Aalto University
School of Science
and Technology

High Cetane Number Paraffinic Diesel Fuel Studies
IEA TLM 2010 in Nara, Japan

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Study Objectives and Collaboration

- Fully utilize the potential of the renewable high cetane number parafinic fuels and their oxygenate blends → develop optimum combustion technologies for them
- Decrease emissions at least by 70%
- IEA and Domestic Collaboration
  - Aalto University
  - VTT
  - Åbo Academy Univ.
  - Tampere Univ. of Tech.
  - Neste Renewable Fuels
  - AGCO Sisu Power
  - Wärtsilä Finland
  - Aker Arctic

Implementation

- Literature review and reaction scheme evaluations
- Fuel spray studies
- Emission mapping calculations
- Optimum combustion design with CFD
- Engine tests with a high-speed research engine, LEO
- Engine tests with a medium-speed research engine, EVE
- Extensive emission measurements
- Particulate emission analysis

Fuels

- HVO, a typical representative of high cetane number parafinic fuel
- HVO+oxygenate blends
  - oxygenates will be decided based on literature review

Fuel properties

FUEL PROPERTIES *)	NExBTL biodiesel	GTL diesel	FAME (RME)	EN590 @ 2005
Density @15°C [kg/m3]	775...785	770....785	≈ 885	≈ 835
Viscosity @40°C [mm2/s]	2.9...3.5	3.2...4.5	≈ 4.5	≈ 3.5
Cetane number	84...99 **)	73...81	≈ 51	≈ 53
Distillation 90 vol% [°C]	295...300	325...330	≈ 355	≈ 350
Cloud point [°C]	- 5...- 30	0...- 25	≈ - 5	≈ - 5
Lower heating value [MJ/kg]	≈ 44	≈ 43	≈ 38	≈ 43
Lower heating value [MJ/litres]	≈ 34	≈ 34	≈ 34	≈ 36
Polyaromatics [wt%]	0	0	0	≈ 4
Oxygen [wt%]	0	0	≈ 11	0
Sulfur [mg/kg]	< 1	< 10	< 10	< 10

SAE 2005-01-3771

Fuel properties => effects

Polyaromatics [wt%]	0	0	0	≈ 4
Sulfur [mg/kg]	< 1	< 10	< 10	< 10

- PM reduction
- Chemistry
  - No aromatics (=PM source)
  - No S (=PM source)
  - Paraffins

  ⇒ more stable combustion

  And lower flame T (adiabatic)

  ⇒ NOx decrease

Trad. diesel and synthetic diesel combustion (ASFE 2006)

Milestones

1. Literature study on fuels and emissions. Medium-speed engine fuel spray measurements and CFD study. Hydraulic valve train of LEO engine. (2009)
2. High-speed engine fuel spray measurements. Medium-speed and high-speed EGR and Miller measurements with high cetane number paraffinic fuels. Emission and PM measurements. Emission mapping. (2010)

Milestones

- High-speed engine measurements with high cetane number paraffinic fuel with oxygenate blend. Emission and PM measurements. Reporting (2011)

Literature study

- Previous studies on High CN fuels: as such and with parameter optimization
- Oxygenate candidate study

	Oxygen wt-%	Flash point °C	Distillation °C	Density kg/dm^3	Cetane number
Reference fuels					
Diesel fuel***	0	>56	170-340°C	~0.84	>51
Ethanol***	34.8	13	78	0.794	8
FAME***	10	>100	300-340	0.88	>50
Oxygenate candidates					
n-Pentyl ether, DNPE	10***	57***	187***	0.783***	111-130***
2-Ethoxyethyl ether (Diethyl diglycol, Diethyl carbitol)	30***	71***	189***	0.91***	113-136***
Diethylene glycol dimethyl ether (Diglyme)	35.8	67	162**	0.945	112**
Triethylene glycol dimethyl ether (Triglyme)	35.9	111	220**	0.986	144**
Tripropylene glycol methyl ether (TPGME)	31*		242*	0.96*	65*
Glycerol-t-butyl ether (GTBE)				0.88*	35.2*
Cyclohexanone	16.3*		155*	0.95*	10*
Dibutylmaleate (DBM)	26*	>110	281*	0.99*	28*
Diethoxy butane	22	45***			97***
Dibutoxy methane (Butylal)	20	62	180***	0.8354	>74***
2-Methoxyethyl acetate	40.7		145	1.01	

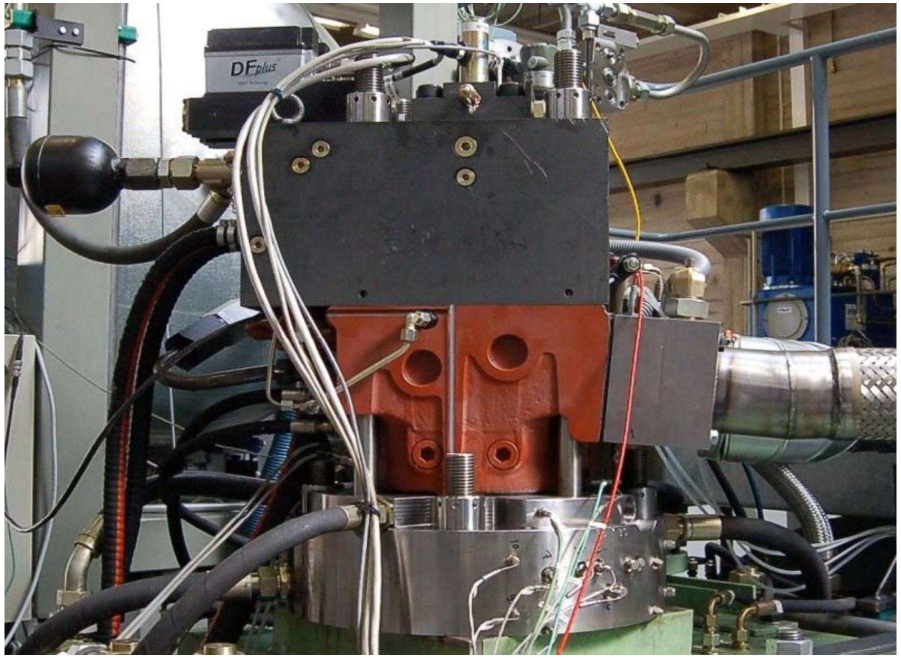
Sources: Natarajan et al. 2001 *) Boot et al. 2007, 2009 **) Kozak et al. 2007 ***) Nylund et al. 2005

