University of Brighton

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

V. Stetsyuk, C. Crua

Centre for Automotive Engineering
University of Brighton

R. Pearson, M. Gold

BP Global Fuels Technology

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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

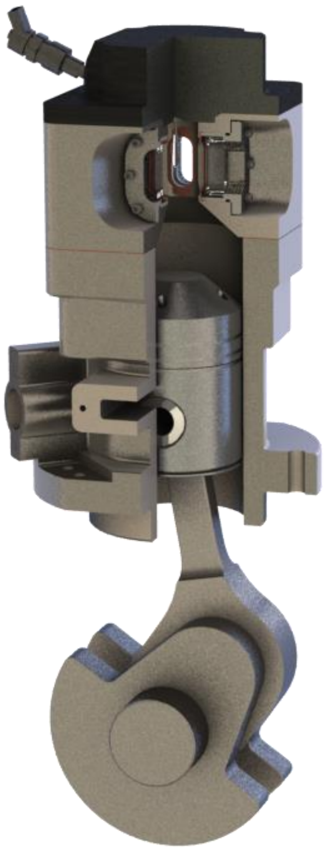
Objectives

- *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.)

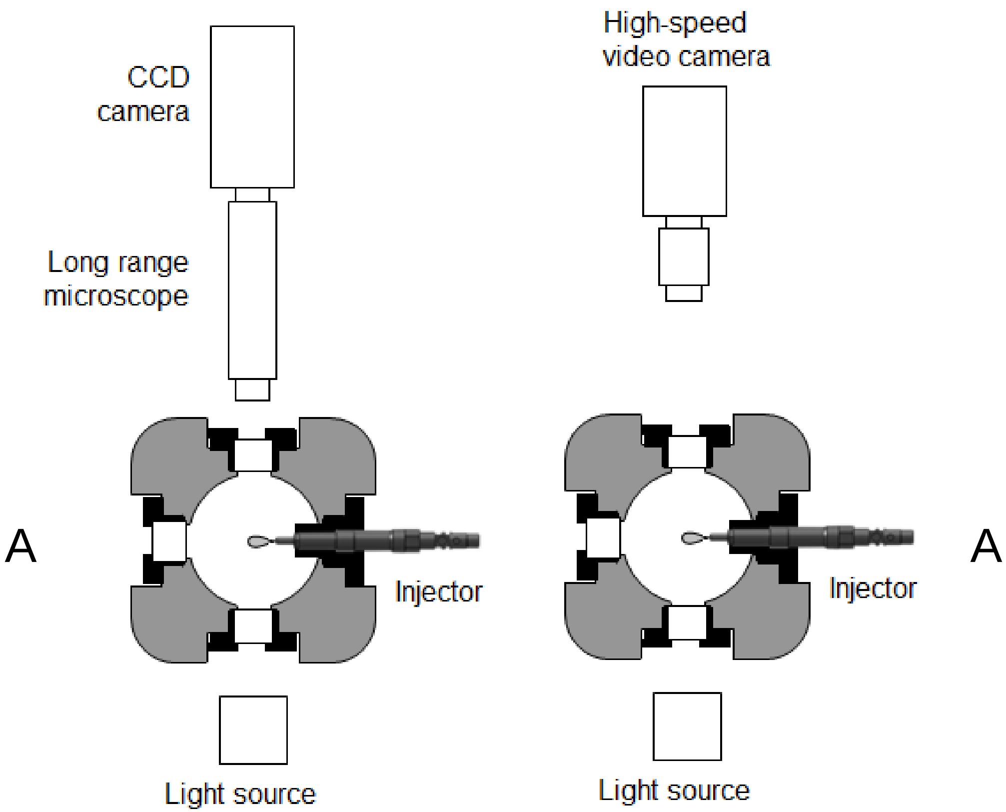
Target operating conditions

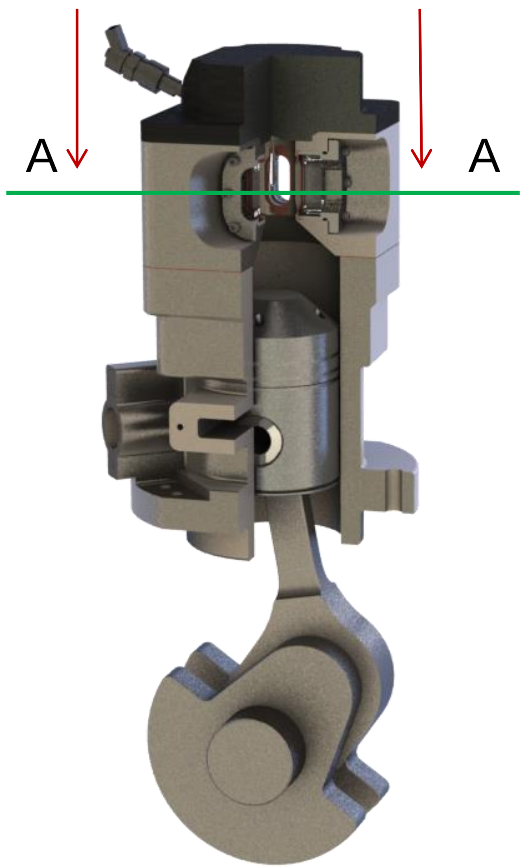
