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Direct imaging of primary atomisation in the near-nozzle region of diesel sprays

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BP Global Fuels Technology

University of Nottingham,17th September 2014

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Contents

- Introduction
- Evaporative test conditions
- High-speed video and shadowgraphic microscopy
- Start of injection phase
- Steady-state period
- End of injection phase
- Conclusions
- Acknowledgement

Introduction

- The liquid fuel is injected at high velocity into a combustion chamber
- It atomizes into small droplets
- The atomized fuel vaporizes and mixes with high-temperature air
- Combustion occurs after vaporized fuel mixes with air

- Mixing and evaporation occurs at microscopic scales
- Initial stage of spray formation influences combustion process
- There is a need to study spray at macroscopic levels

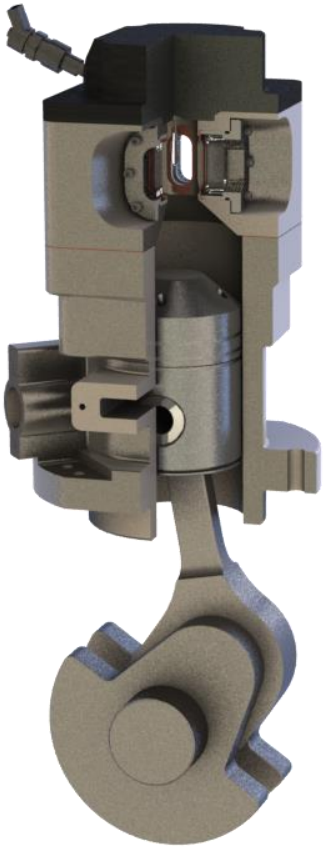
Objectives

- *To study morphology of fuel droplets during the injection process at microscopic scales in near nozzle region to aid model correlation*

Evaporative test conditions

- Rapid Compression Machine (RCM) is:

  A single cylinder Ricardo Proteus two-stroke test engine



- Bore: 135 mm
- Stroke: 150 mm
- Displacement: 2.2 l
- RPM: 500
- Quiescent air motion at TDC

- P_{inj}: 30-200 MPa
- ICP: up to 12 MPa
- TDC temperatures 540-850 K

Evaporative test conditions (cont.)