Literature study: NExBTL benefits

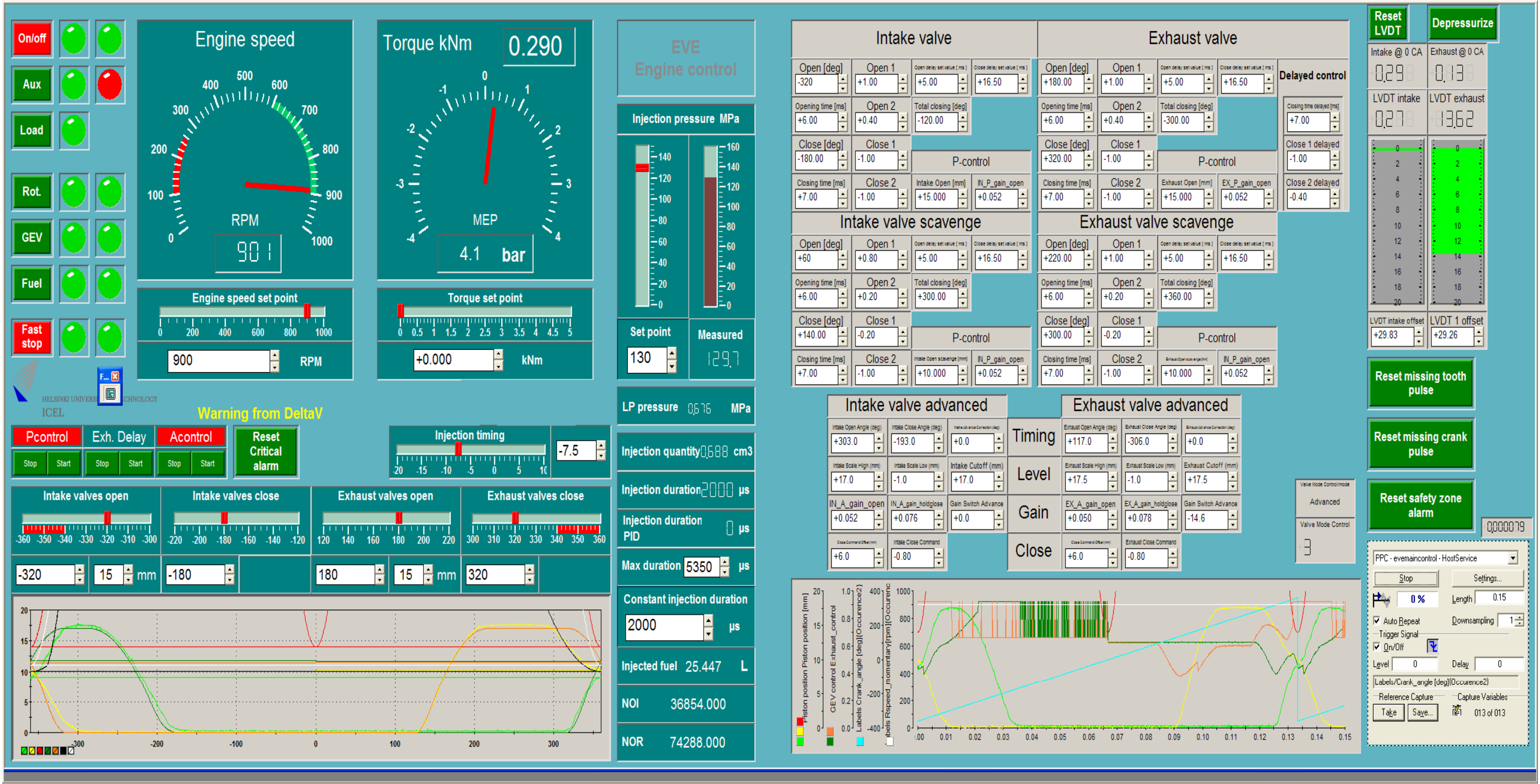
- Physical properties => wide spray, small SMD, quick evaporation => short liquid spray penetration, good mixing => PM reduction
- High CN => extreme Miller and higher EGR rate possible => NOx reduction potential
- No aromatics, paraffinic => clean, complete combustion (=> less PM) at lower temperatures => NOx -reduction
- Low effective compression ratio (Miller): lower T => NOx reduced
- Oxygenates => better combustion, especially in rich zones => PM reduction. Combustion T lower => less NOx.

Tests runs with medium speed engine - EVE

- **Valve timing:**
  - **Miller cycle as Early Intake Valve Closing**
  - **Reduced Scavenging Phase**
  - **Additional opening of the exhaust valve**
- **Three engine loads**
  - **only the highest is presented**
- **Work phases:**
  - **Simulation with GT-power**
  - **Test runs**