O_2	In-cylinder Temp, K	In-cylinder Density, kg/m^3	ICP, bar	Inj. Pressure, bar	Fuel	Inj. Duration Based on trigger, ms
21%	700	22.8	48	500, 1000, 1500	n-dodecane	1.5

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





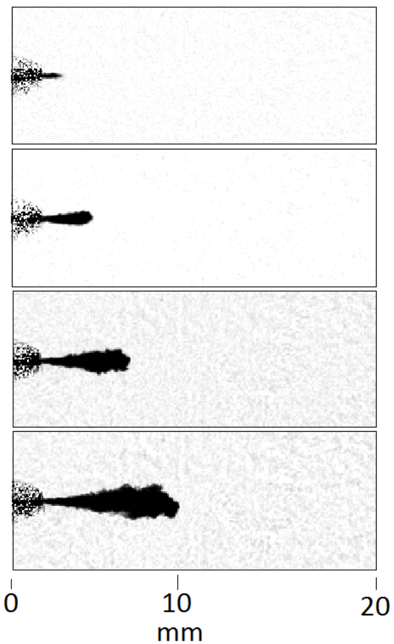
High-speed video and microscopy system

Long-distance microscope

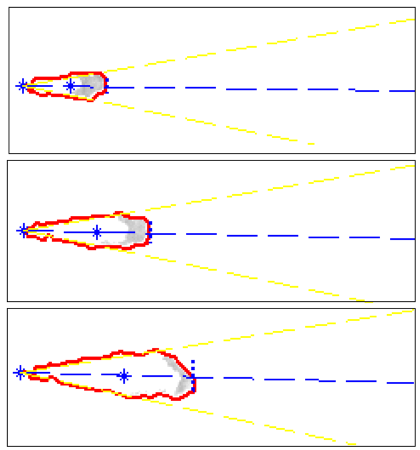
CAVILUX Smart 640 nm
pulsed diode laser light source

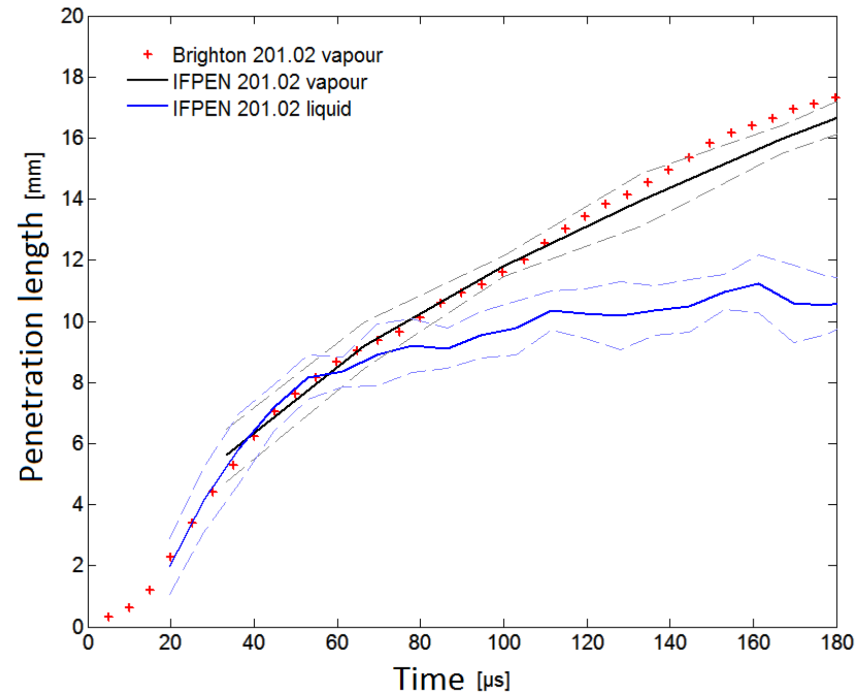
Phantom V710 high-speed camera
80-200 mm Nikon AF Nikkor