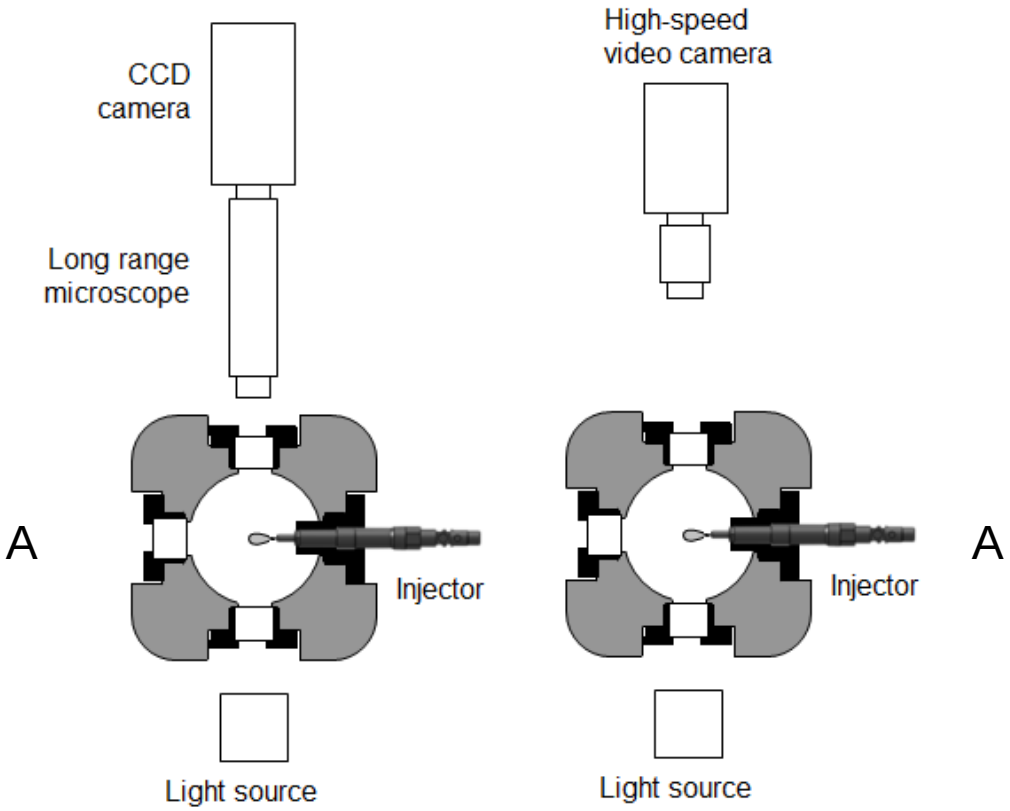
Target operating conditions

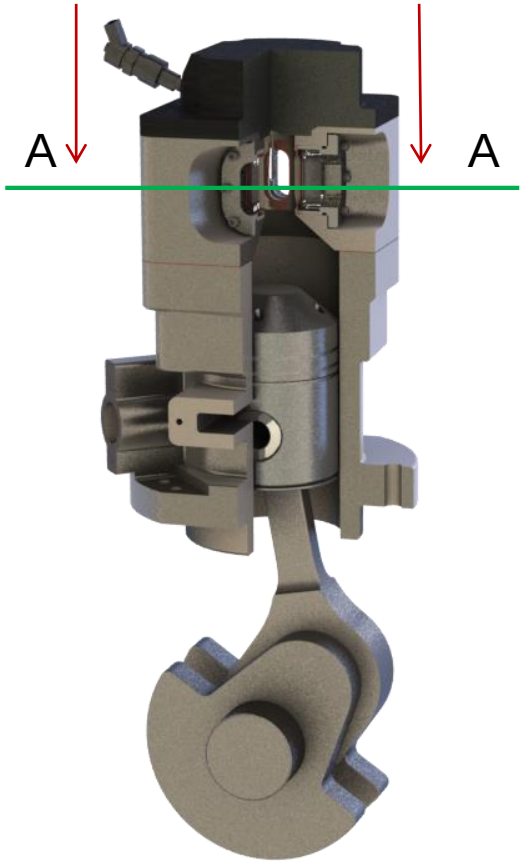
O_2	In-cylinder Temp, K	In-cylinder Density, kg/m^3	ICP, bar	Inj. Pressure, bar	Fuel	Inj. Duration Based on trigger, ms
21%	700	22.8	48	500, 1000, 1500	n-dodecane	1.5

Specifications for the injector (IFPEN 201.02 ECN spray A)

Description	Value
Type	Bosh solenoid-actuated, generation 2.4
Nominal nozzle outlet diameter	0.090 mm
Nozzle K factor*	1.5
Nozzle shaping	Hydro-erosion
Mini-sac volume	0.2 mm^3
Number of holes	1 (single hole)
Orifice orientation	Axial (0˚ full included angle)

