Comparative Investigation of Spray Formation, Ignition and Combustion for LFO and HFO at Conditions relevant for Large 2-Stroke Marine Diesel Engine Combustion Systems

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Outline

Background and Introduction

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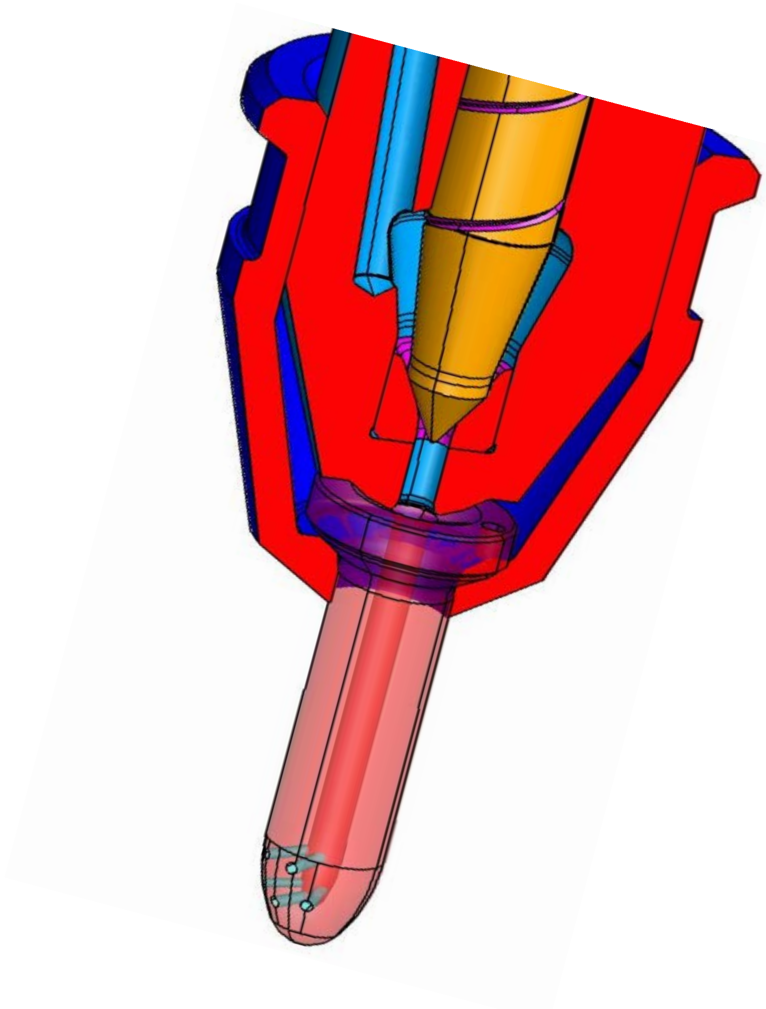
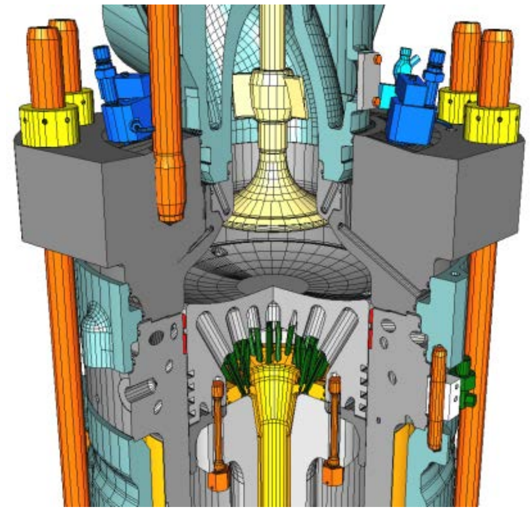
Background and Introduction

Large (2-stroke) Marine Diesel Engines





- Dimensions (up to 96 cm bore)
- Low-Speed (61 – 167 rpm)
- Swirl (uniflow scavenged, tilted inlet ports)
- Injection (peripherical, multiple orifice)
- Large p-, T-levels (13 MPa / 900 K)
- Range of fuel qualities (HFO, MDO, LFO)

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Background and Introduction

Diesel Combustion Process

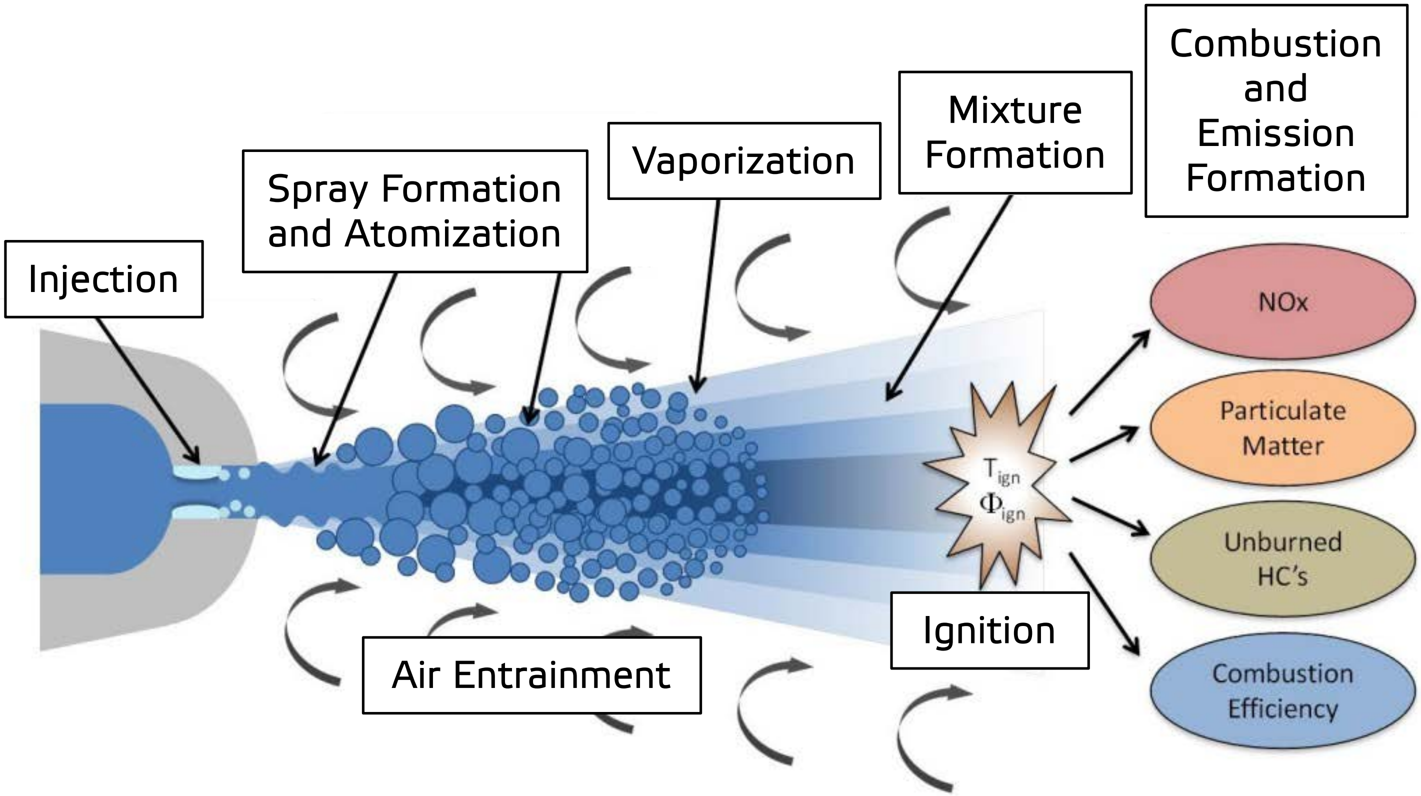


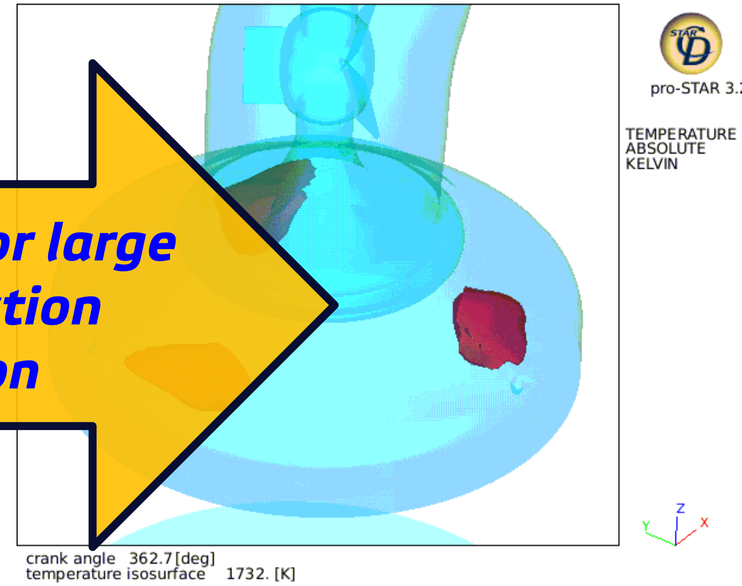
Illustration: Spray Physics and Engine Research Lab, Georgia Tech, Atlanta, USA