Start of injection (HSV)

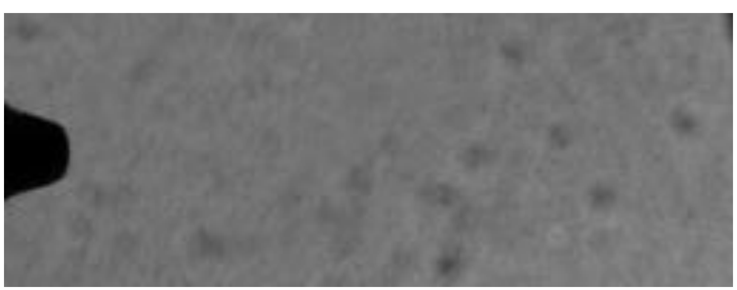


Processed





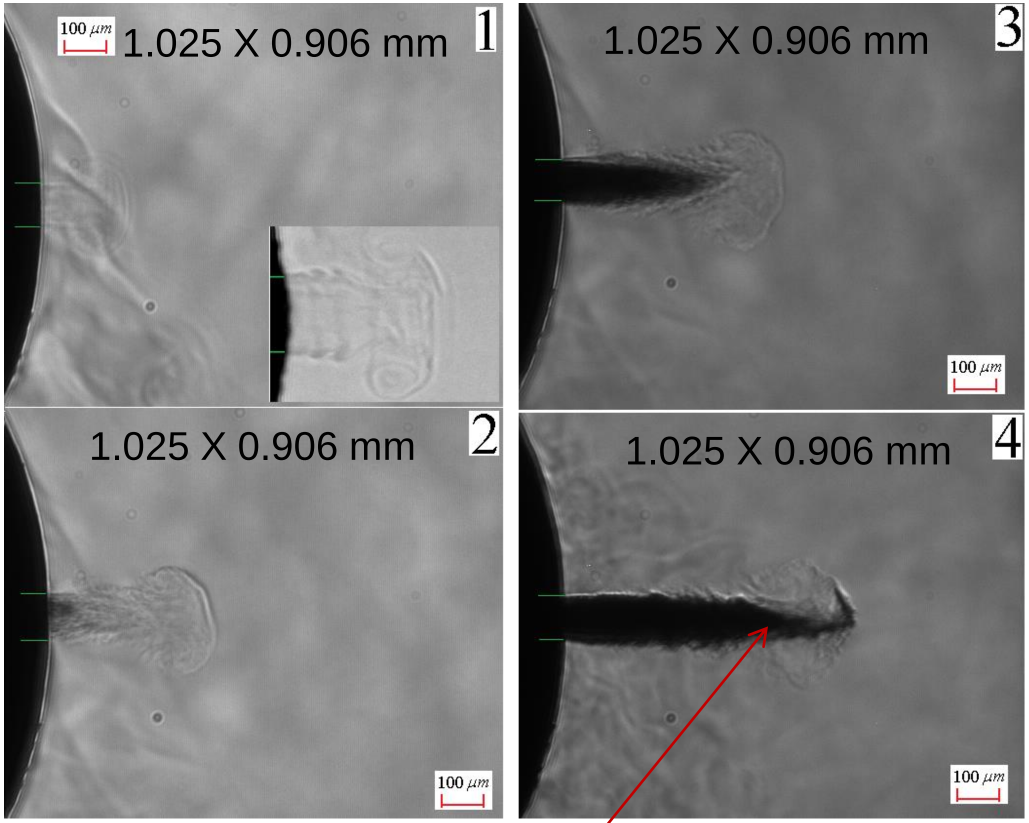
Motored @ ICP 4.5 MPa

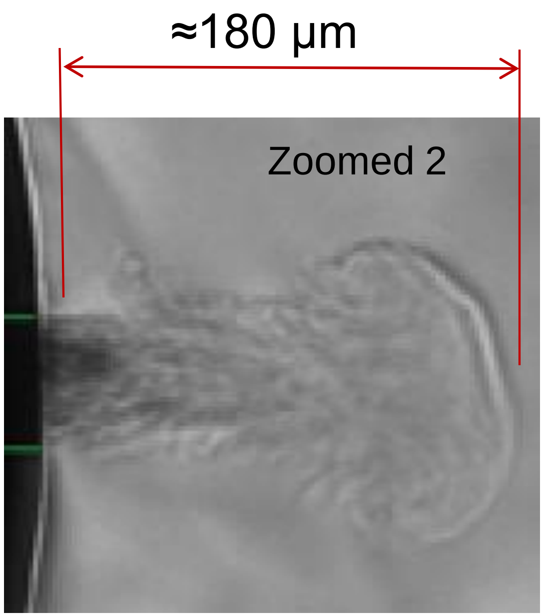


- Dashed line is standard deviation
