Spray parameter comparison between diesel and vegetable oils for non-evaporating conditions in a Constant Volume Combustion Chamber

Jonas Galle

ERCOFTAC
13-12-2011
Ghent University

Overview

- Why this research
- Modeling demands
- Why/Which spray parameters
- Why vegetable oils
- Why non-evaporative conditions
- Presented research goal
- Experimental setup
- Remarks to experiments
- Results & discussion
- Conclusions
- Future work

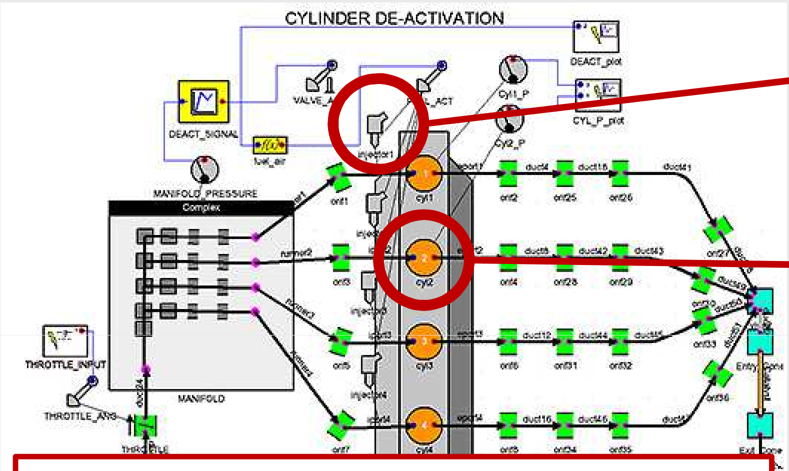
Why this research: project situation

- Emissions: - regulations, - environment
- Power: - Load capacity
- Fuel consumption: - Costs, - resources, - environment
- Durability: - noise, - wear

→ **Controlled by diesel combustion process**

→ **Spray properties** | **Combustion properties**

Why this research: goal



Power train modeling

- Emissions
- Power
- Fuel consumption
- Durability

Spray submodel

Combustion submodel

ADAPTATION for

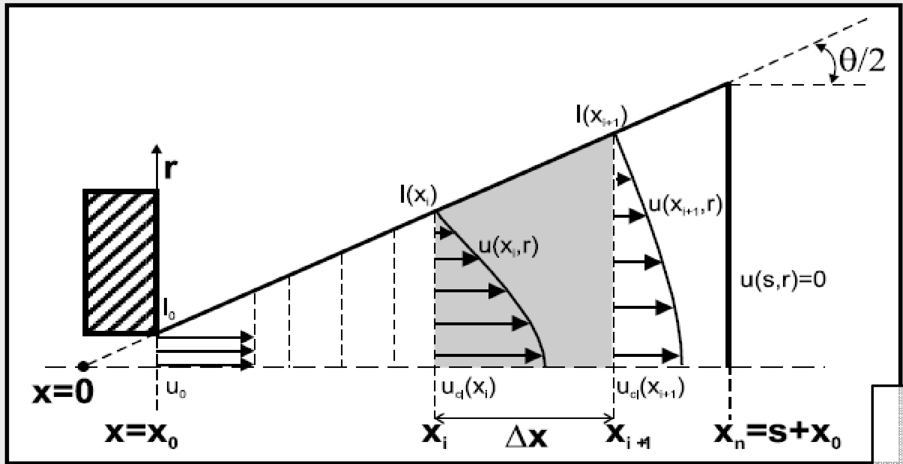
- Variable injection pressure
- Bio-oils (diesel hypothesis valid?)

Engine settings : real-time control
Engine design : off line design

Modeling demands

- Time & place of ignition
- Mixture ratio in space & time
- Temperature (enthalpy) in space & time

Proposal: 1D phenomenological model



Main assumptions

- Gaussian distribution for u, f, h
- constant spray pressure
- “mixing limited” hypothesis

Universidad Politécnica de Valencia
Fuel 87 (2008) 2871-2885

Why/Which spray parameters

- Why spray parameters
  - sprays preceed and initiate combustion (premixed & diffused)
  - sprays influence the emissions
- Which spray parameters

  (depends on the model assumptions)
  - Spray angle (related to air entrainment rate & breakup quality)
  - Liquid length (related to evaporation speed)
  - Penetration length (related to initial combustion behavior)
  - Vapor/liquid concentration (related to evaporation speed)
  - [Droplet size distribution (related to breakup quality)]

➔ **Good spray prediction = better prediction of combustion process**

Why vegetable oils

- Reduced fuel cost compared to biodiesel
- Lack of knowledge (in engines)
- Implementable on medium speed diesel engines
- Interest from the sector (in Belgium: ABCdiesel, Van Wingen)