Background and Introduction

Development and Optimization of the Combustion System

Test Engine (RTX-4)

Reference experiment for large diesel engine combustion system optimization



Spray / Combustion Simulation

Spray Combustion Chamber

Experimental Setup

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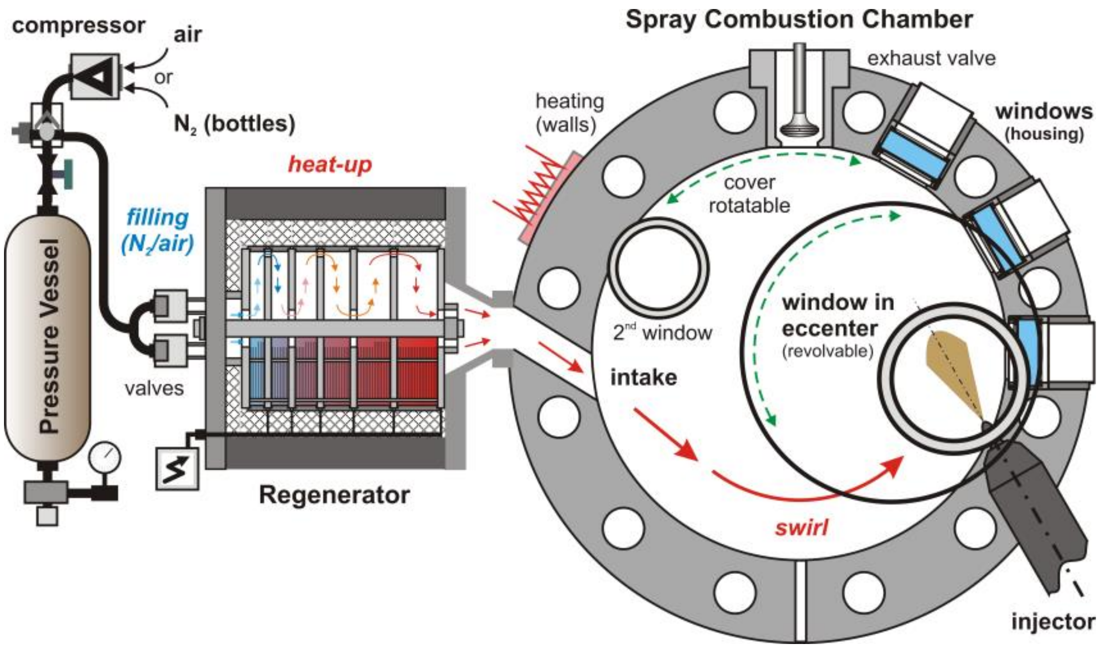
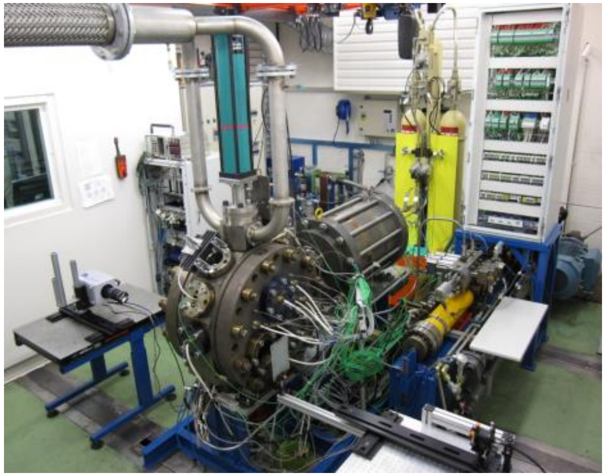
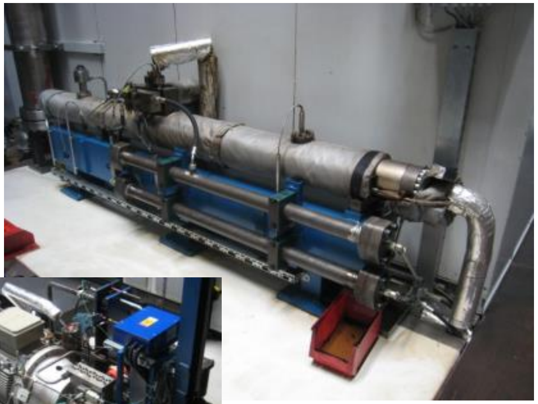
Experimental Setup

Spray Combustion Chamber Concept



- Dimension: Ø 500 x 150 mm
- Optical Access: Ø 150/100/65 mm sapphire windows
- Specifications: p_{SCC} ≈ 20 MPa; T > 900 K
- Swirl: ca. 10 - 20 m/s (ω ≈ 75 rad/s)
- Process gas: Air / N_2
- Injector: RT-flex50 Injector
- Injection system: p_{max} = 120 MPa





HFO Injection System

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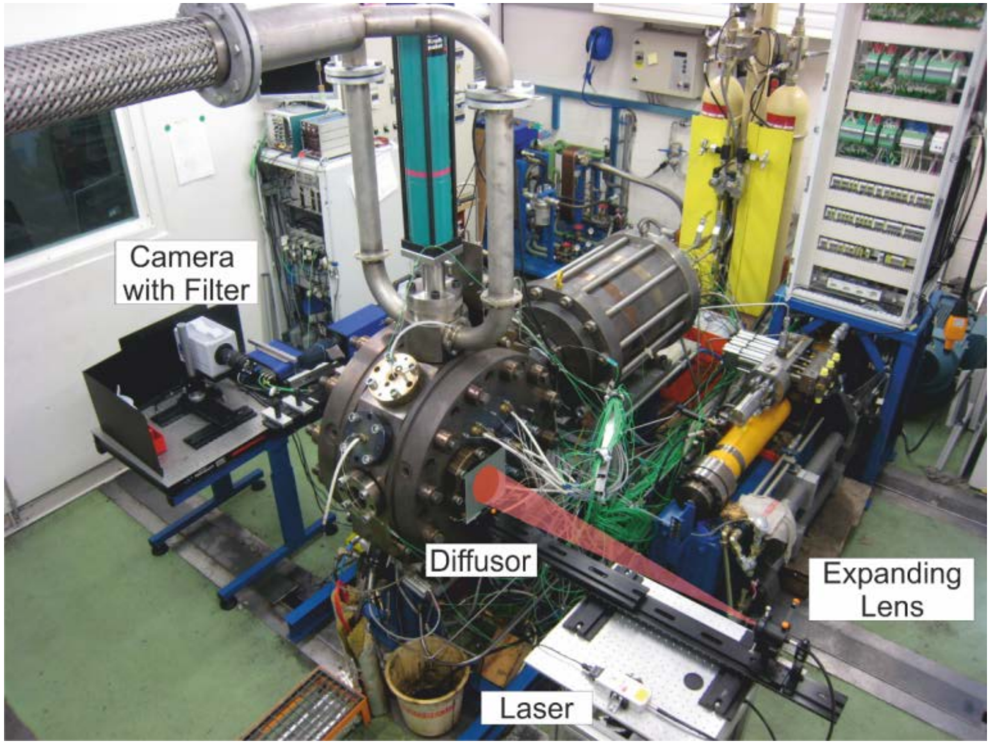
Spray Formation & Morphology

