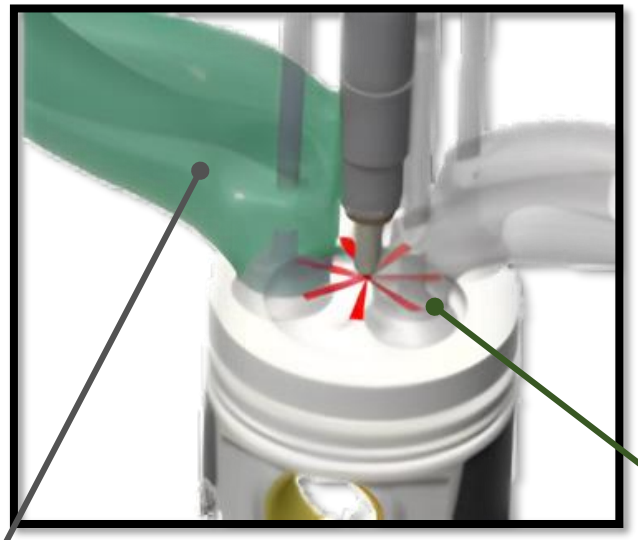
N_2O emissions





Low N_2O emissions, difficult to conclude as the levels are too low for the detection limit

Testing points



- **For different air-fuel equivalence ratios (AFR)**
- **Expose performance of base LRF/HRF blends**
- **Add CEN to show effects on performance (and combustibility)**

- ***All tested points are comparable in terms of introduced quantities.***