Why non-evaporative conditions

- The used hypotheses are strongly linked with the breakup behavior:
  - Mixing limited hypothesis:
    - evaporation dominated by air entrainment
    - spray is saturated @ each moment
  - Droplet size hypothesis:
    - evaporation dominated by droplet size & evaporation

- Current setup limitations

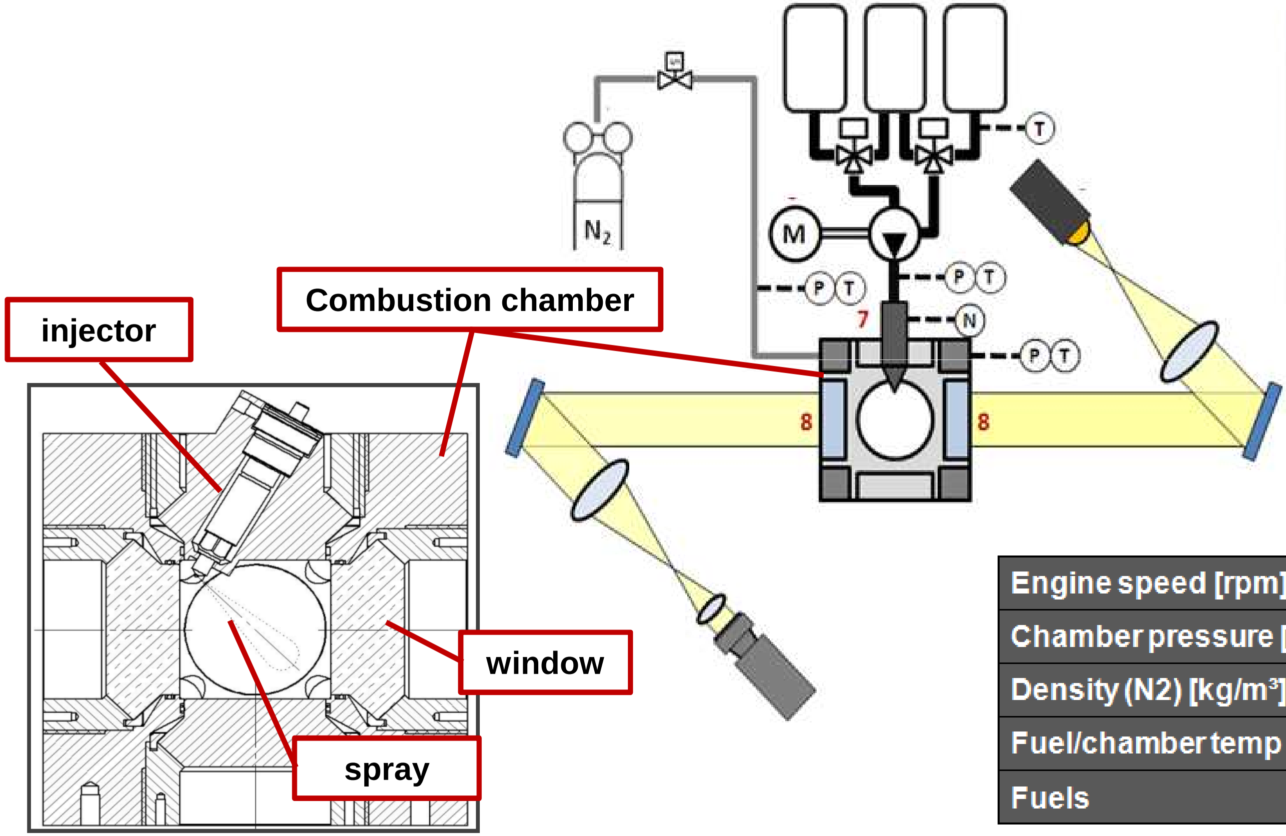
Goal of Presented research

- Qualitative evaluation of physical fuel properties effects on the spray and injection process for 3 fuel types:
  - Conventional diesel
  - Biodiesel (Rapeseed Methylester or RME)
  - Straight oil (Rapeseed Oil or RSO)

	Diesel	RME	RSO	Water
Density @15°C [kg/m^3]	835	833	920	998
Kin. viscosity @40°C [mm^2/s]	3.2	3.5-5	33.1	0.658
Surface tension @40°C [mN/m]	27	27.7	>33	69.6
Bulk modulus [GPa]	1.07-1.5	~1.7	1.6-4	2.2

- Can the "Mixing Limited"-hypothesis be applied?