Spray Formation & Morphology

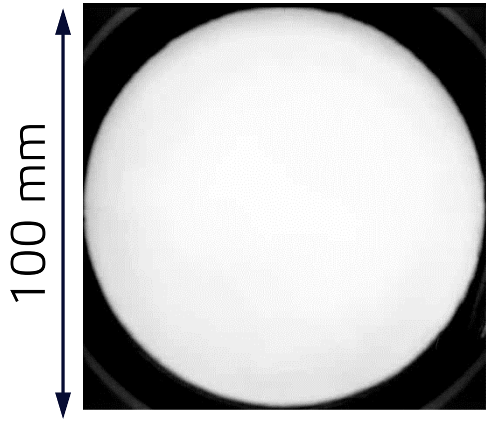
"Improved" Shadow-Imaging Setup (Diffused Back-Illumination)



- Light Source: pulsed laser diode 690 nm
- Filter: CWL 689.1 nm, T 60%
- Recording rate: 20 kHz (512 x 512 pixel)
- Exposure time: 1 µs
- Laser pulse: 50 ns

9 MPa / 900 K

4 MPa / 400 K



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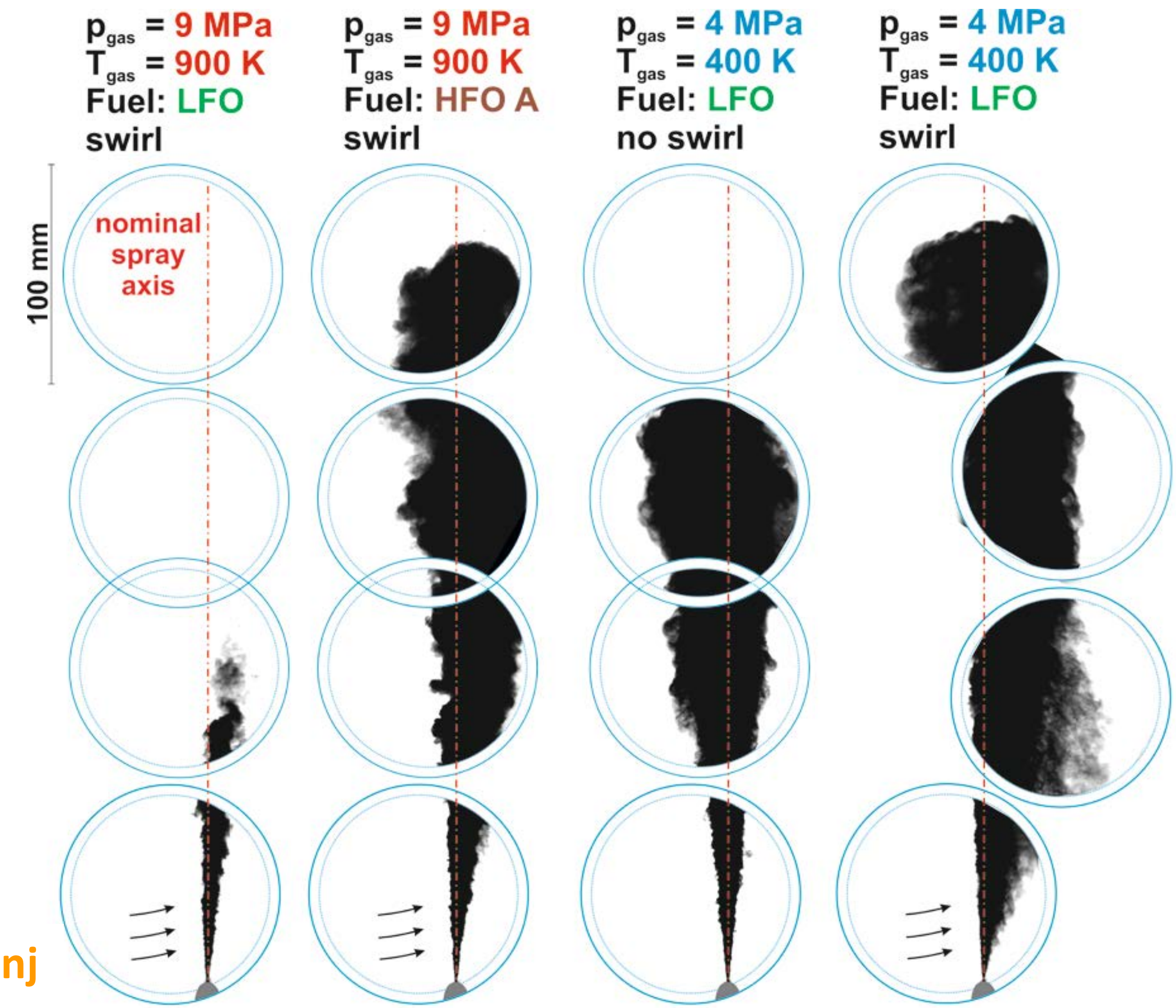
Spray Formation & Morphology

Spray Evolution (Assembled)



Ca. 6ms aSOInj

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Spray Formation & Morphology

Marine Diesel Fuel

LFO

HFO

- HFO is generally more complex in composition and impurities than distillate fuels (LFO)
- HFO consists of longer HC-chains
- HFO has increased density and viscosity (orders of magnitude)

Properties	Unit	LFO	HFO A	Method
Density at 15ºC	kg/m³	851.4	1001.1	ISO 12185
Viscosity at 40ºC	mm²/s	2.928	-	ISO 3104
Viscosity at 50ºC	mm²/s	-	1255	ISO 3104
Gross Heat of Combustion	MJ/kg	45.02	42.74	ASTM D240/D4809
Surface Tension at 20ºC	mN/m	30.9	38.2	EN 14370 / HFO: calc. *
Flash Point	ºC	58	103	ISO 2719
Pour Point	ºC	<-6	6	ISO 3016
Calculated Cetane Index	-	47	(21)	ASTMvD976
Pseudo-critical Temp.	K	727.7	985.7	Calc. *
Pseudo-critical Pressure	bar	19.05	9.29	Calc. *
Marine Fuel Specification		DMX	RMK	ISO-8217

**P. Kontoulis, D. Kazangas, and L. Kaiktsis. A new model for marine Heavy Fuel Oil thermophysical properties: validation in a constant volume spray chamber. Chania, Greece, Sept. 2013.*

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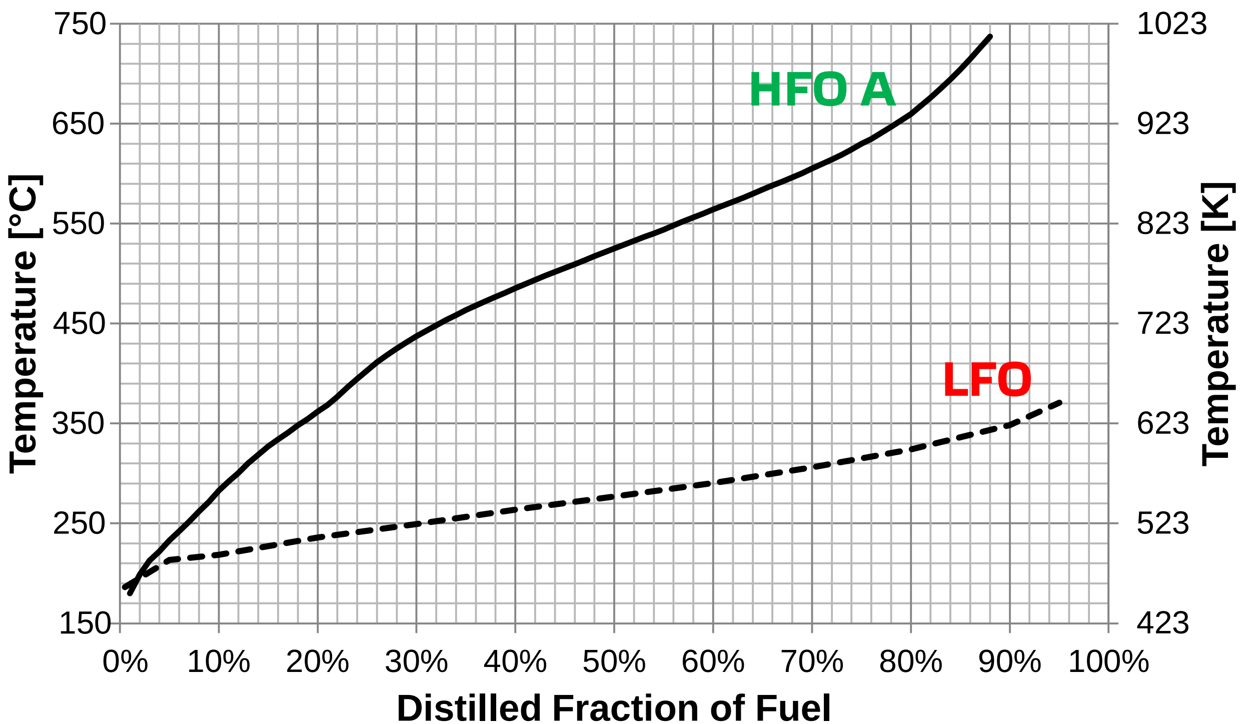
Spray Formation & Morphology