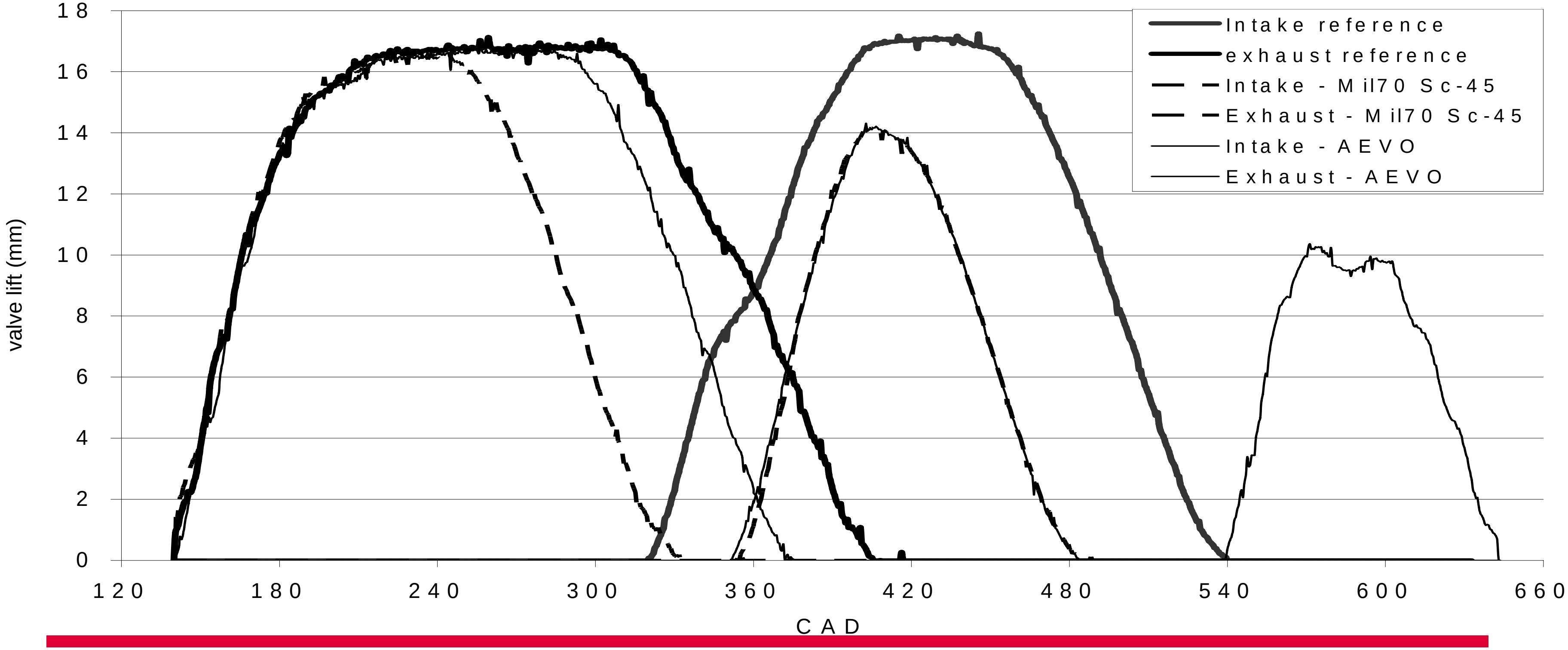


EVE Main Control



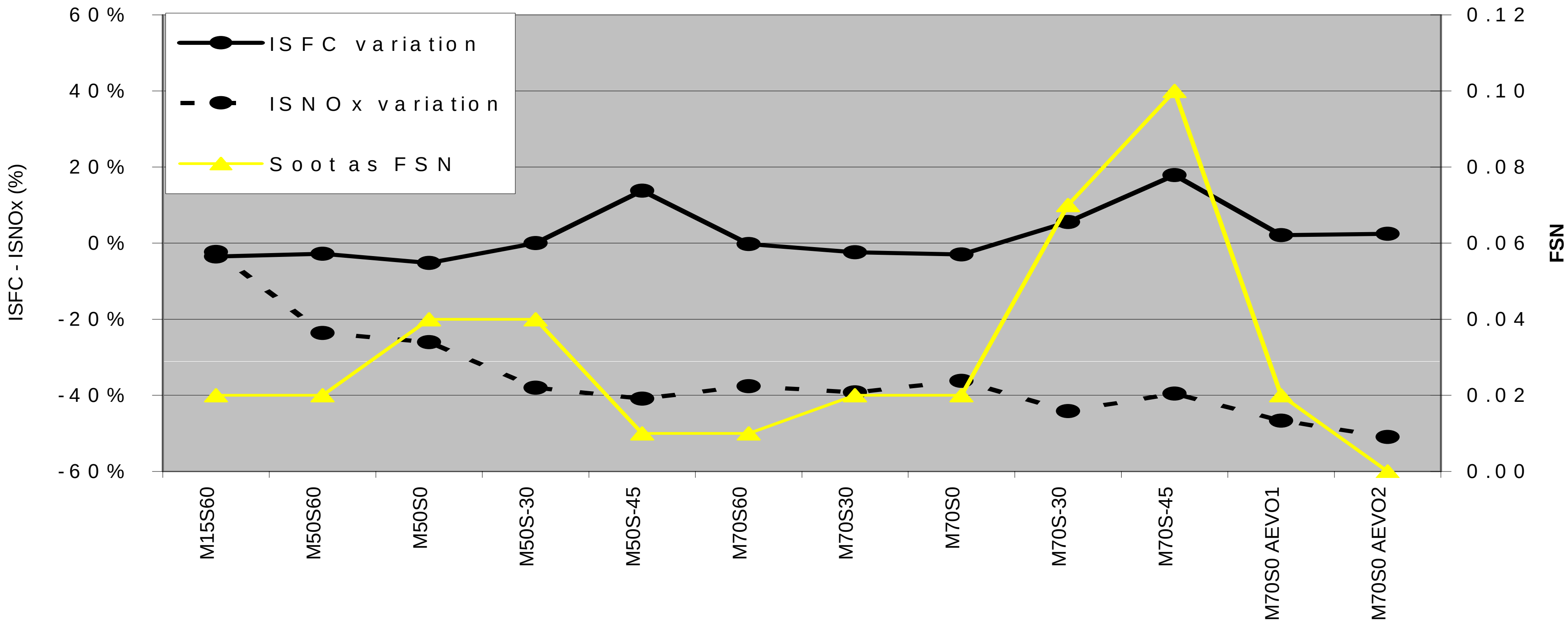
EVE Valve Timing

- extreme IVC = 70 CAD BBDC, negative scav. up to 45 CAD
- additional exhaust valve opening in compression stroke



Main results

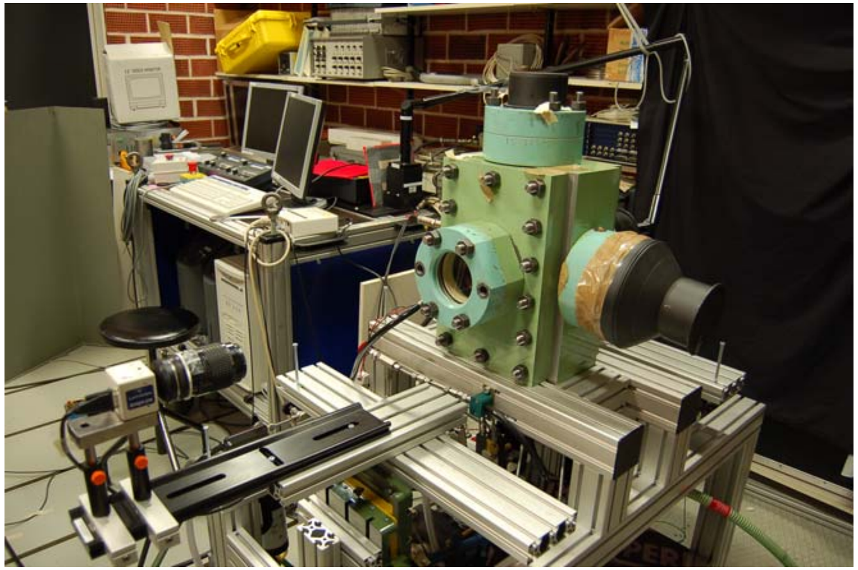
- NOx reduced over 50% compared to the ref. Diesel
- With many configurations the fuel penalty is negligible or absent
- It is possible to keep soot values very low, even with extreme timing



Experimental fuel spray studies

- Properties of fuel spray have a major effect on engine combustion.
- Measurements are carried out to figure out fundamental spray properties and to support the computational studies.
- The spray penetration and spray angle of different nozzles and fuels are measured with laser based backlight imaging.
- Studies are made using a pressurised test chamber imitating real engine conditions at the end of the compression stroke.