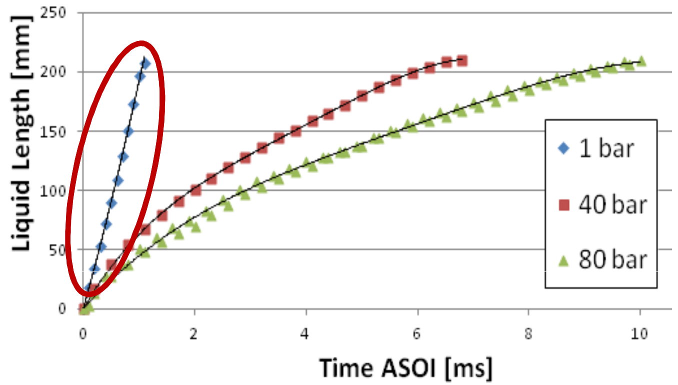
Experimental setup



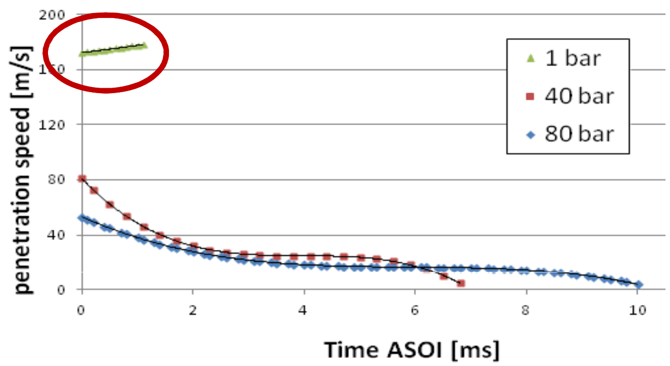
	Min	Max
Engine speed [rpm]	400	1000
Chamber pressure [bar]	1	80
Density (N2) [kg/m³]	1.2	94.8
Fuel/chamber temp [°C]	Room temperature	
Fuels	Diesel/RME/RSO	

Remarks about experiments

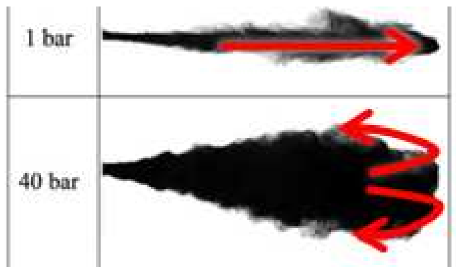
Air entrainment in sprays depends on chamber density