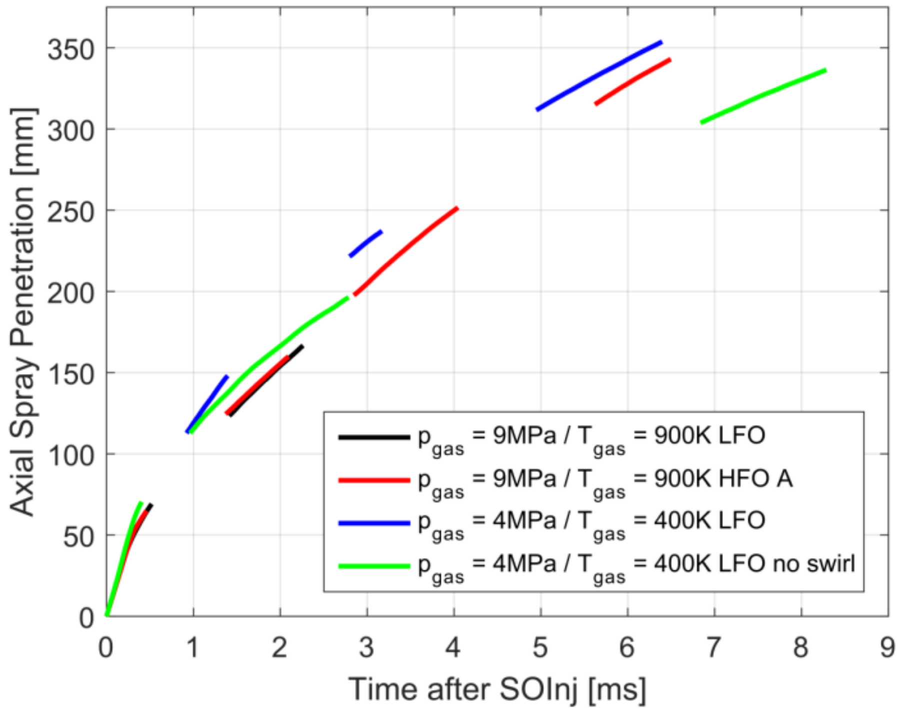
Marine Diesel Fuel



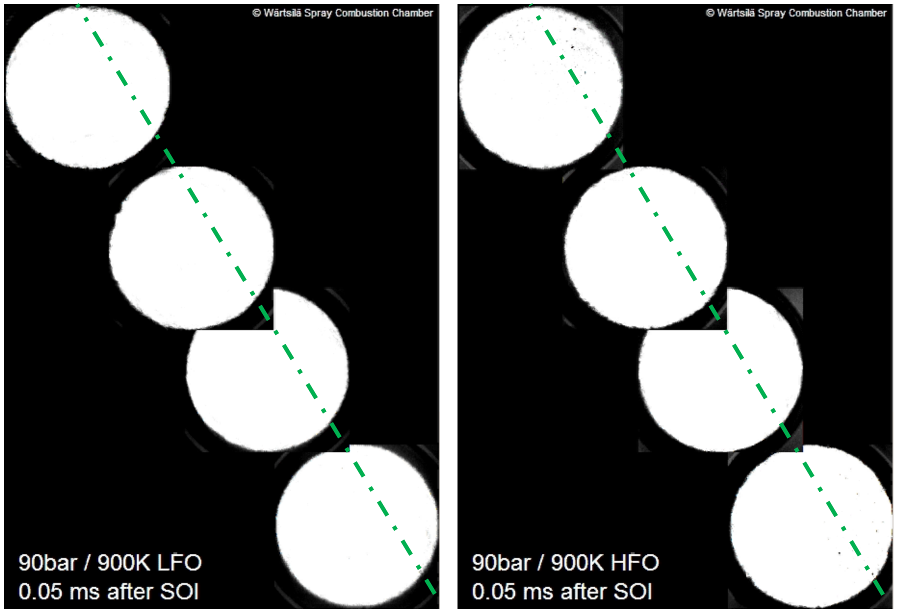
- Clear difference in evaporation behaviour due to fuel composition
- HFO A higher amount of high-boiling components

Spray Formation & Morphology

Spray Penetration



9 MPa / 900 K non-reactive (N_2)



LFO **HFO**

Penetration length (spray contour):

- Further spray propagation of HFO
- Faster penetration of non-evap. Sprays in the beginning
- Afterwards additional swirl momentum acting on the spray recognizable

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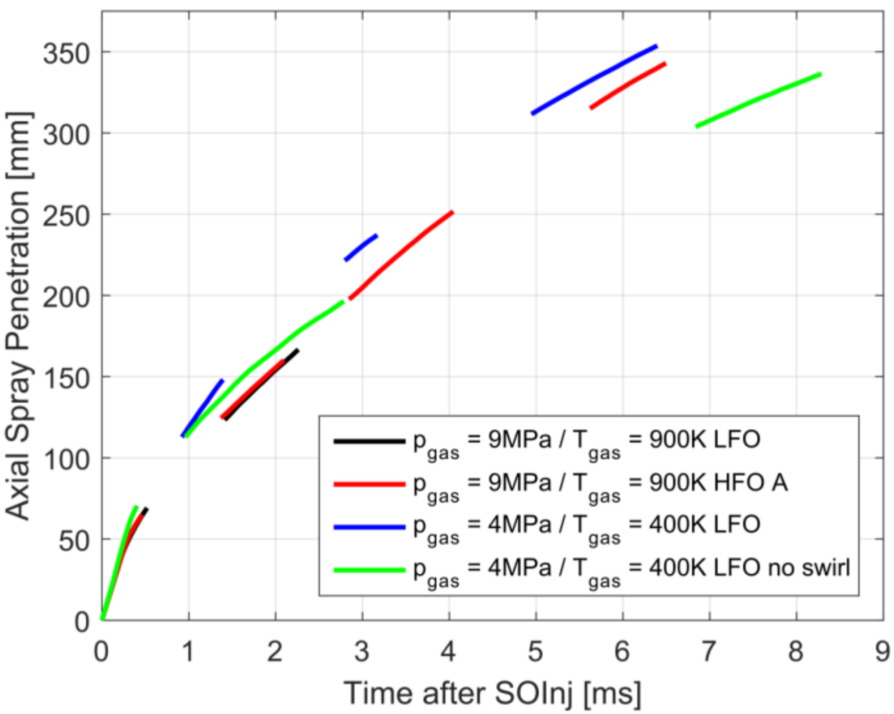
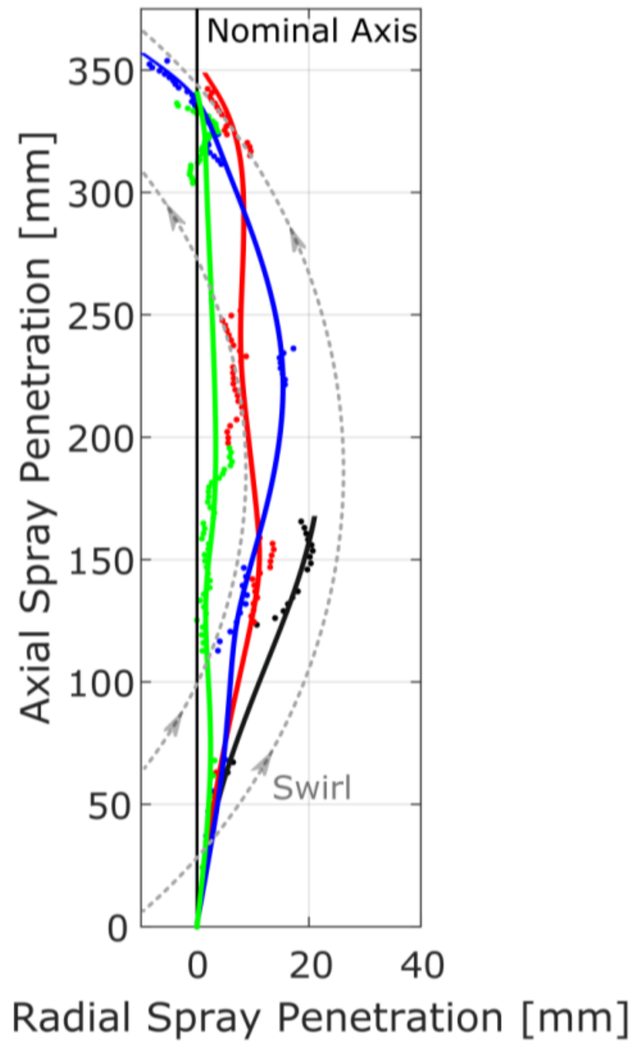
Spray Formation & Morphology