High-speed video and microscopy





High-speed video and microscopy system

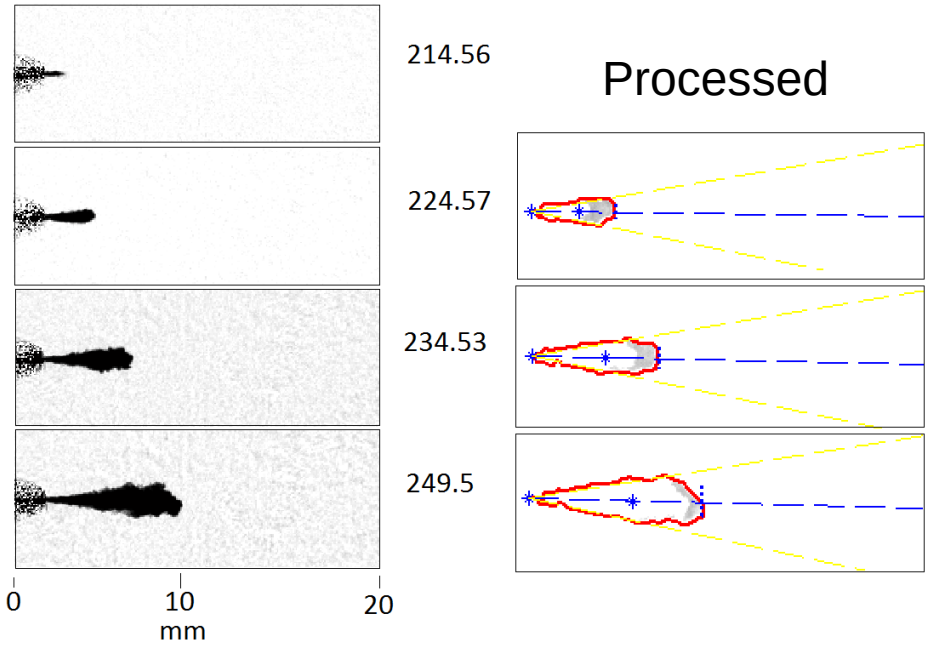
Long-distance microscope

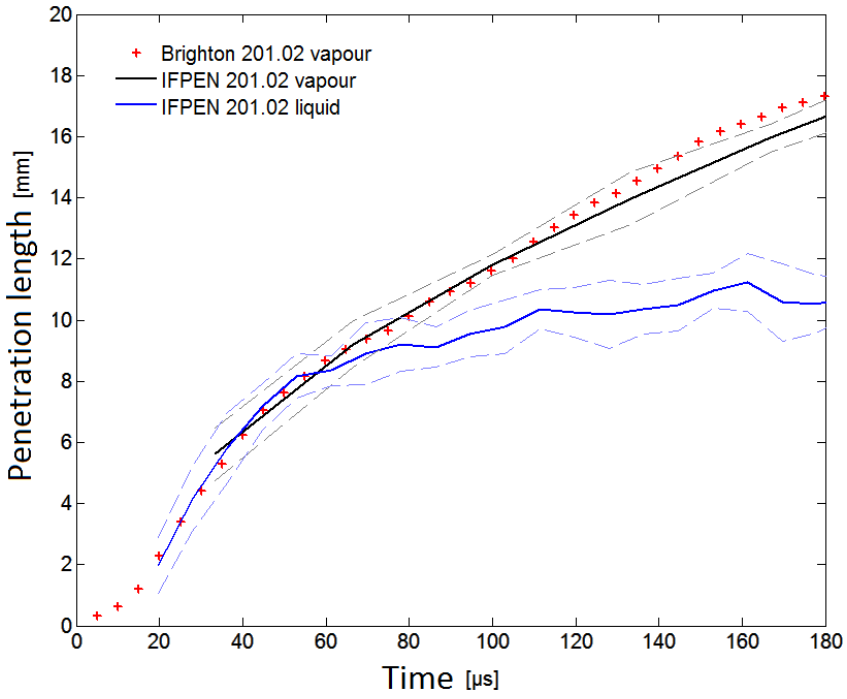
CAVILUX Smart 640 nm
pulsed diode laser light source

Phantom V710 high-speed camera

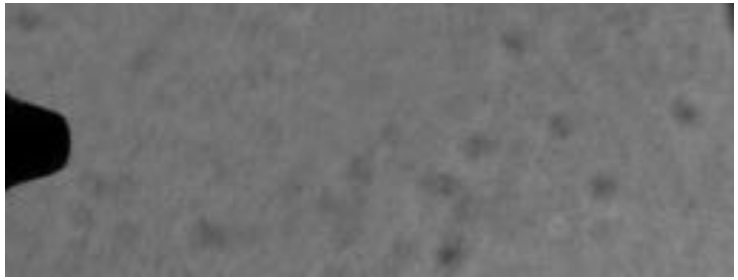
80-200 mm Nikon AF Nikkor

Start of injection (HSV)