Liquid length development



Tip velocity development



Spray structure

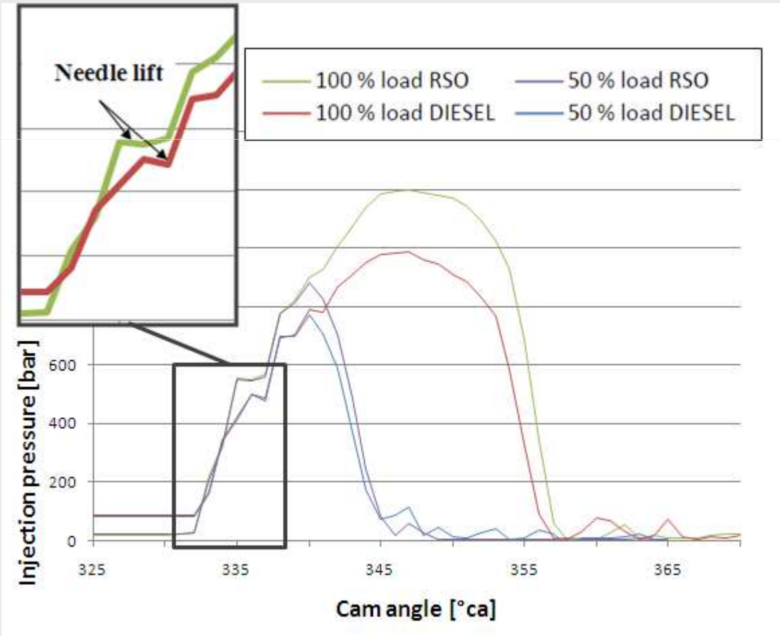
⇒ not all assumptions are valid

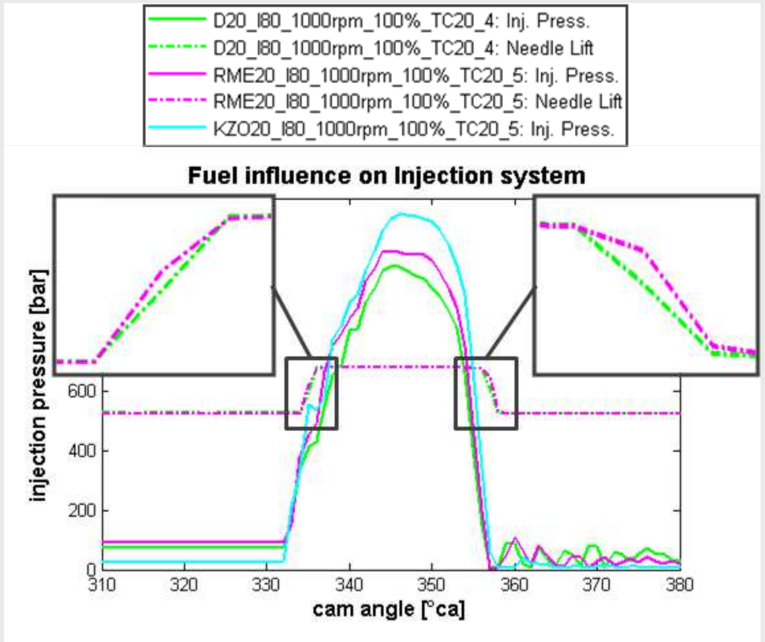
⇒ not relevant for engine simulations

Results & discussion: injection system

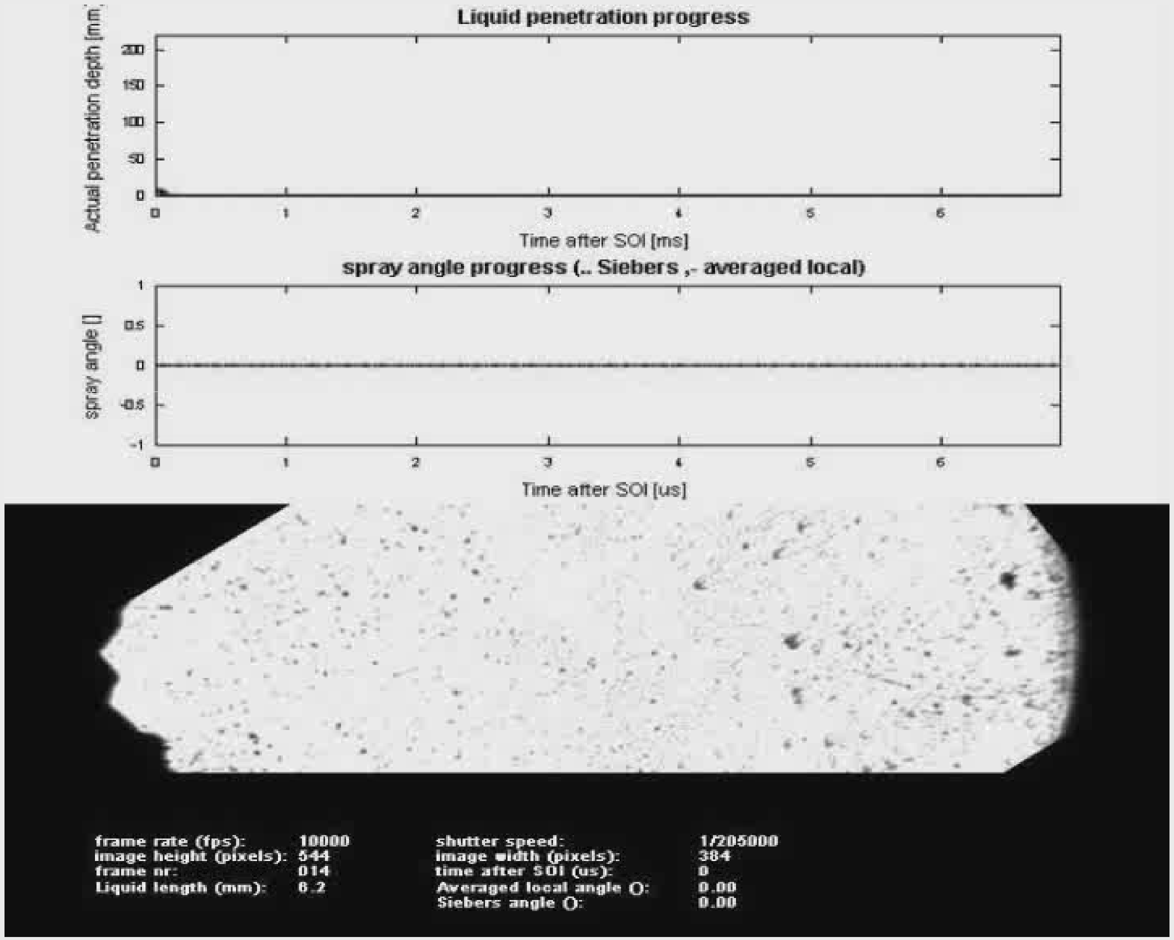
- Higher bulk modulus causes
  - Higher pressure build-up
  - Faster needle opening