Spray Penetration / Trajectory





Spray Trajectory (spray contour):

- Clear deflection with acting swirl flow
- Change of the sprays windward side along propagation (from lee to luv)

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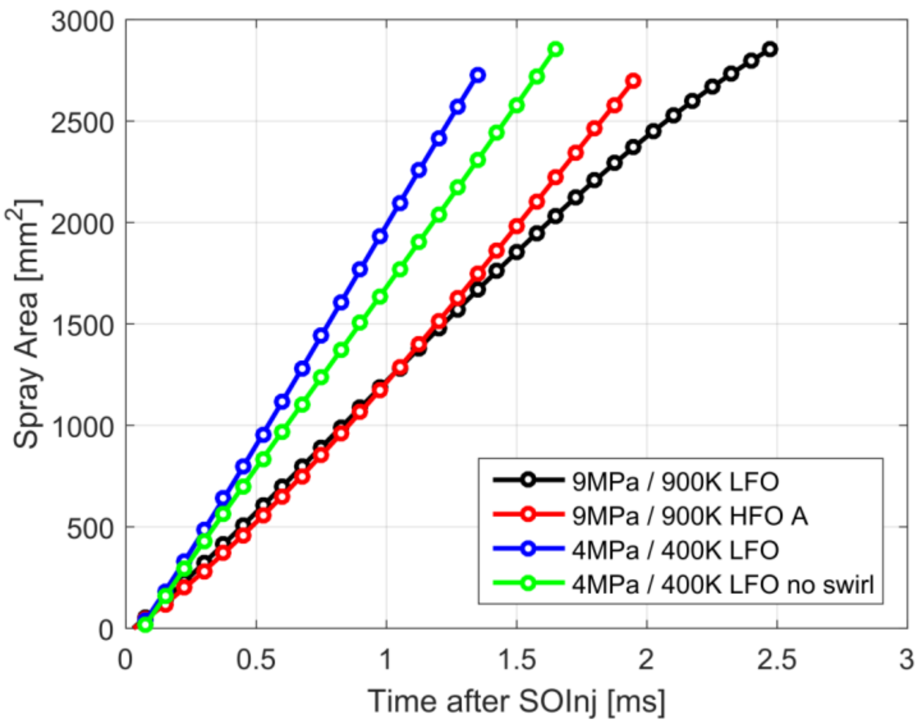
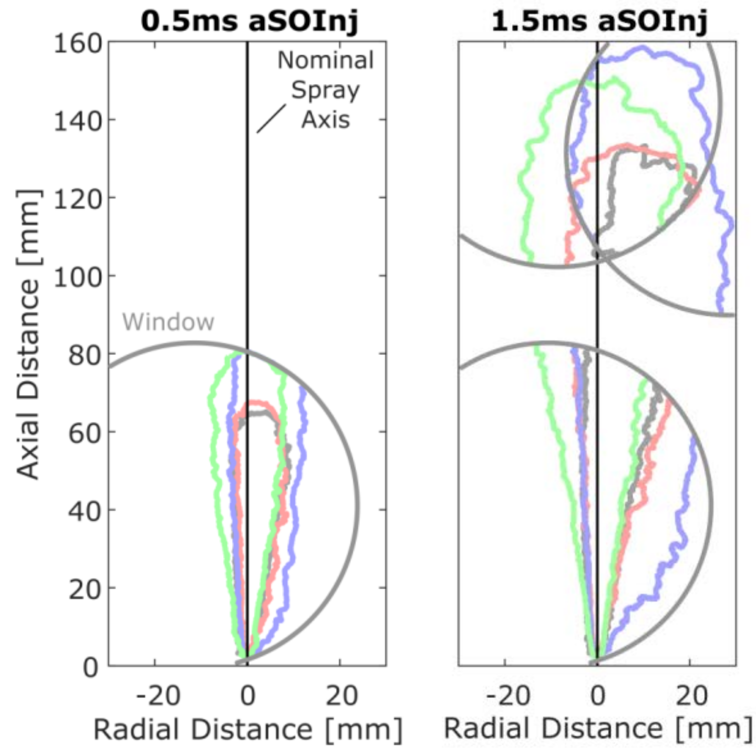
Spray Formation & Morphology

Spray Area





Spray Area (projected, spray contour):

- Impact of evap. to non-evap. conditions
- Area increase at non-evap. due to swirl
- Fuel quality influence recognizable

Ignition Behaviour

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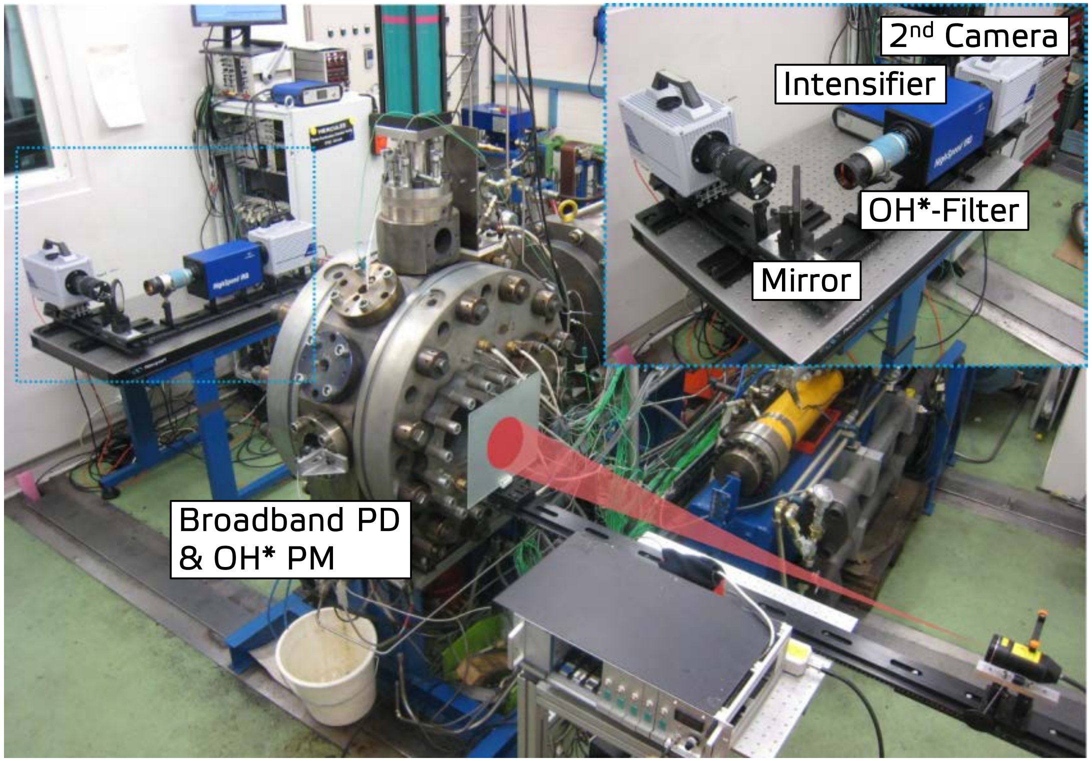
Ignition Behaviour