- IFPEN injector 201.02 at 900K 22.8 kg/m³
- Good correspondence with liquid and vapour IFPEN data

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

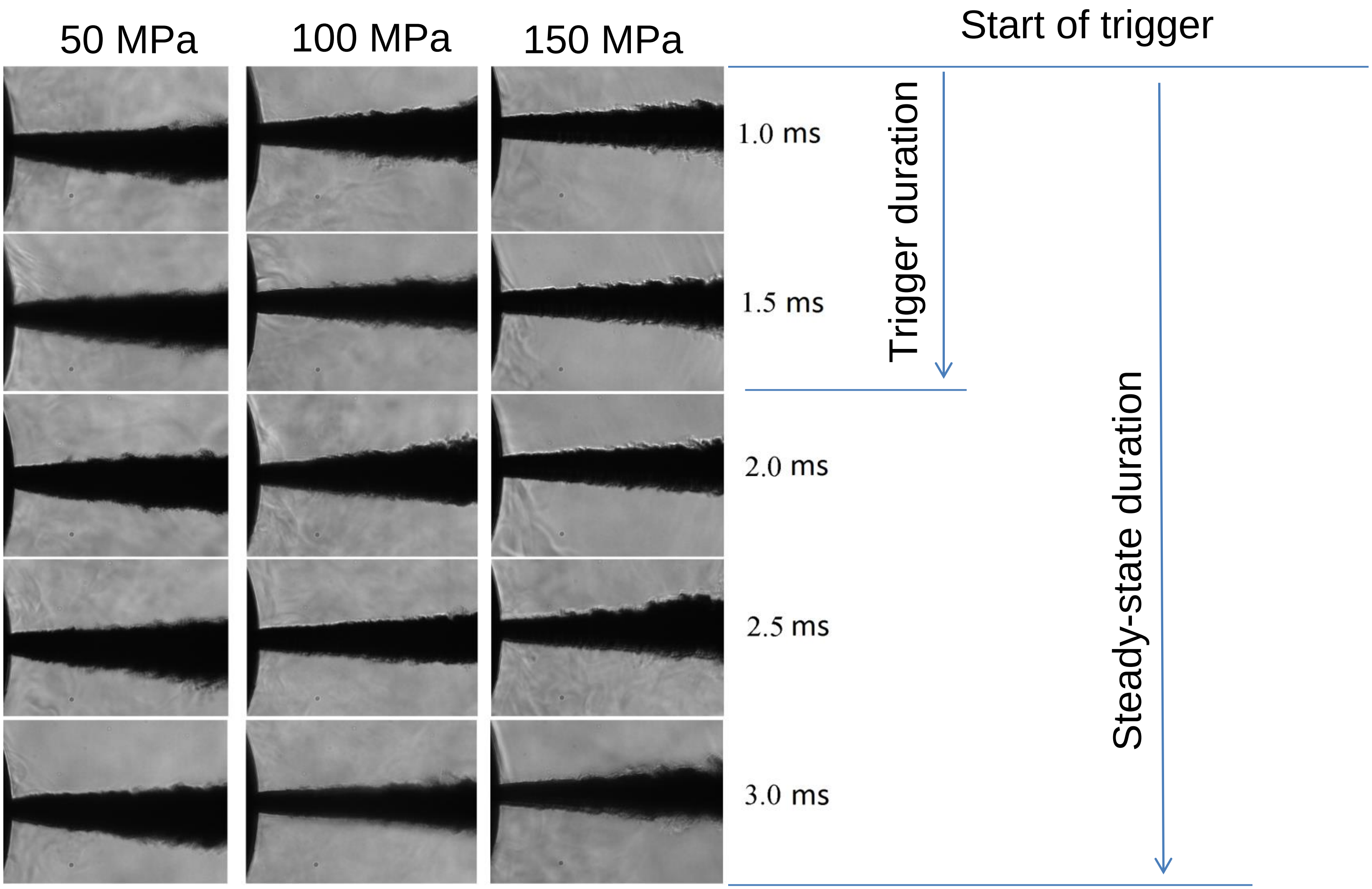
Start of injection (Microscopy)