Pressurised test chamber

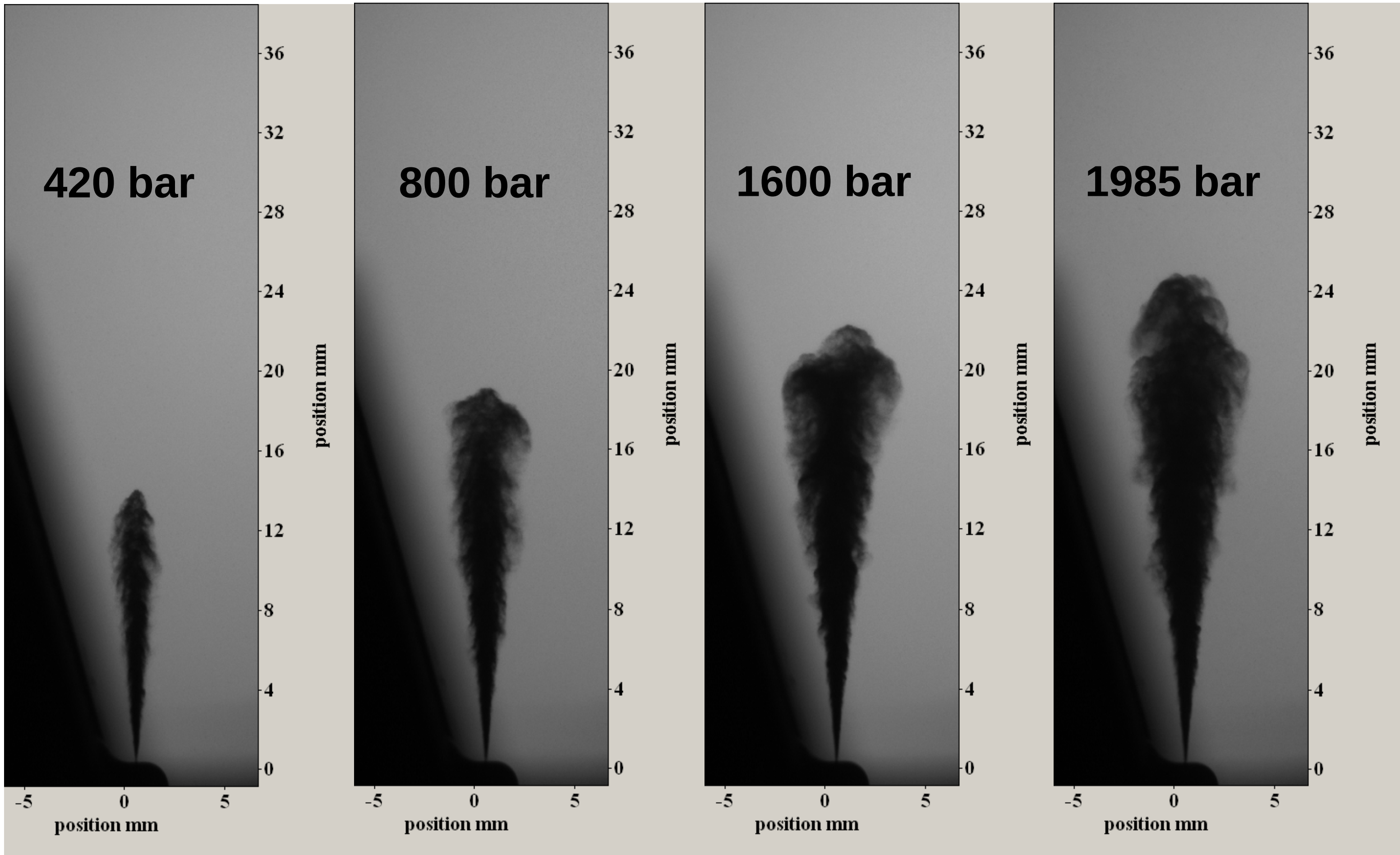


Experimental fuel spray studies

- High speed engine: The spray penetration and spray angle measurements have been finished.
- Following measurements have been completed:
  - **NExBTL**:
    - Nozzle orifice diameter: 0,08 mm and 0,12 mm
    - Injection pressure 1000 bar and 1985 bar
  - **Diesel**:
    - Nozzle orifice diameter: 0,08 mm and 0,12 mm
    - Injection pressure 1000 bar and 1985 bar

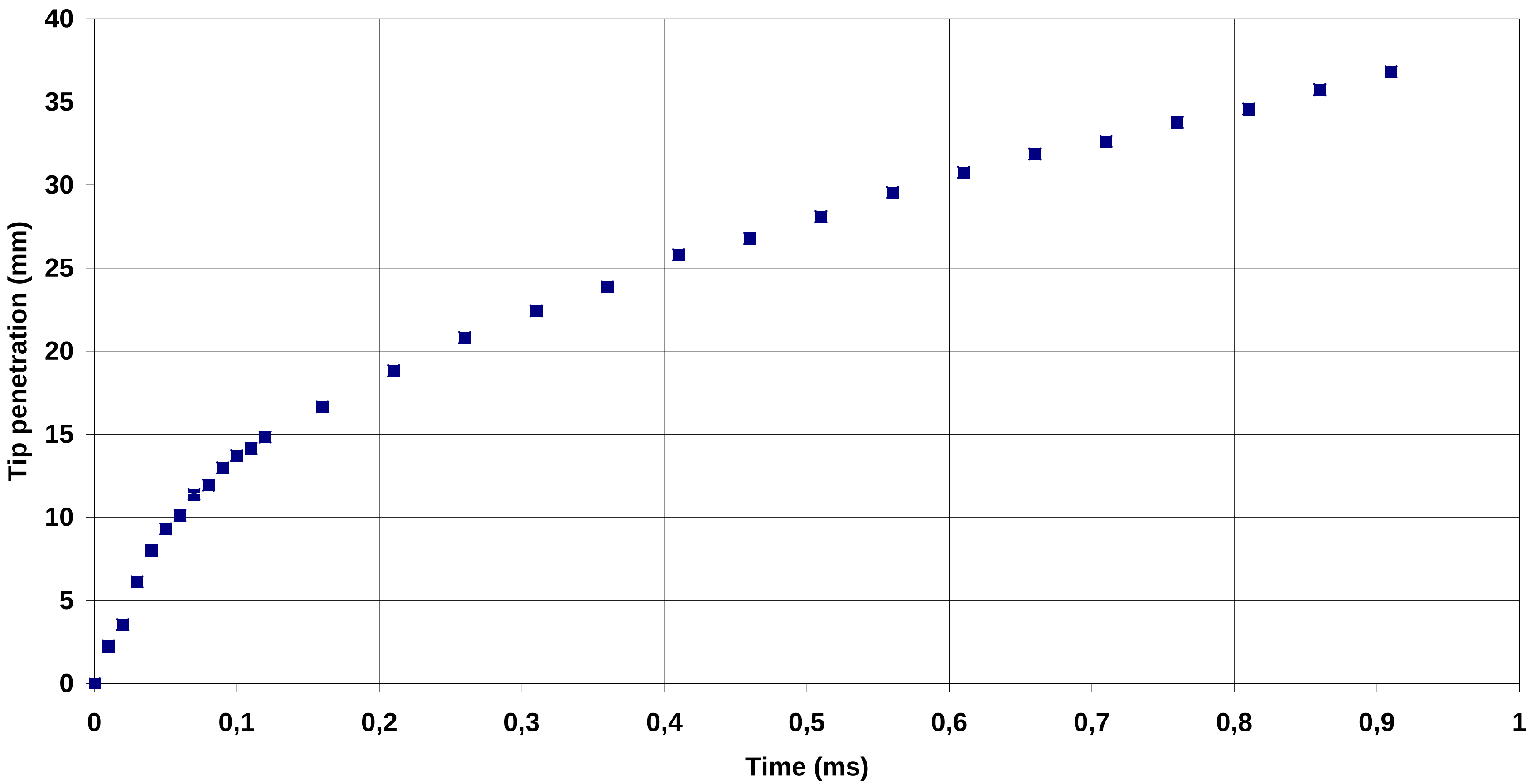
Injection pressure

NExBTL, 0,08 mm, 0,6 ms after start of injection (mechanical delay 0,34 ms).