Measurement Setup



Study of Natural Flame Light Emission (Spectrography)

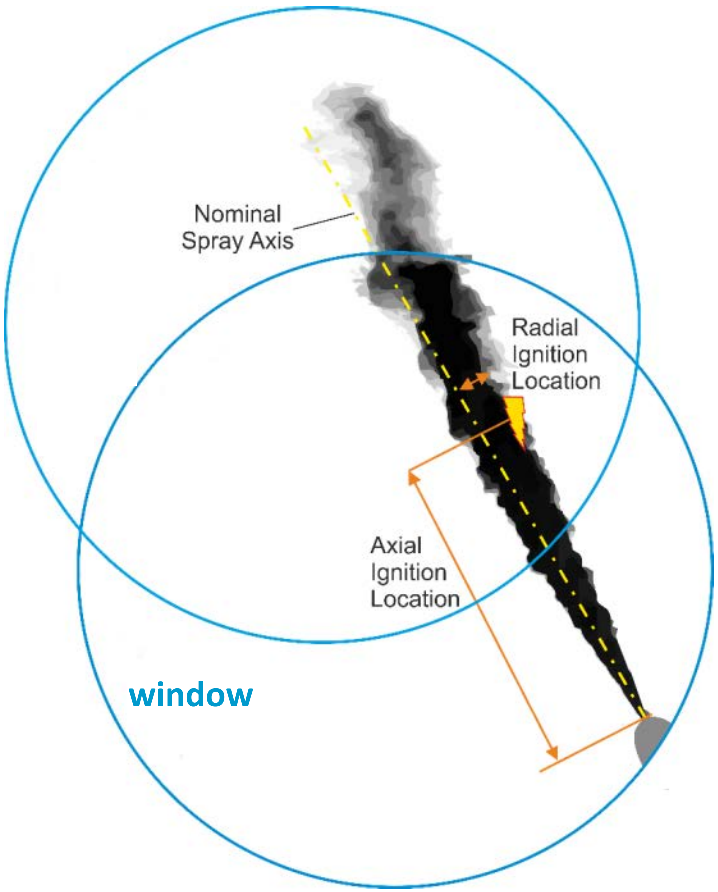
Ignition Delay:

- Broadband Photodiode (250 kHz sampling rate)

Ignition Location:

- Simultaneous DBI / OH* Chemiluminescence (16 kHz fps)

90 bar 900 K LFO



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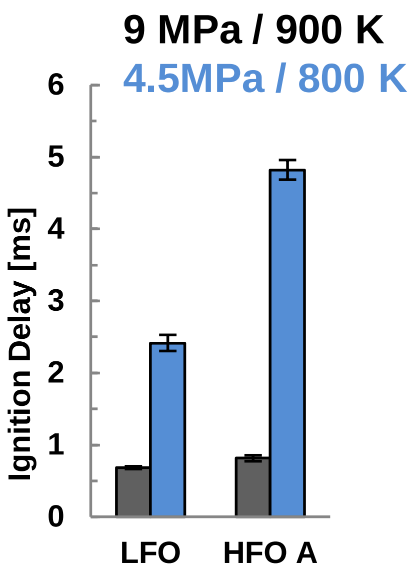
Ignition Behaviour

Ignition Delay / Location and Lift-off Length



Ignition delay :

- Lightly prolonged for HFO A at engine like conditions
- At FIA conditions (with swirl) almost 100% longer ID for HFO A

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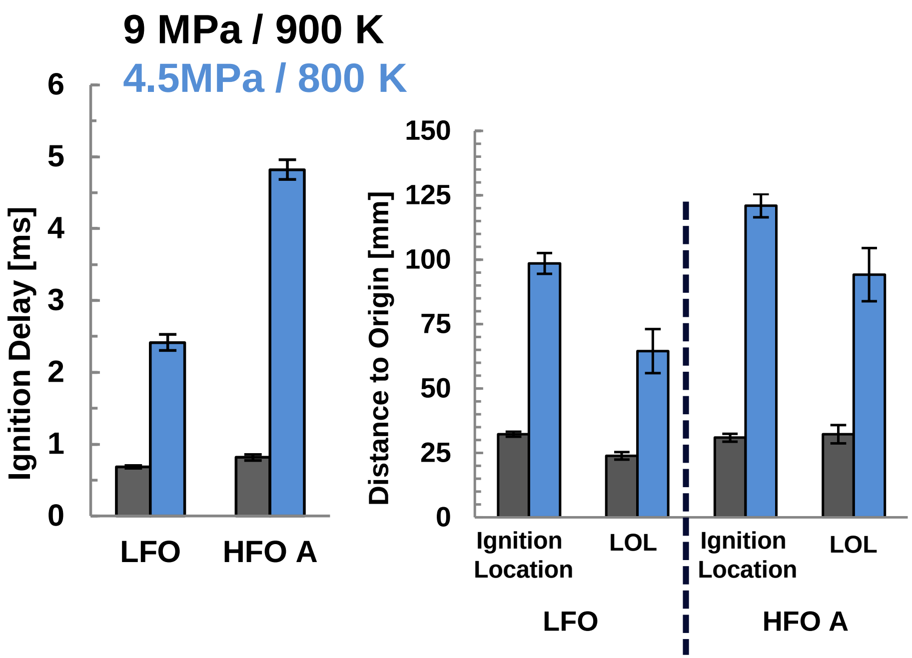
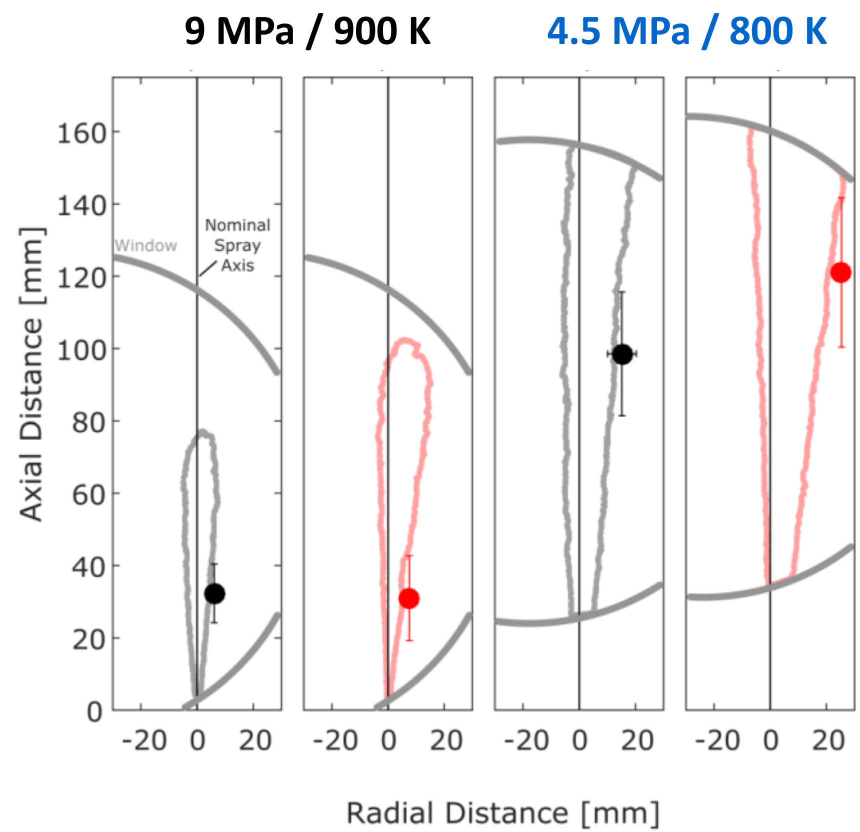
Ignition Behaviour

Ignition Delay / Location and Lift-off Length





Ignition location:

- Similar for engine-like conditions
- At FIA conditions significantly downstream of nozzle tip
- Same behaviour for lift-off length

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Combustion Investigation

Combustion Investigation

Fuel Quality (Properties)