less important for Common-rail systems



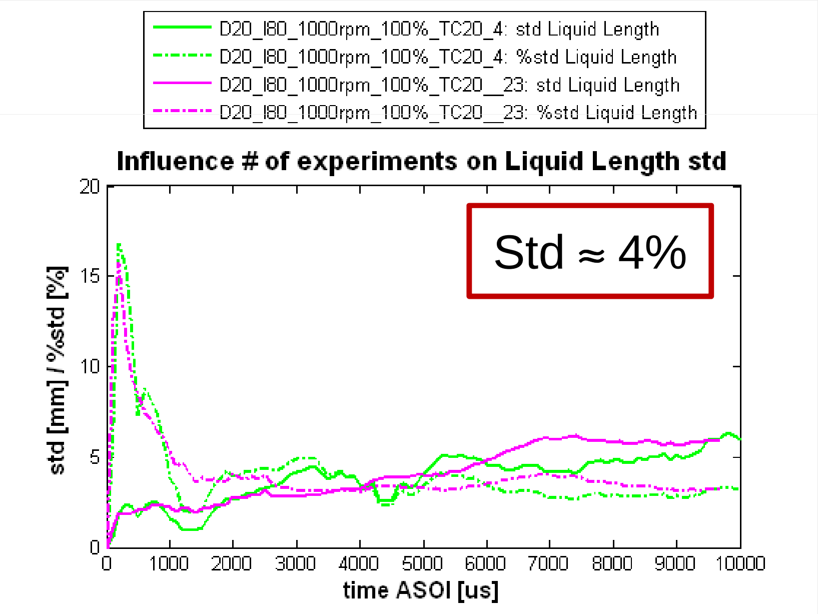


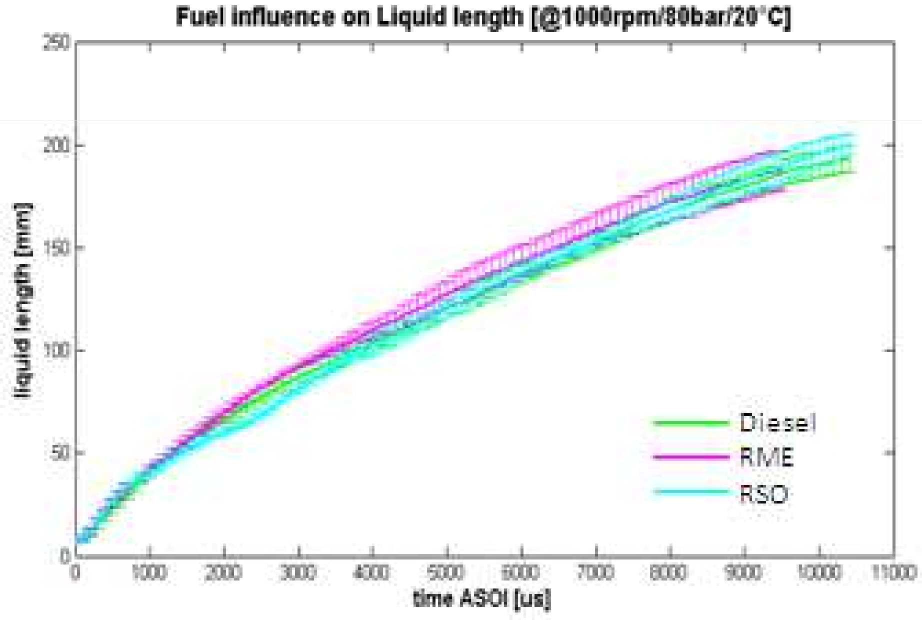
Results & discussion: image processing



Results & discussion: penetration length

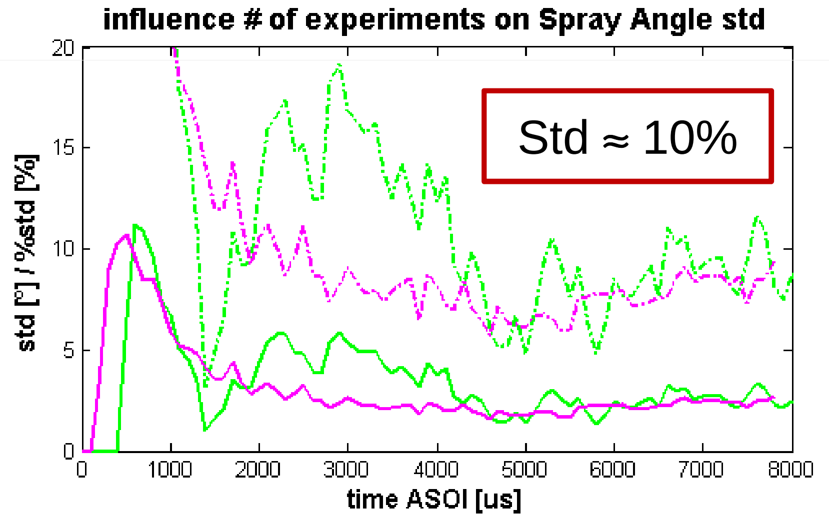
- No significant difference in Liquid penetration for same settings
- Error analysis: standard deviation for more experiments