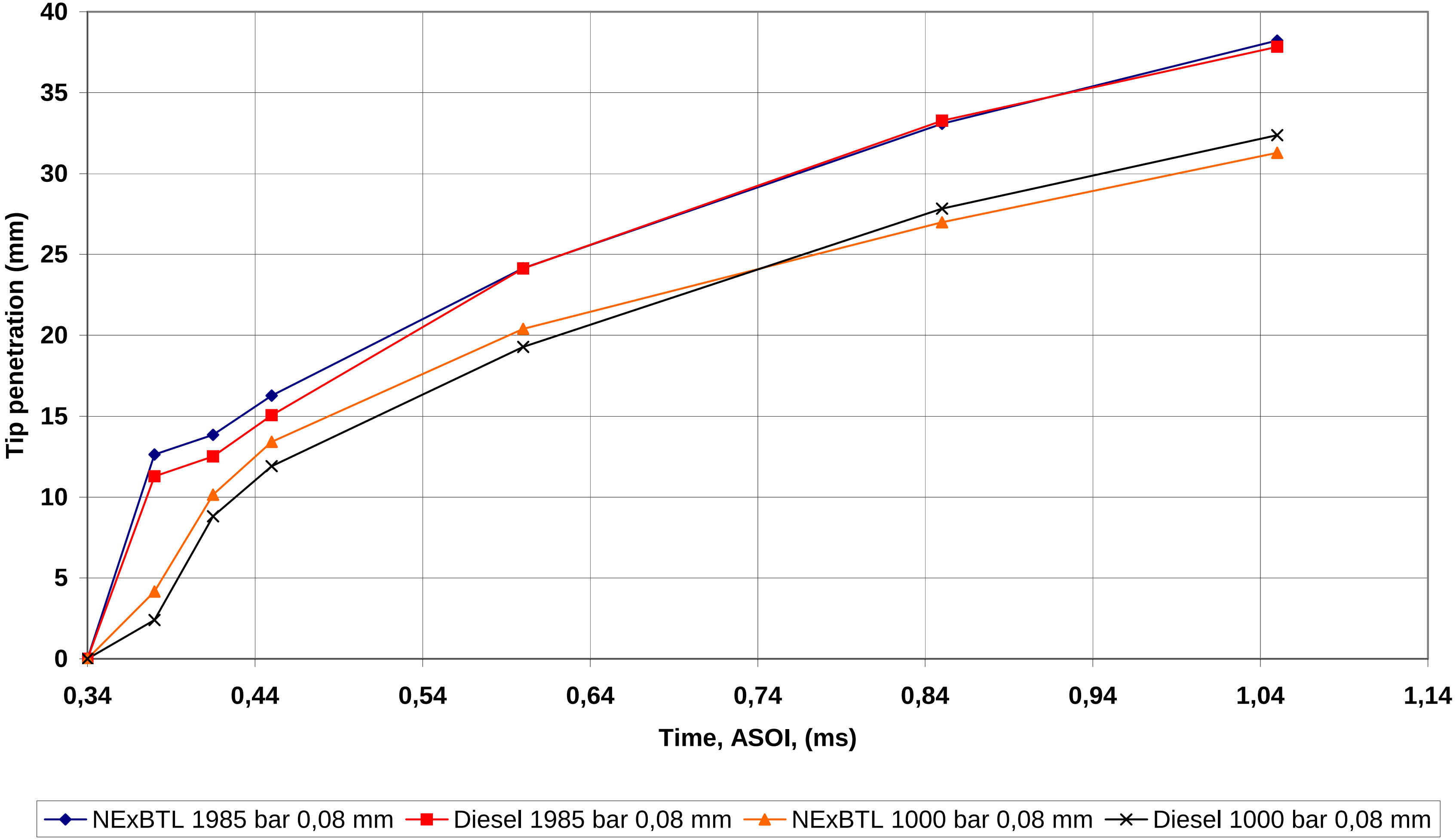


Spray tip penetration

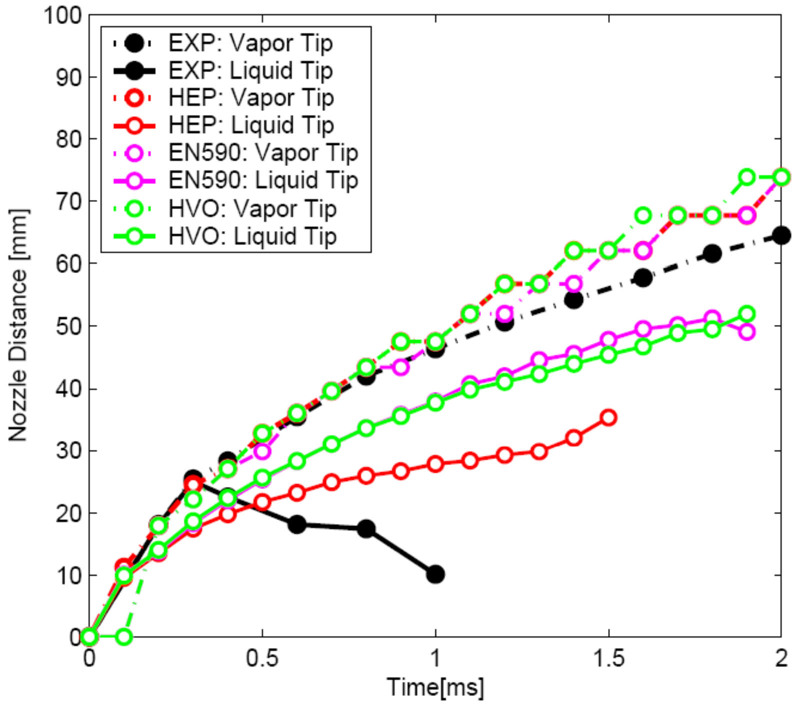
Fuel: **NExBTL**, Injection pressure: **1000 bar**, Nozzle orifice diameter: **0,08 mm**