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

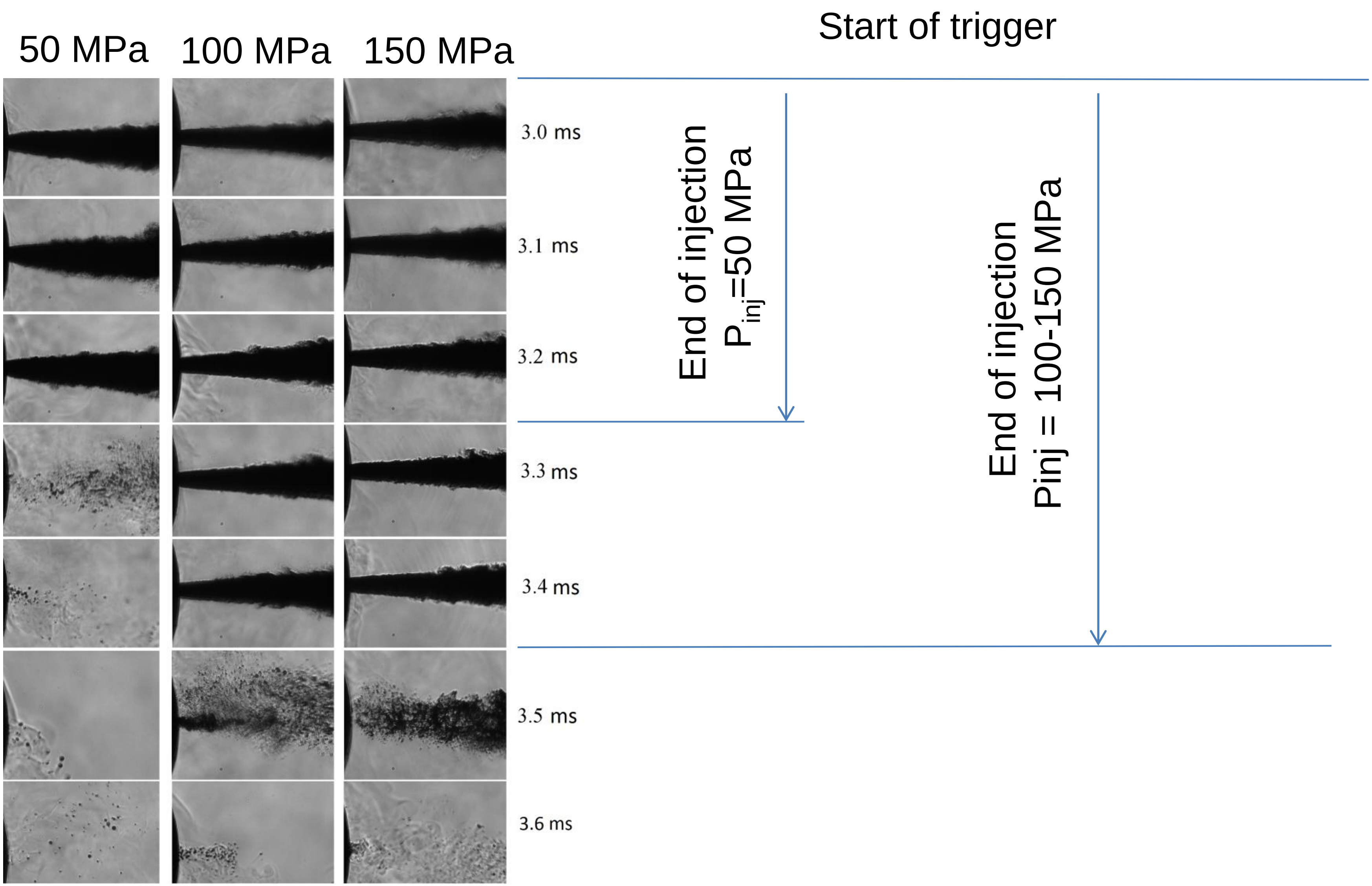
The vapour pre-jet can be caused by:

- 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)

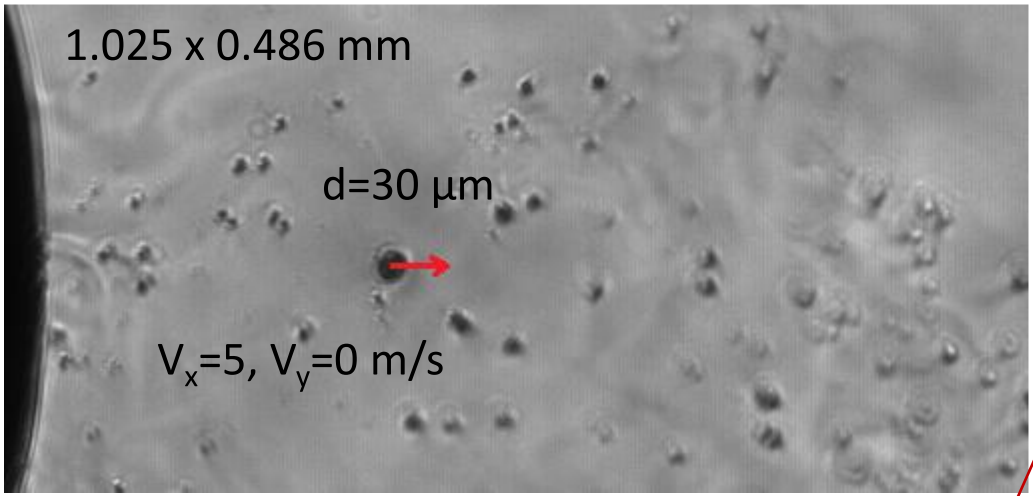


End of injection (3.0-3.6 ms)