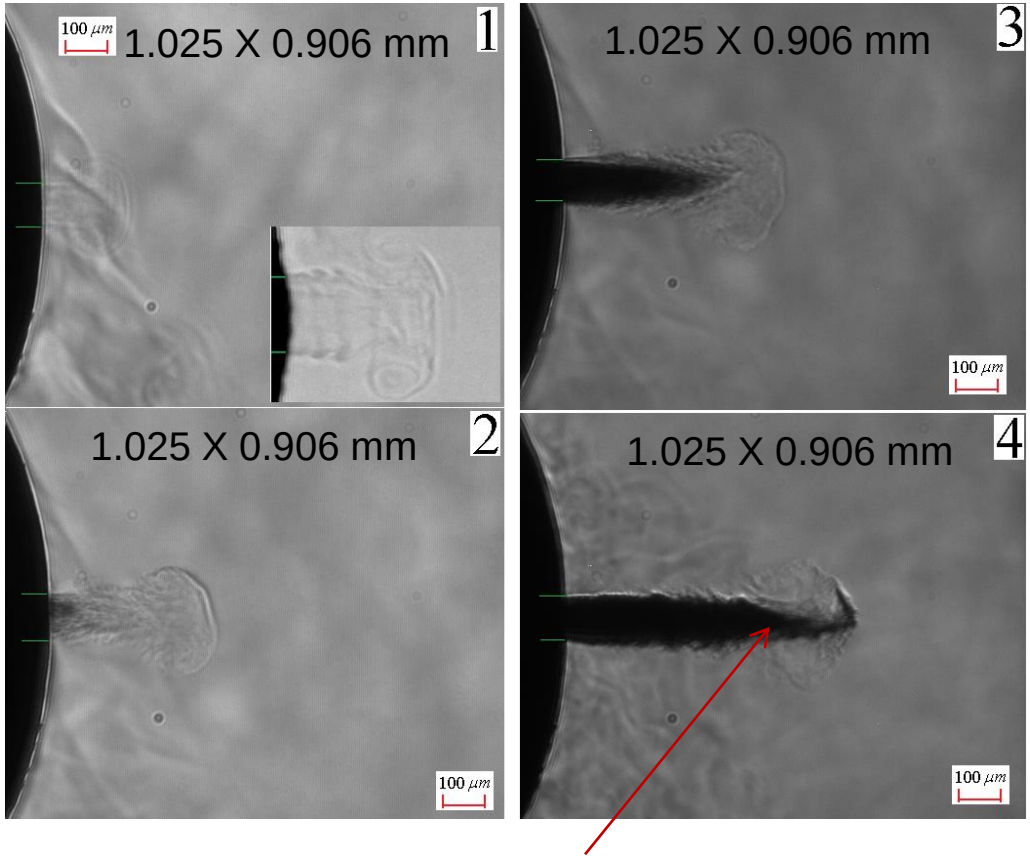
Motored @ ICP 4.5 MPa

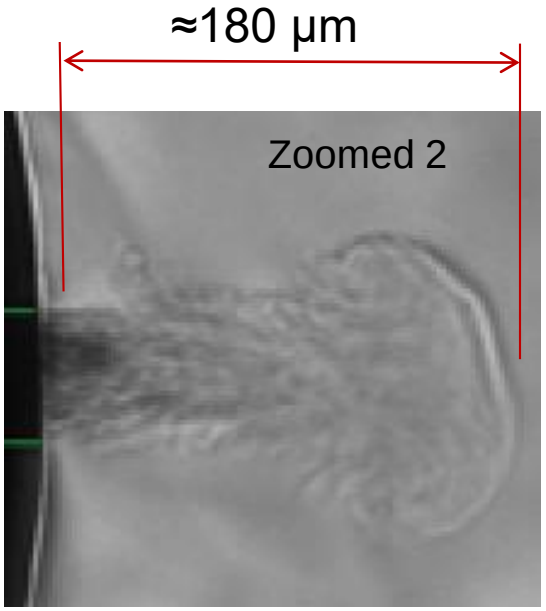


- Dashed line is standard deviation
- IFPEN injector 201.02 at 900K 22.8 kg/m^3
- Good correspondence with liquid and vapour IFPEN data

Start of injection (Microscopy)

Liquid-vapour mixture exiting the nozzle hole for 0.295 ms ASOI
P_{inj} = 150 MPa, ICP 4.8 MPa





Fuel jet eventually pierces through this vapour cap

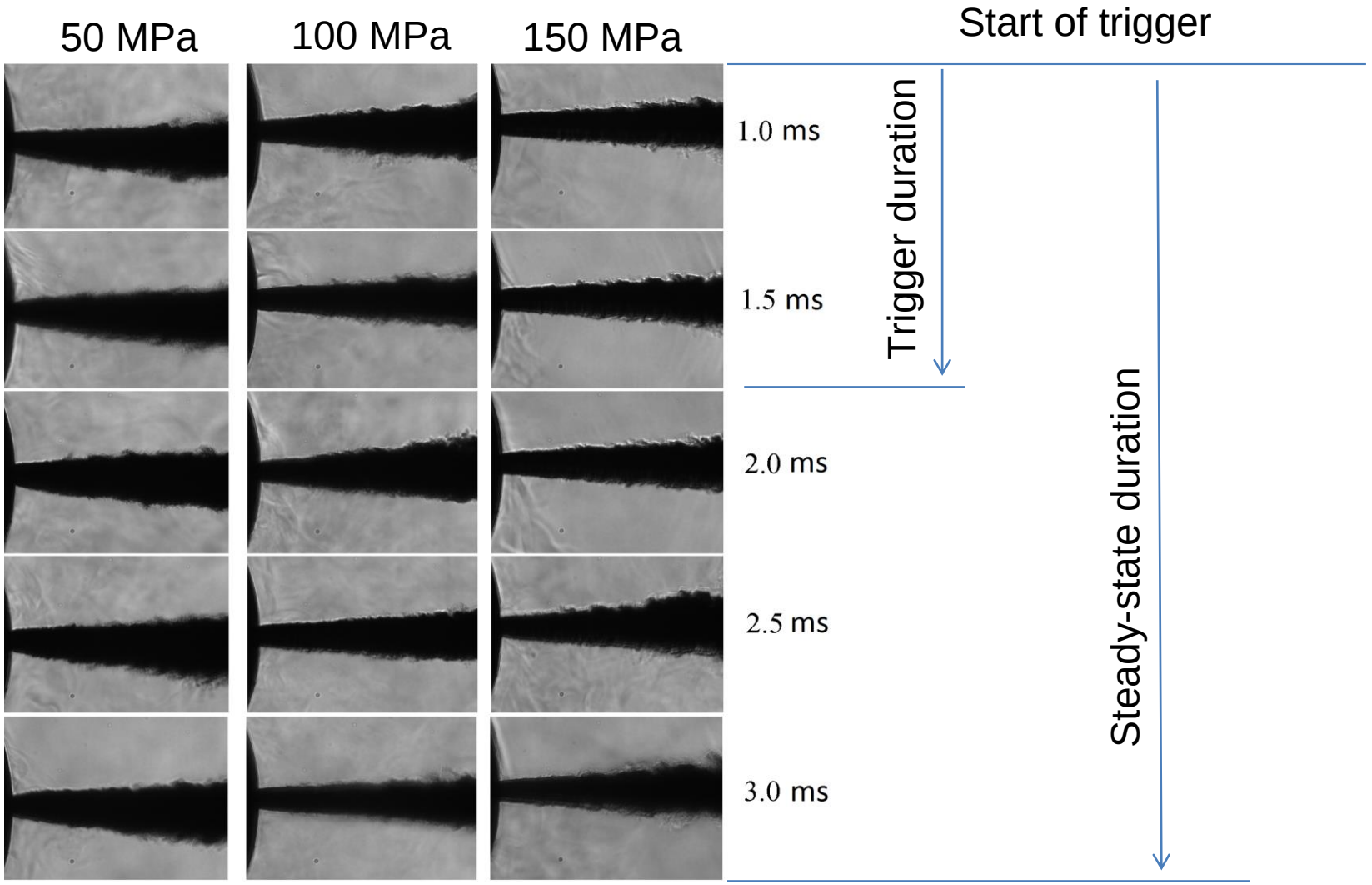
Start of injection (Microscopy)