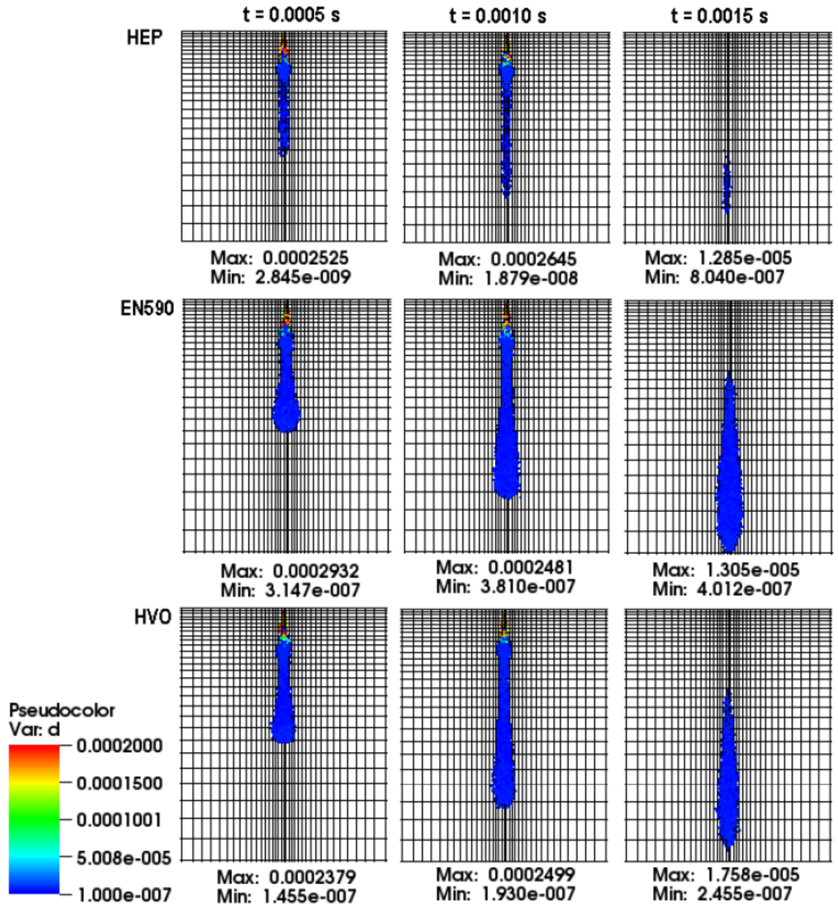


Spray tip penetration

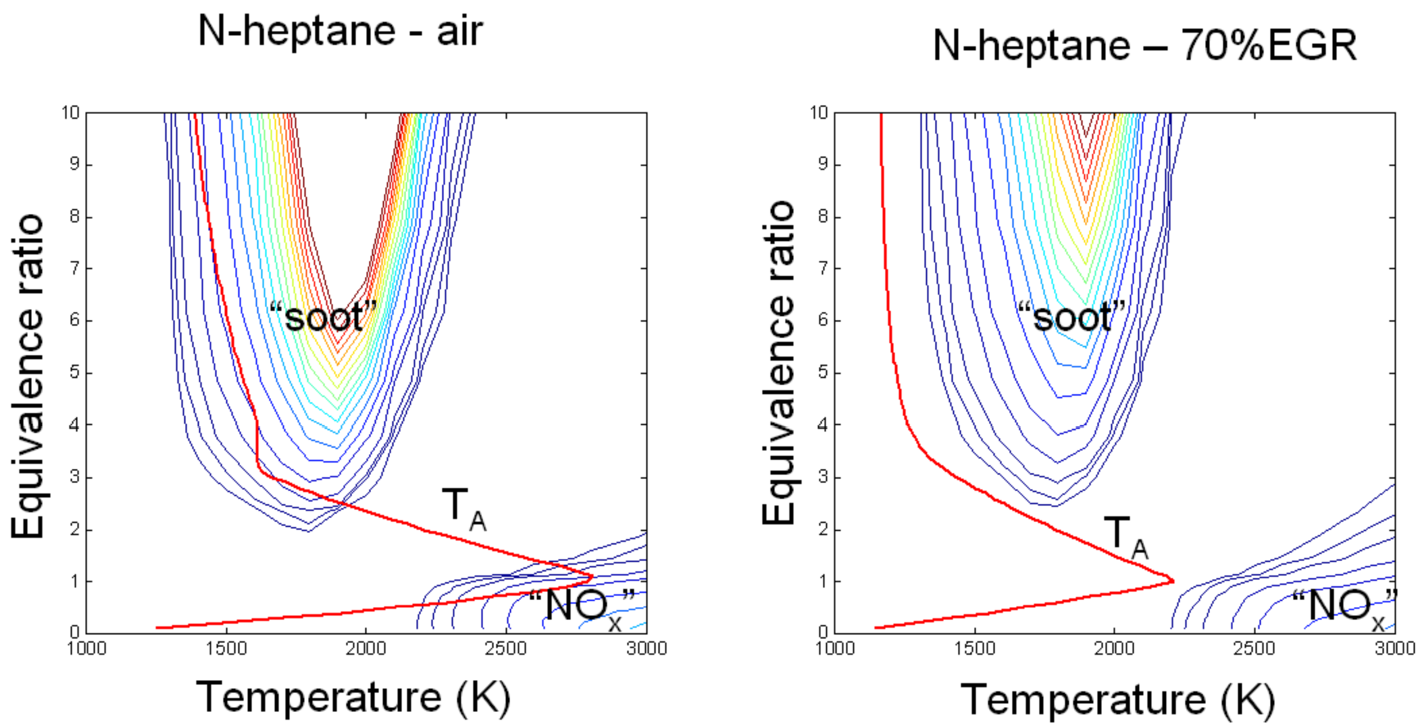


Spray Studies with OpenFoam





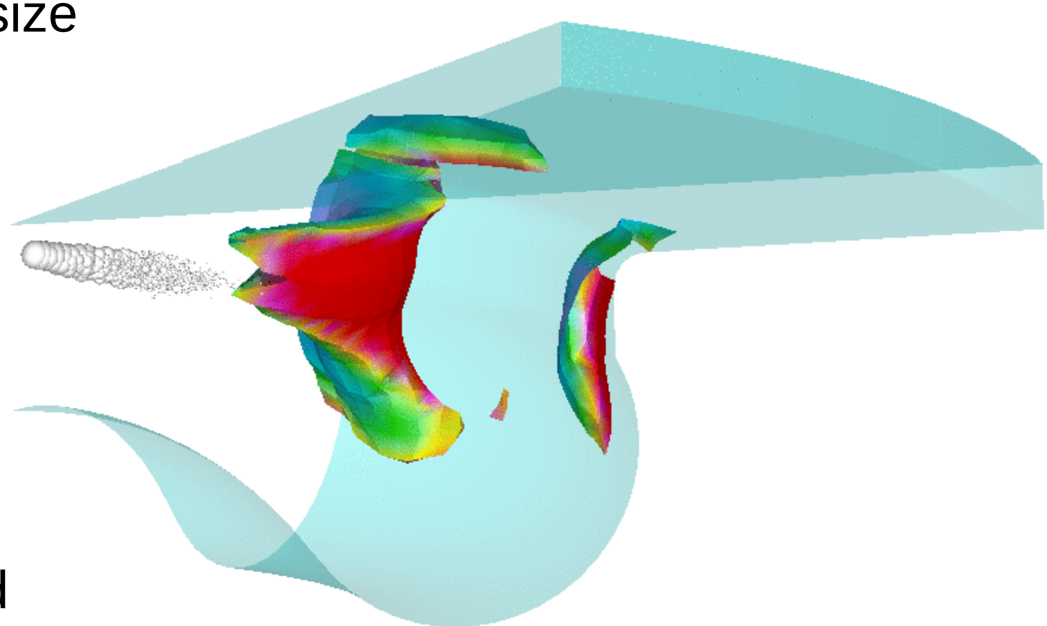
Emission mapping



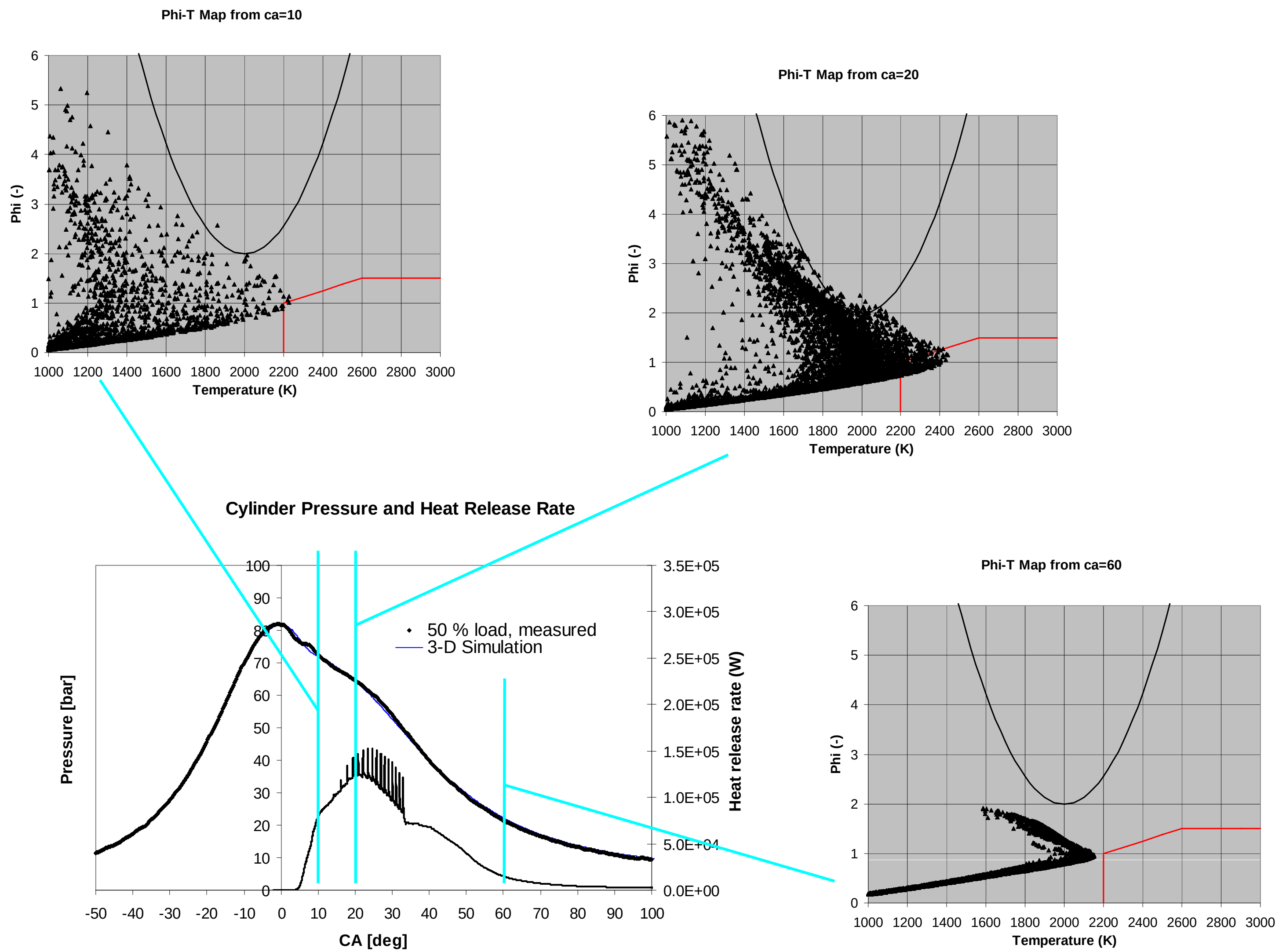
Anders Brink

CFD and Phi-T Maps

- Fuel injection, combustion, and emission simulations in a single-cylinder heavy-duty size research engine
- Using Phi-T maps and CFD to analyze current combustion system
- Locate areas where the strongest emission formation is taking place