Properties	Unit	LFO	HFO A	HFO B	Method
Density at 15ºC	kg/m³	851.4	1001.1	965	ISO 12185
Viscosity at 40ºC	mm²/s	2.928	-	-	ISO 3104
Viscosity at 50ºC	mm²/s	-	1255	146	ISO 3104
Net Calorific Value	MJ/kg	42.47	40.58	39.17	ASTM D240/D4809
Surface Tension at 20ºC	mN/m	30.9	38.2	35.2	EN 14370 / HFO: calc. *
Flash Point	ºC	58	103	118	ISO 2719
Pour Point	ºC	<-6	6	3	ISO 3016
Calculated Cetane Index	-	47	21	26	ASTMvD976
Pseudo-critical Temp.	K	727.7	985.7	916.5	Calc. *
Pseudo-critical Pressure	bar	19.05	9.29	11.42	Calc. *
Marine Fuel Specification		DMX	RMK	RME	ISO-8217

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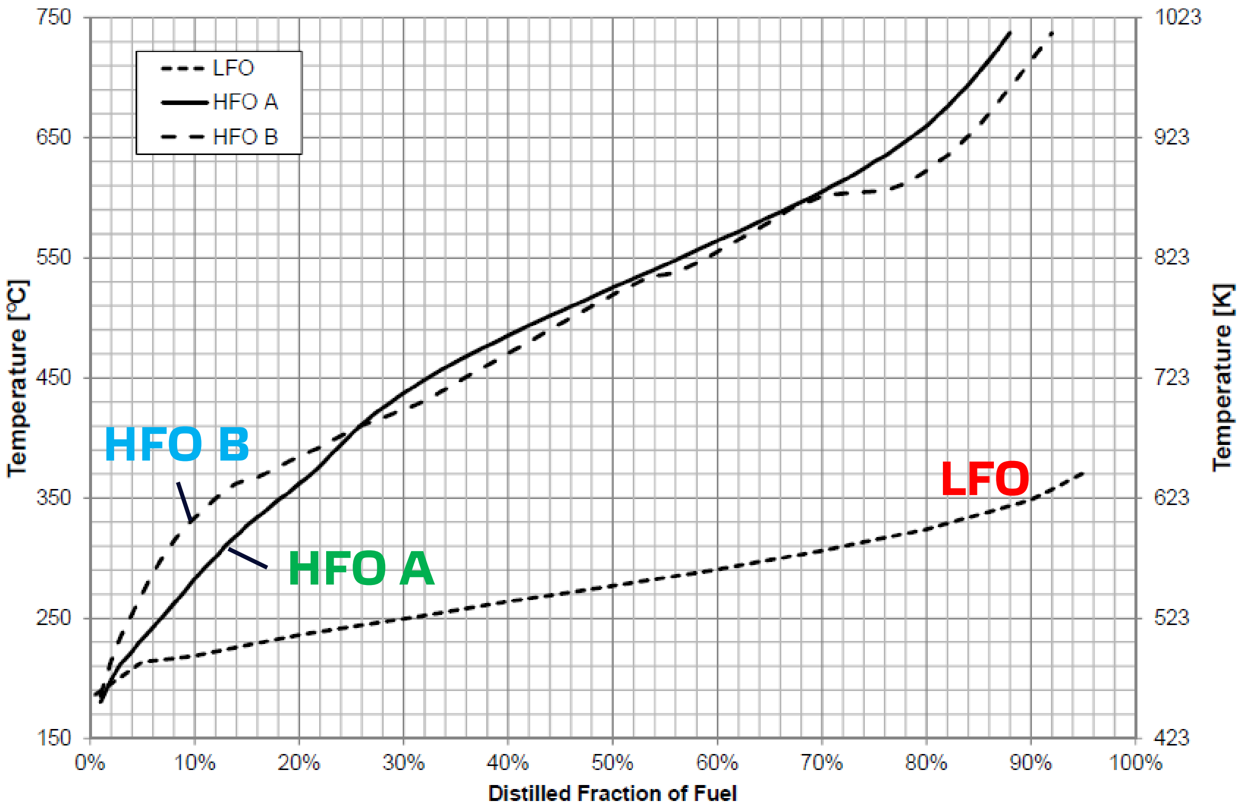
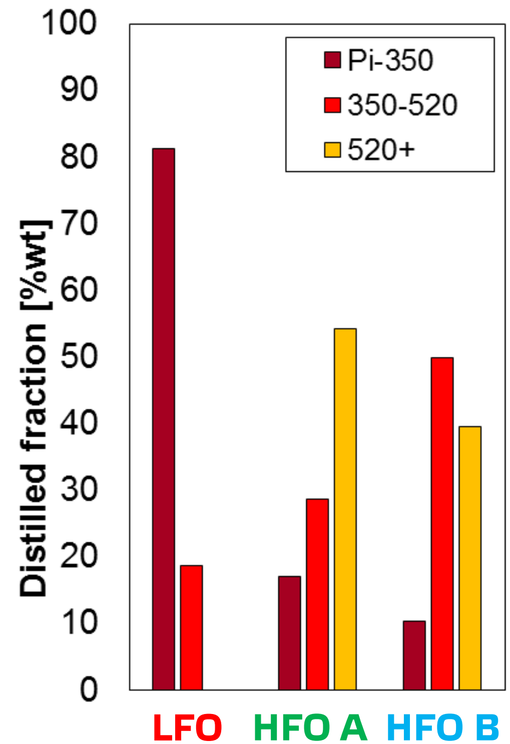
Combustion Investigation

Fuel Quality (Properties)





- LFO completely distilled after 360°C
- Similar distillation curves of HFO A and B (besides start/end)
- Highest amount of high-boiling components for HFO A

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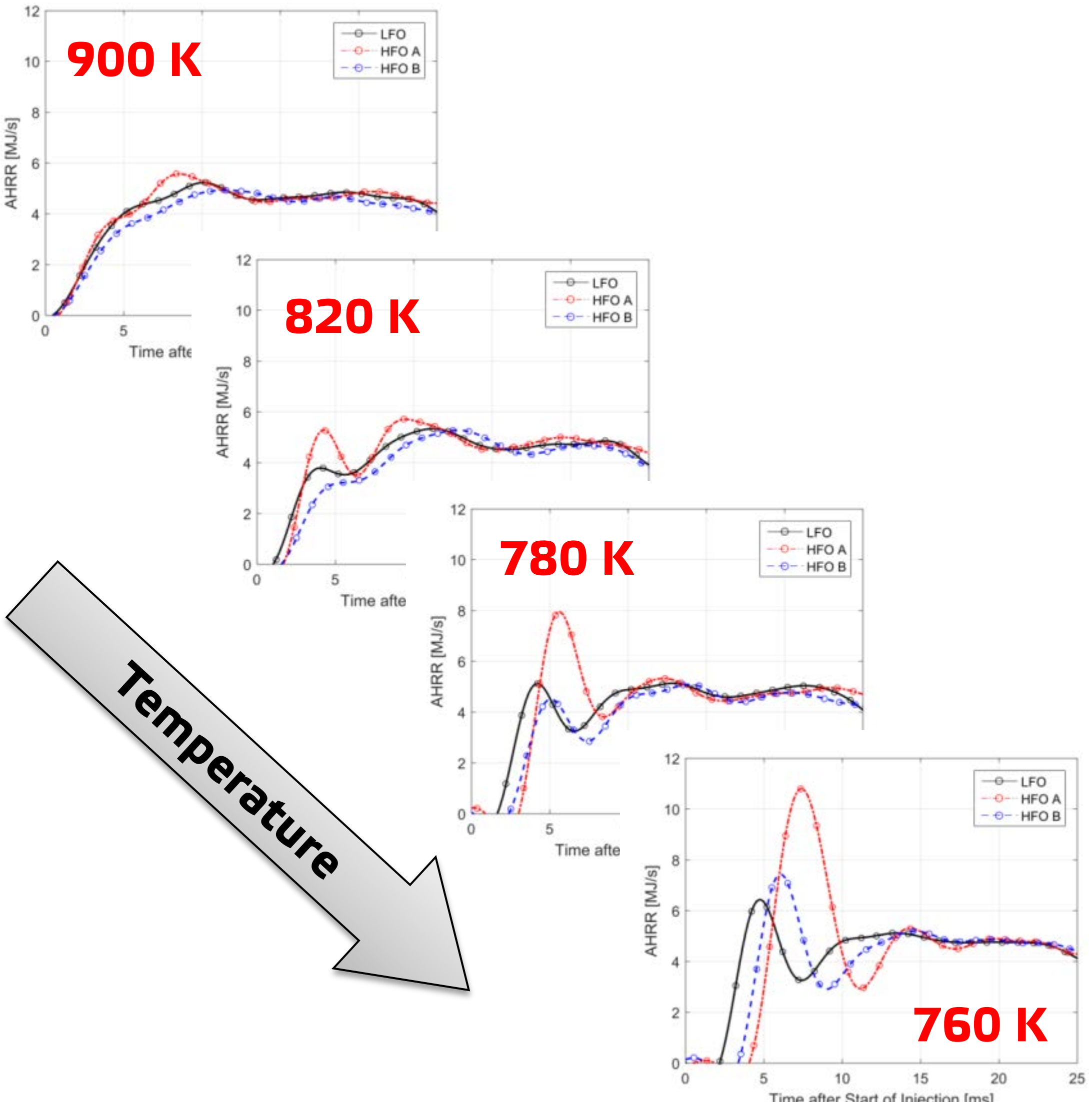
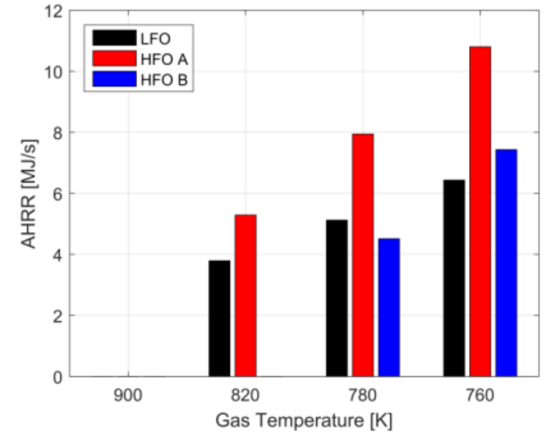
Combustion Investigation