Vapour pre-jet was also reported for other injectors e.g.
Delphi 1.3 7-hole, 135μm VCO and fuel (ULSD)

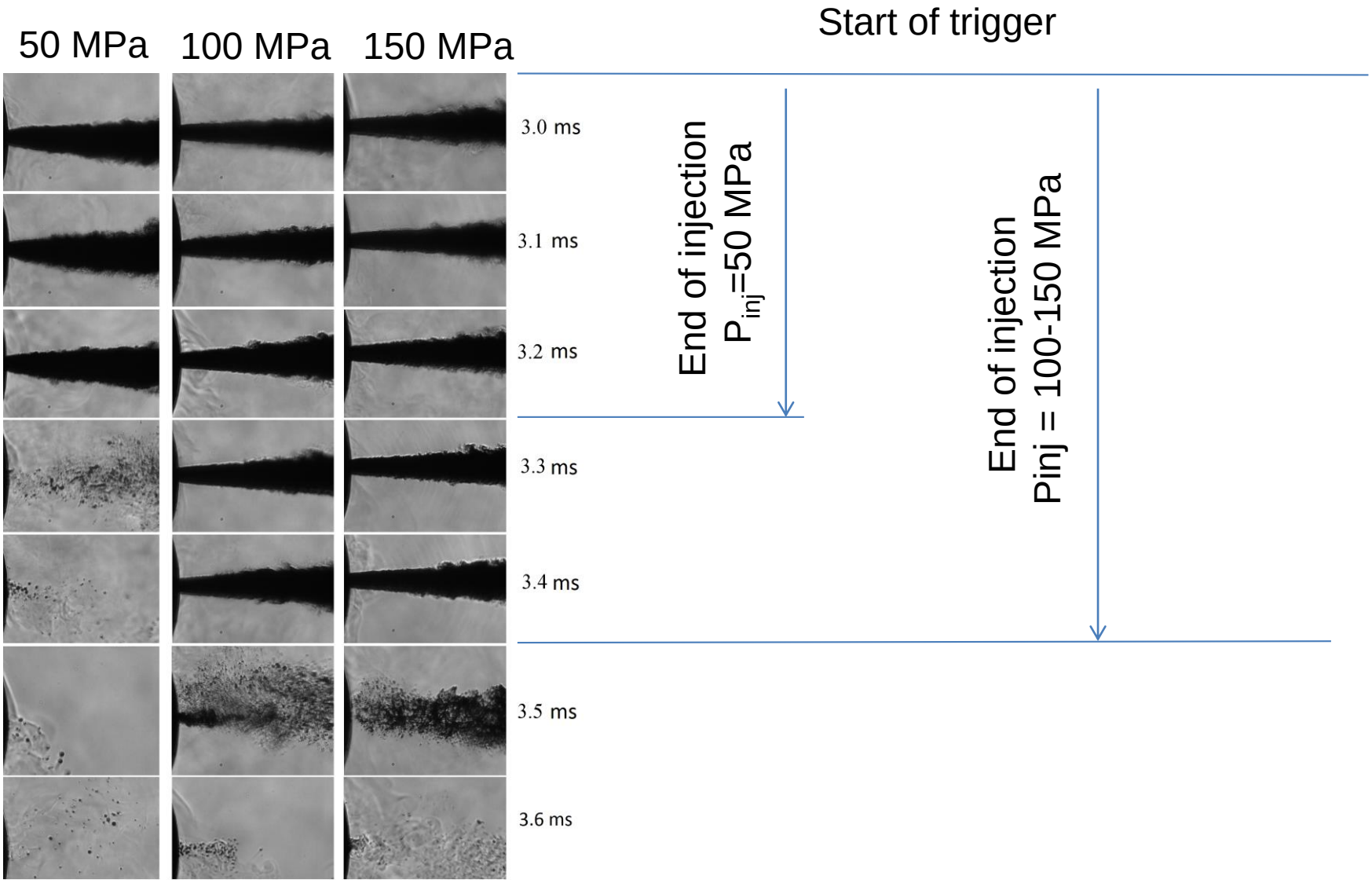
The vapour pre-jet can be caused by:

- Expansion of cavitation pockets after previous injection
- Ingestion of in-cylinder gases after previous injection
- Heating and evaporation of fuel inside orifice
- Can be ignited (if it is fuel vapour)
- Modelling may need to account for in-nozzle fluid properties

Steady-state (1.0-3.0 ms)

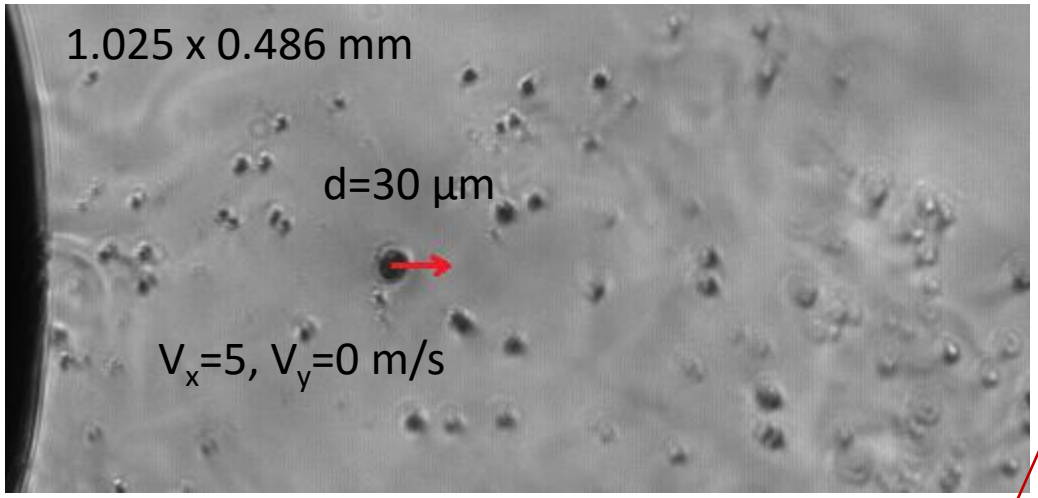


End of injection (3.0-3.6 ms)



End of injection in ECN injector

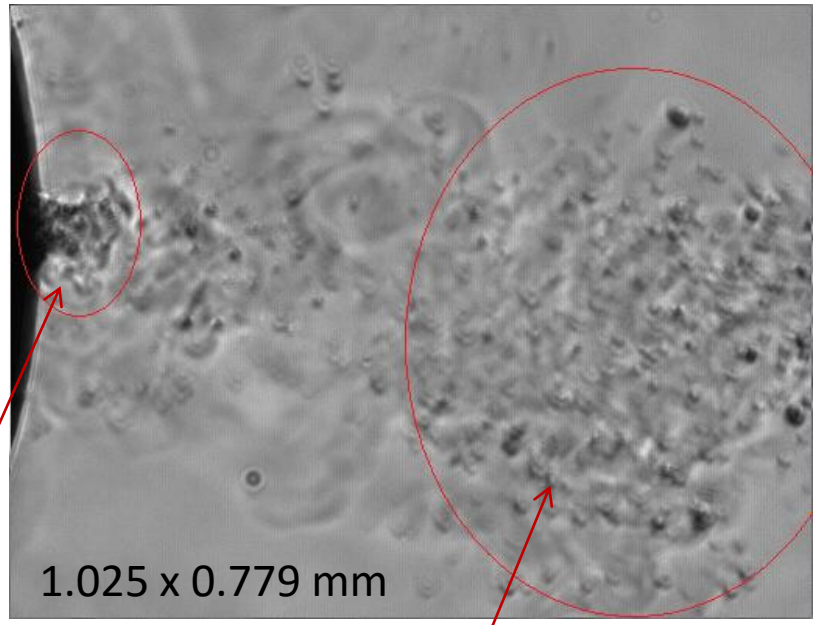
P_{inj} =100 MPa, 3.7 ms ASOI



- Large ‘slow’ droplets
- Micro-injection events
- Random droplet trajectory
- Spherical droplets