  - Is more stable
  - Does not decrease

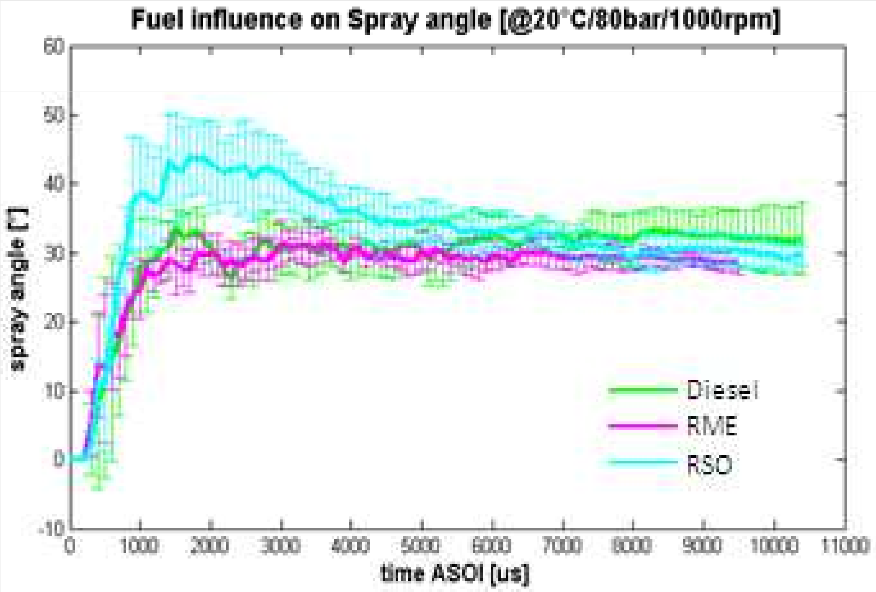




Results & discussion: spray angle

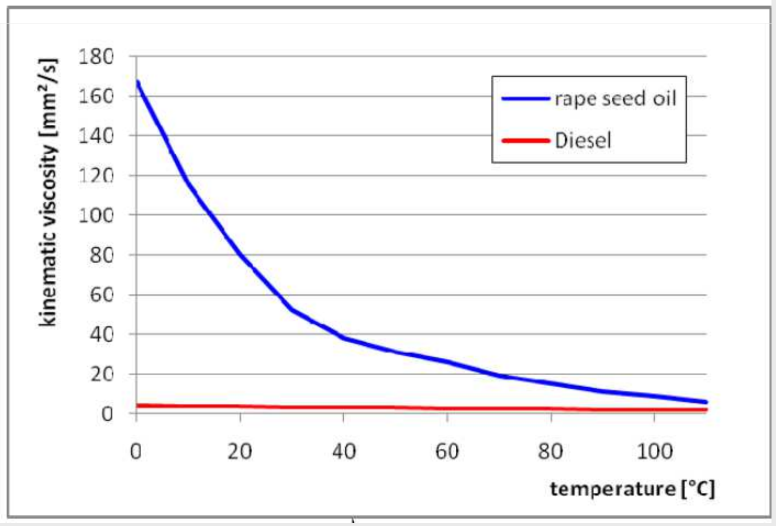
- Initially higher spray angle RSO (higher injection (rate) pressure)
- Error analysis: standard deviation for more experiments
  - Is more stable, but still high
  - Does not decrease