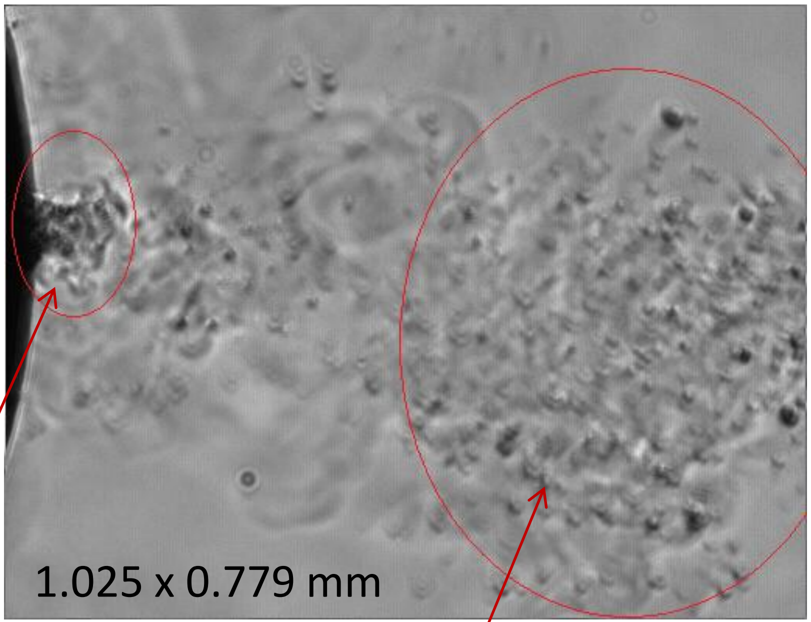


End of injection in ECN injector

P_{inj} =100 MPa, 3.7 ms ASOI



Micro-injection events after EOI
P_{inj} = 150 MPa for 3.6 ms ASOI



Start of micro-injection event

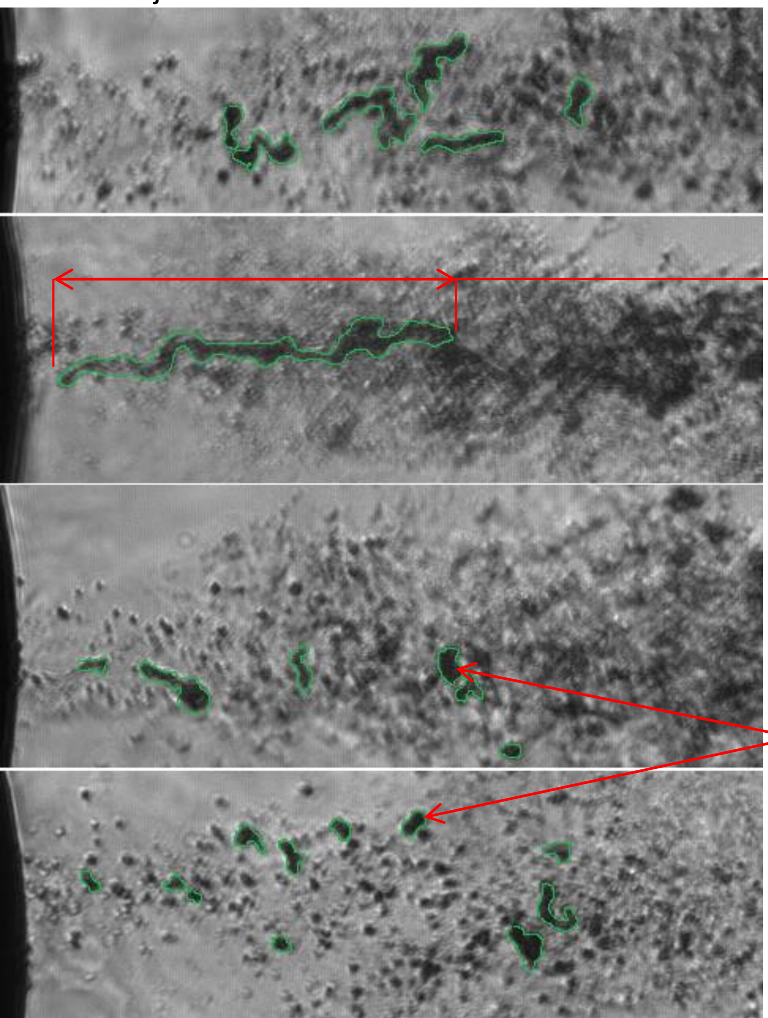
Droplets from 'main end of injection'

- Large 'slow' droplets
- Micro-injection events
- Random droplet trajectory
- Spherical droplets

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 structures (~420 μm)

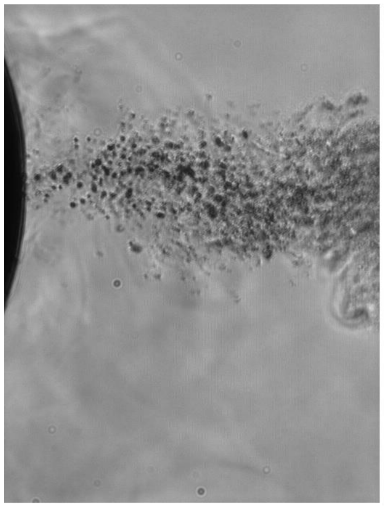
- Long irregular ligaments present significant modelling challenges for
  a) initialisation of emerging fluid
  b) modelling of subsequent evaporation and transport

Non-spherical droplets

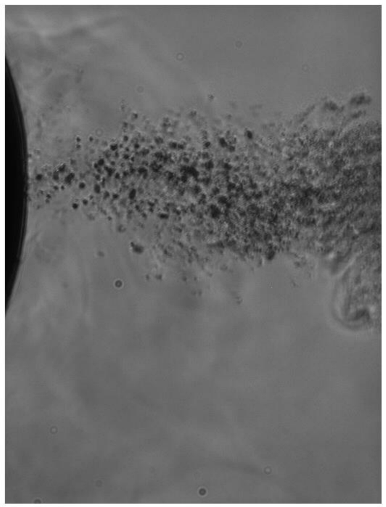
3D shape reconstruction, is needed in order to estimate the droplet surface area and volume

End of injection (cont.)