Influence Gas Temperature (at p_{gas} = 9 MPa)



(detectable) premix peak



- Similar AHRRs for all fuels at the high temperature conditions
- Highest premixed combustion peak for HFO A
- Increased spray penetration/ advancing air entrainment enabling the formation of an larger amount of ignitable mixture

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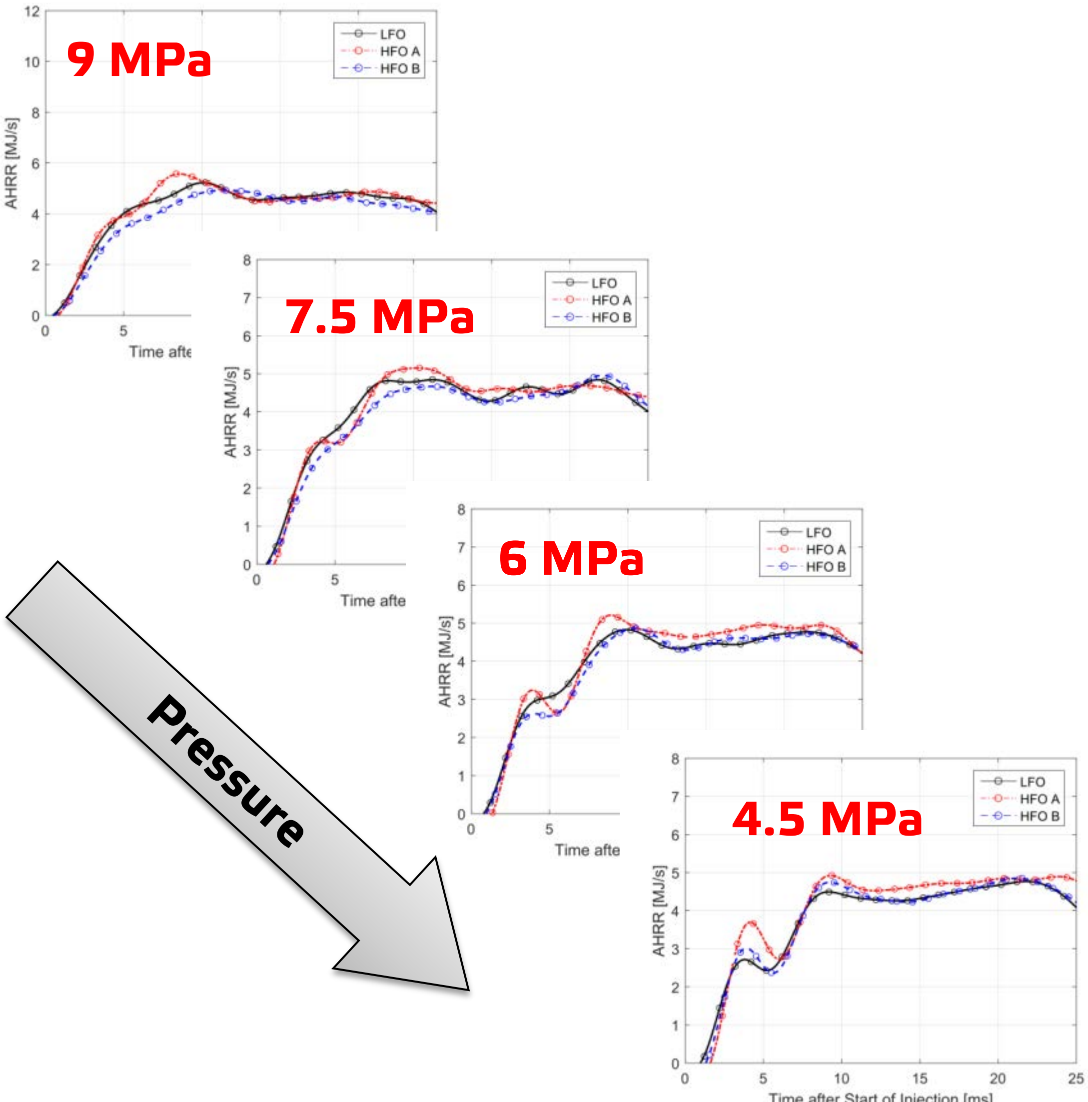
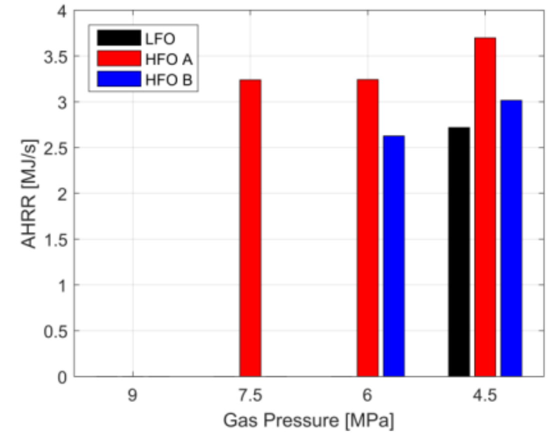
Combustion Investigation

Influence Gas Pressure (at T_{gas} = 900 K)



(detectable) premix peak



- Slight evidence of premixed combustion towards lower gas pressures for the heavy fuel oils
- Almost no premixed peak for LFO (only at 4.5 MPa)
- Reduction of gas density influences spray formation and subsequent fuel evaporation

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Conclusions

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Conclusions

Summary

- Comparative study with regard to spray formation, ignition behaviour and combustion characteristic for LFO and HFO under engine realistic conditions for large 2-stroke marine Diesel engines.
- The fuel quality has a highly significant impact on the spray formation and morphology with regard to the spray and swirl interaction.
- Ignition delay/location are in a similar range for the different fuel qualities at engine-like conditions compared to larger discrepancies at FIA conditions (with swirl).
- The combustion characteristic shows an effect of the fuel on the premixed combustion at lower temperatures/pressures due to the according difference in the spray formation/morphology in combination with the ignition behaviour
- The investigations suggest a high influence of the physical processes on the ignition and combustion behaviour (especially the acting swirl flow).

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- ETH - LAV
- PSI

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- Winterthur Gas & Diesel Ltd

Thank you!

Question and Answers

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