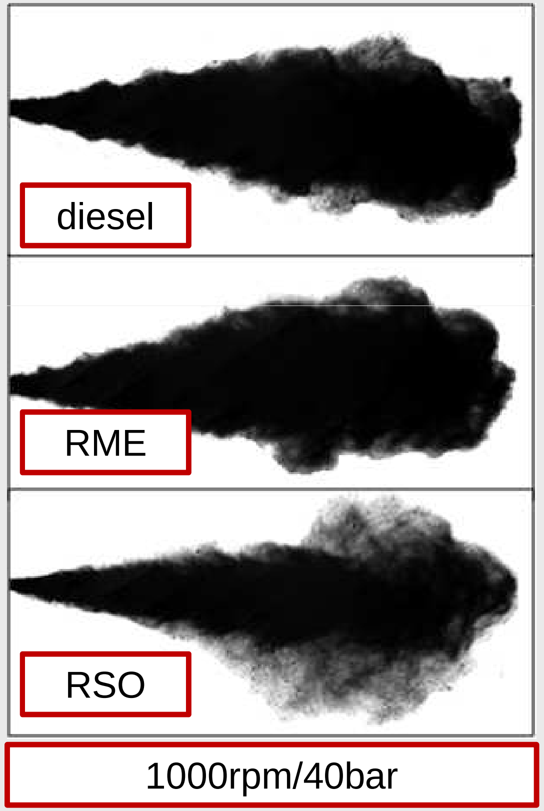




Results & discussion: spray structure

- Similar results for lower rpm (~injection pressure)
- Viscosity & surface tension
  more important than injection pressure
  for the break-up quality





Conclusions

- Difficult to measure spray angle and strongly depends on used definition
- Constant regime spray angle is reasonable, even for
  - variable injection profiles
  - different type of fuels
- "Mixing limited"-hypothesis needs to be questioned
- Large influence of viscosity on 'Mixing limited' hypothesis
- additional structure parameter needed for the comparison of spray of different fuels

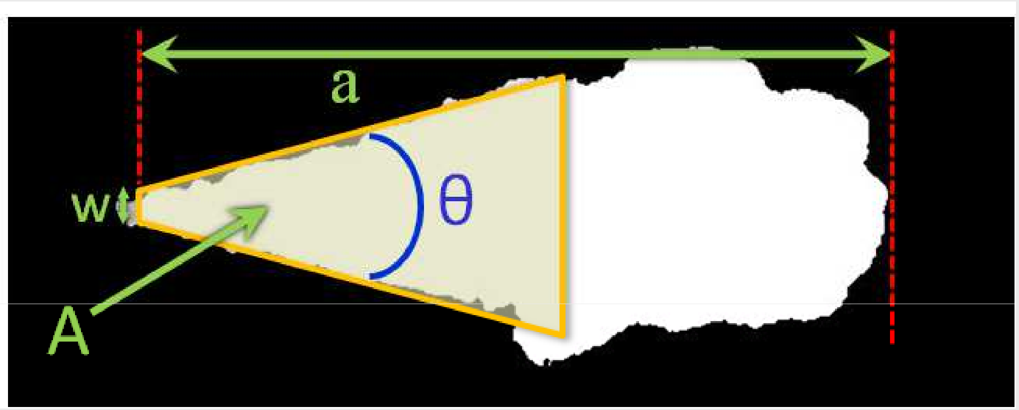
Future work

- Extension to Evaporative conditions:
  - How the structure affects the evaporation
  - influence of supercritical conditions (case for engines)
- 1D-model adaptation:
  - Variable injection pressure
  - Evaporative conditions: diesel hypothesis valid?

- Higher measuring frequency for sensors/camera
- Higher resolution can give more insight on droplet diameters