Micro-injection events after EOI

P_{inj} = 150 MPa for 3.6 ms ASOI



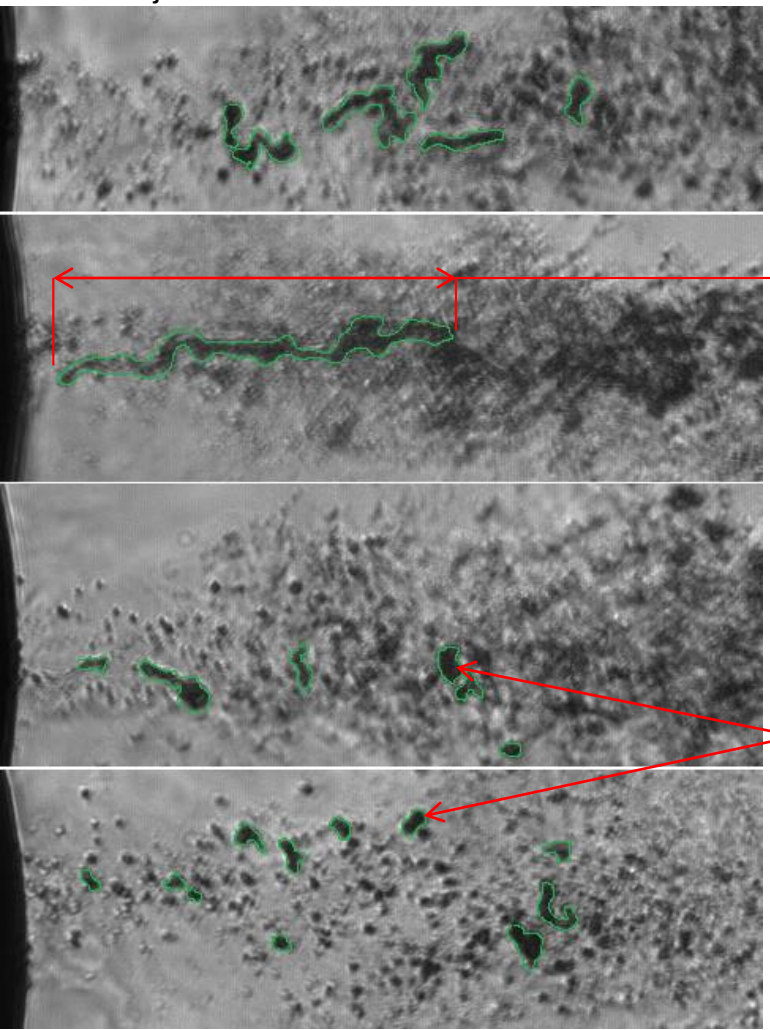
Start of micro-injection event

Droplets from ‘main end of injection’

Secondary micro-injection events in the ECN injector could be caused by:
The needle bouncing from the seat or by expansion of the fluid in the sac

End of injection (cont.)

P_{inj} = 50 MPa, 3.3 ms ASOI



- Large ligaments as well as highly deformed droplets are observed for low P_{inj}
- Hard to process in order to extract statistics

- Long irregular ligaments present significant modelling challenges for
  a) initialisation of emerging fluid
  b) modelling of subsequent evaporation and transport

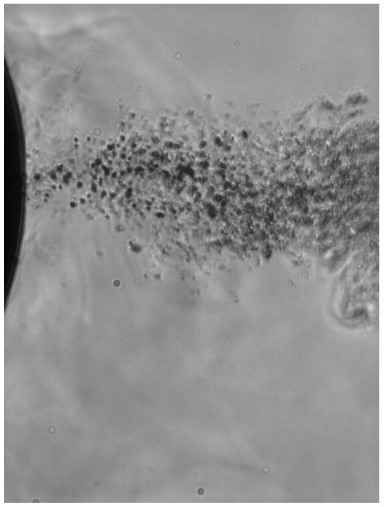
3D shape reconstruction, is needed in order to estimate the droplet surface area and volume

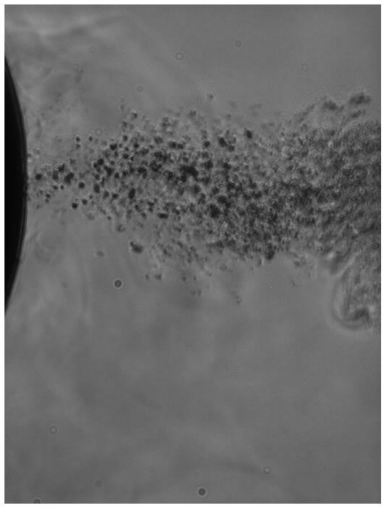
End of injection (cont.)