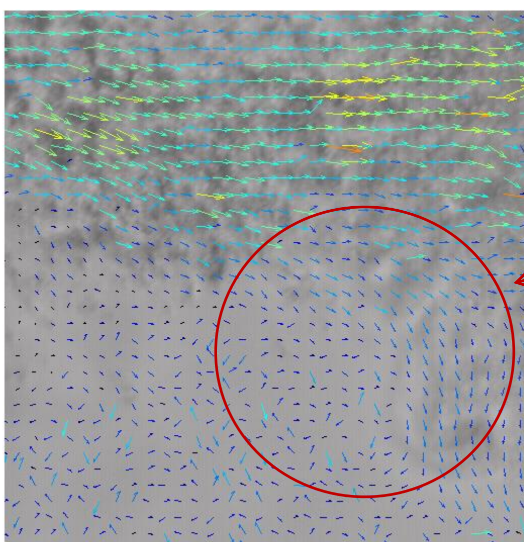
Frame 1



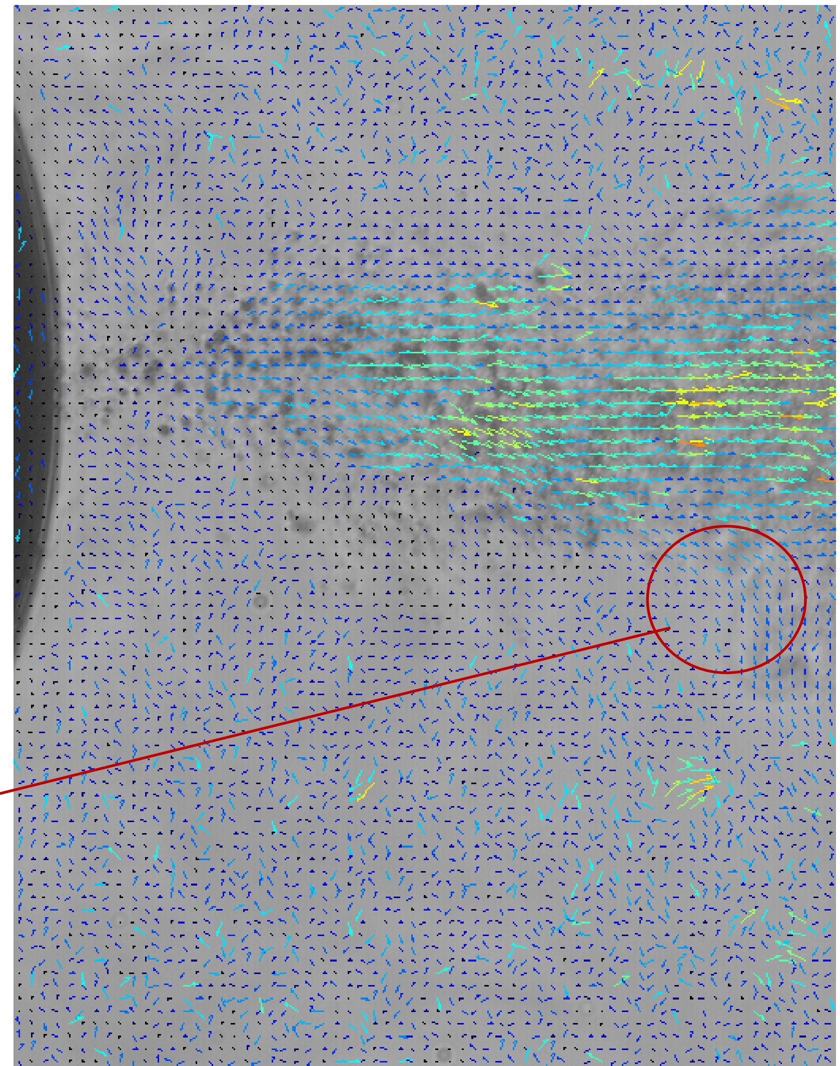
Frame 2



m/s



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

Equipment

EPSRC Engineering Instrument Pool

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