- The target is to optimize the combustion system to avoid strongly sooting and NOx producing areas in the Phi-T map

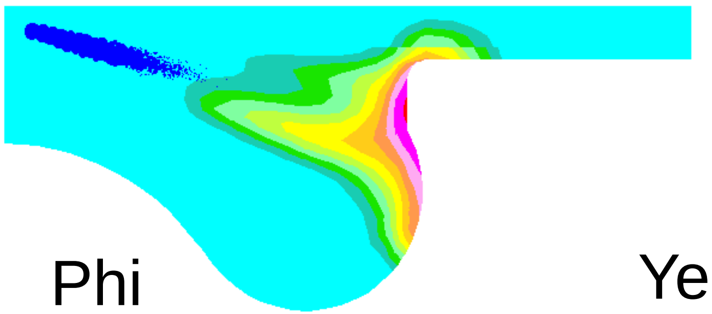


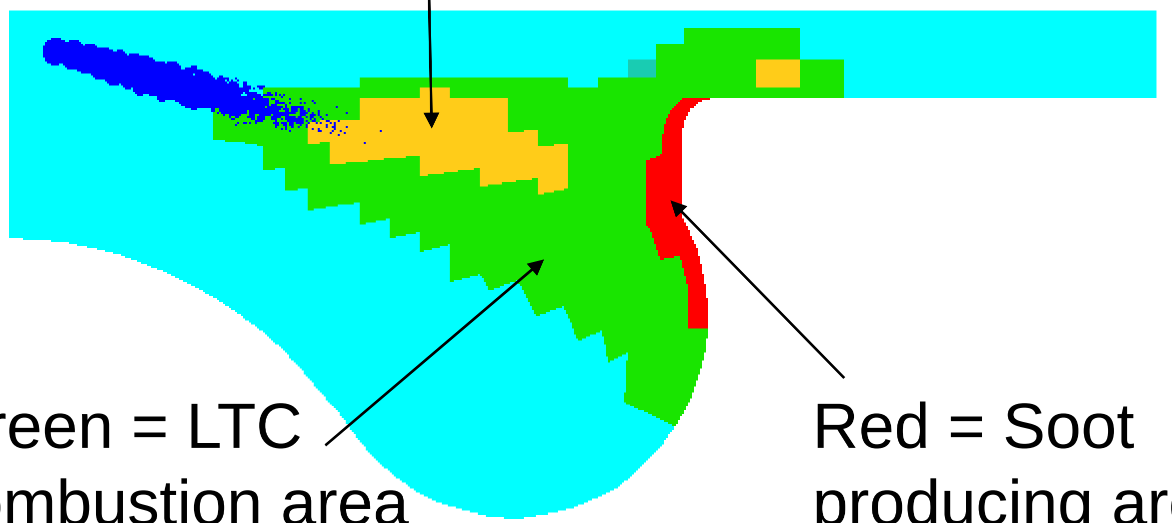
Temperature iso-surface (2500K) in a diesel engine sector model during combustion 10 crank angle degrees after the start of fuel injection. Ossi Kaario


Phi-T Map from ca=10
Phi (-)
Temperature (K)
Phi-T Map from ca=20
Phi (-)
Temperature (K)
Cylinder Pressure and Heat Release Rate
50 % load, measured
3-D Simulation
Pressure [bar]
Heat release rate (W)
CA [deg]
Phi-T Map from ca=60
Phi (-)
Temperature (K)