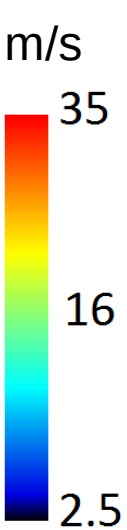
Frame 1

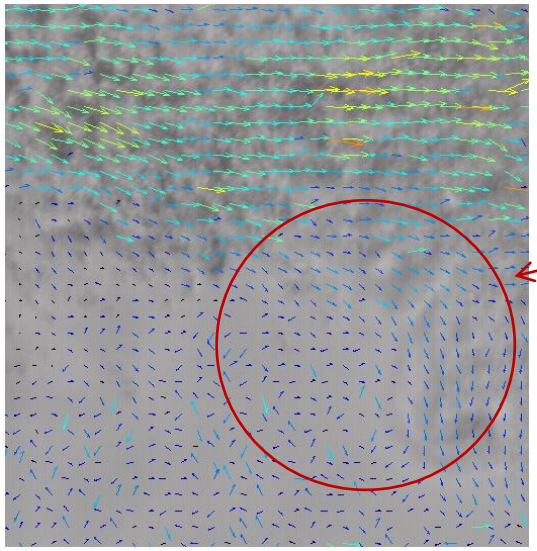
Frame 2

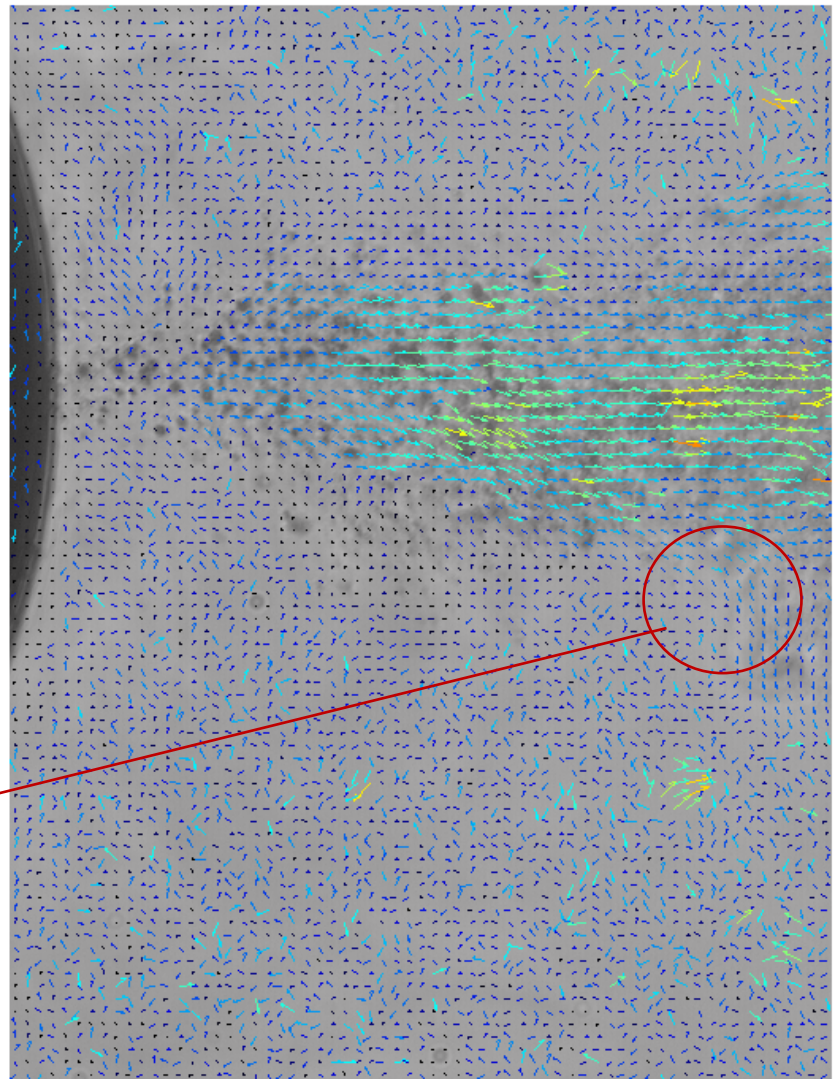
P_{inj}=50 MPa 3.3 ms ASOI











Velocity vectors

Conclusions

- Long injection process (compared to trigger duration) due to single-hole design
- Vapour pre-jet for a range of pressures of circa constant length was observed
- Secondary injection even due to possible needle bouncing or fuel expansion in sac
- Large droplets and long ligaments with low velocity for low injection pressures
- Quantitative velocity field of droplets or gas phase can be obtained

Acknowledgments

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