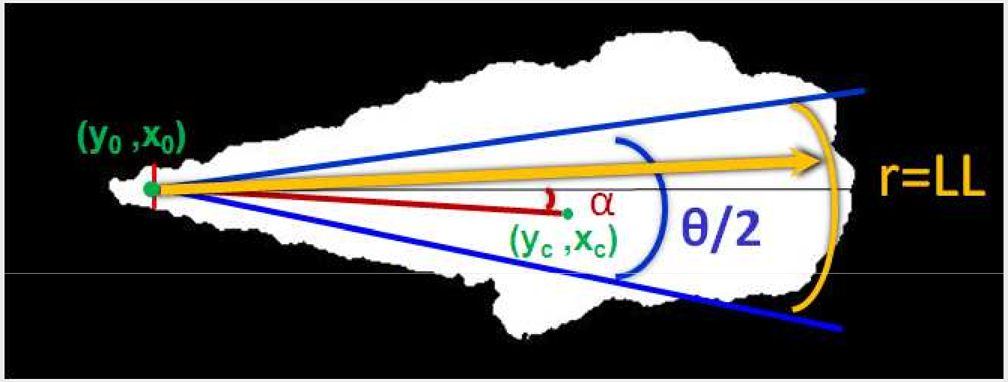
Thanks for your attention

Appendix: spray angle definition



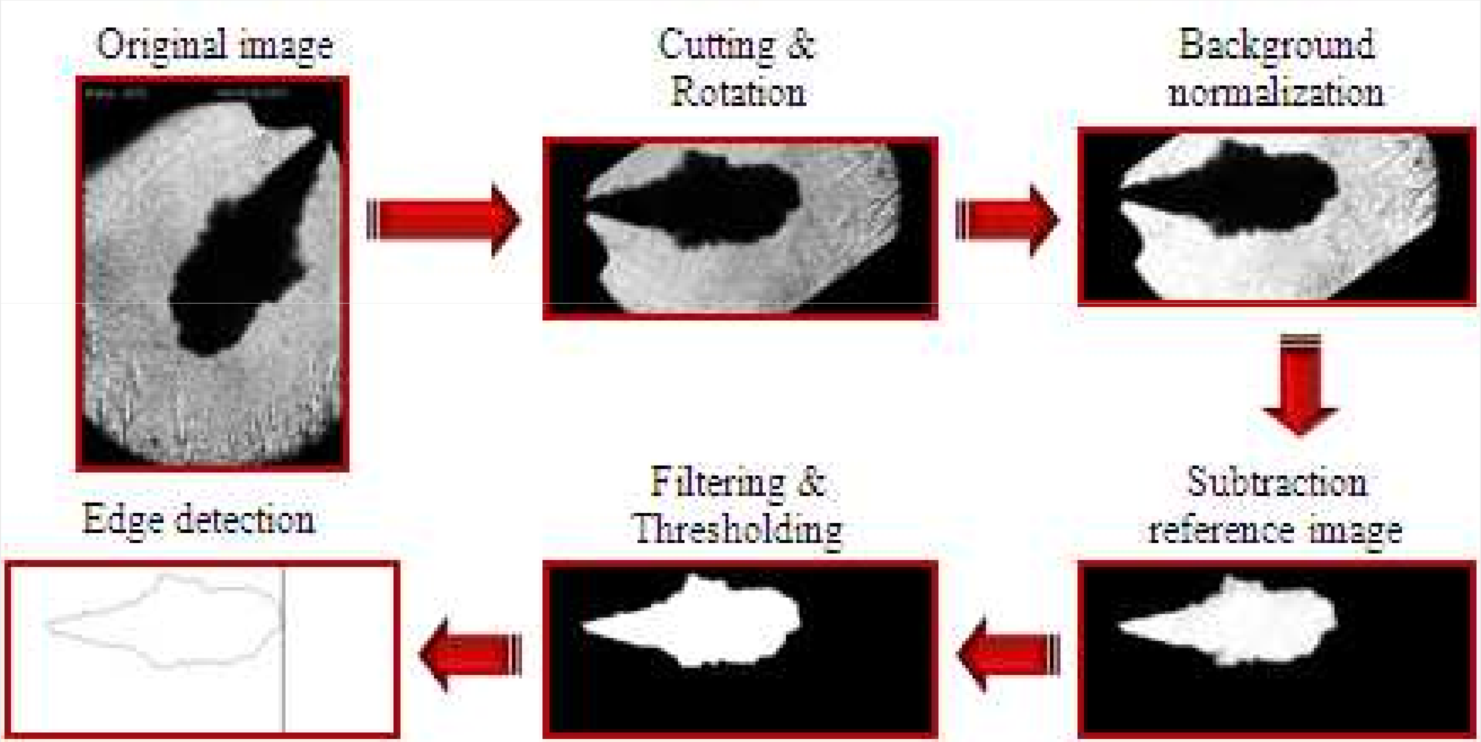
$$\theta = 2.\tan^{-1}\left(\frac{(A-w.a)/2}{(a/2)^2}\right)$$

Appendix: liquid length definition



$$\mathbf{real\ liquid\ length} = \frac{image\ liquid\ length}{sin(45°)} + \mathbf{invisible\ part}$$

Appendix: image processing



Appendix: injector information

Nozzle hole diameter	440 um
Opening angle holes	150 °
L/D	2.7
Nozzle shape	cylindrical
Amount of nozzle holes	8
Needle lift	0.65 mm
Sac diameter	2.8 mm
Average mass flow (diesel)*	1.45 mg/cycle
Needle opening pressure	275 bar

*according to engine measurements @1000rpm, full load

Appendix: measurement accuracy

Table 5 – Reproducibility of the measured parameters

Camshaft speed	+/-1,2%
Chamber pressure	+/- 5% (@40bar), +/-2.5% (@80bar)
Chamber temperature	+/-4%
Injection pressure	+/-1% (during the injection)

Table 6 – Accuracy of the image processed data

Start of injection	+100us (@10000fps)
Spray angle std	+/- 10% (20 measurements)
Liquid Length std	+/- 6%
Injection pressure std	+/-2%