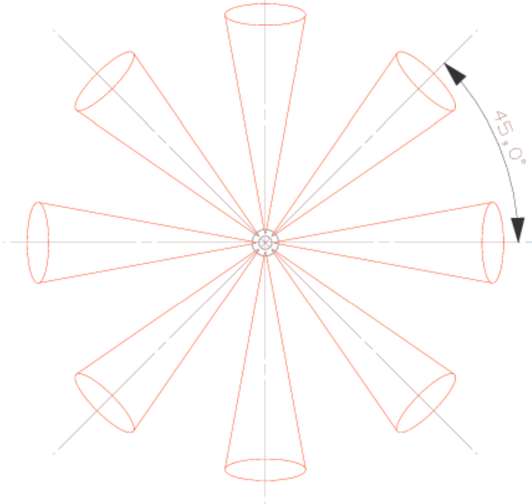
Ossi Kaario

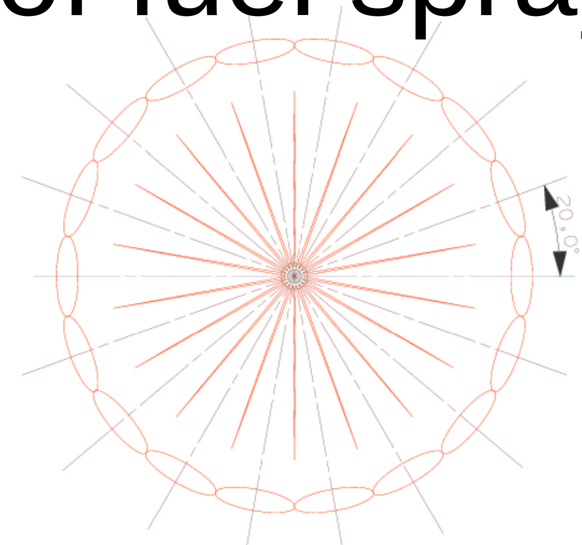
Combustion Areas

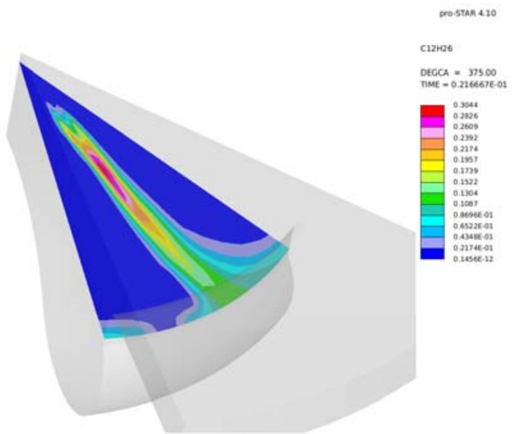


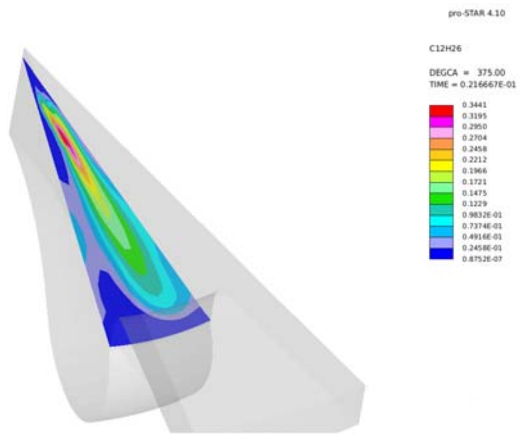


Interaction of fuel sprays









Armin Wehrfritz

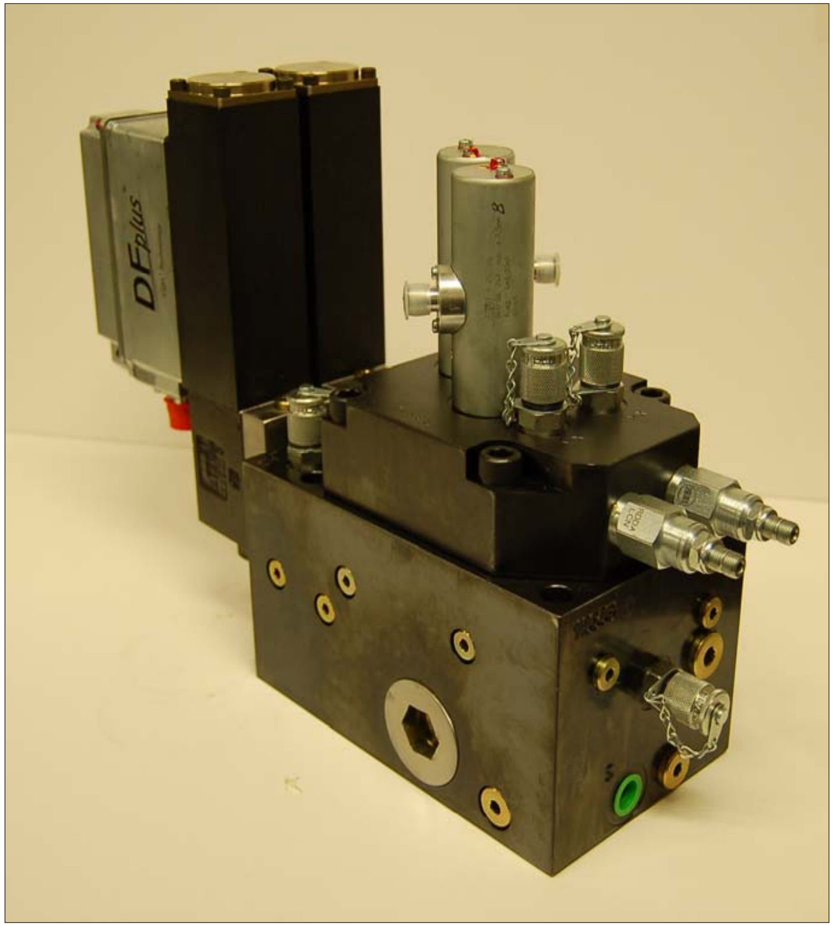
Engine LEO

- High-speed single-cylinder research diesel engine based on SisuDiesel 84 CTA
- Electrohydraulic valve mechanism

Engine LEO

Done:

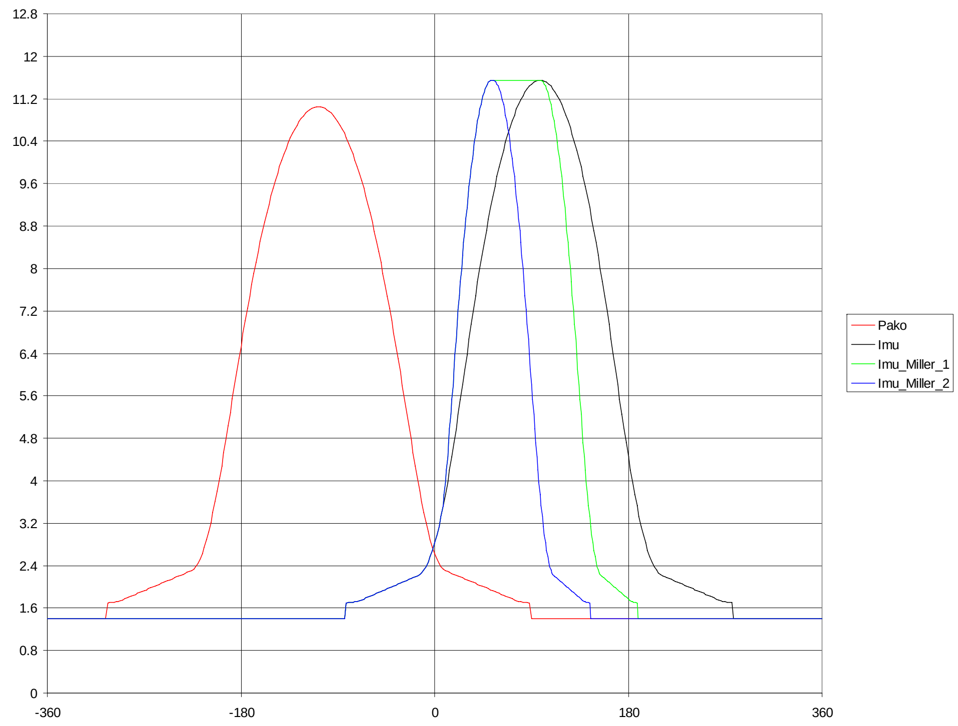
- reference runs
- reference emission levels
  - regulated emissions
  - particle size measurements (VTT)
  - unregulated emissions (VTT)



Engine LEO

What next..?

- during 2010 EGR- and Miller runs
- at the end of 2010: optimized process runs
- 2011 oxygenate runs



Tasks still ahead

- Analysing all the computational and experimental results got so far
- CFD optimization
- High speed engine tests (going on)
- Tests with oxygenate blends in 2011