WP Leaders: Johan Hult/Christian Kunkel

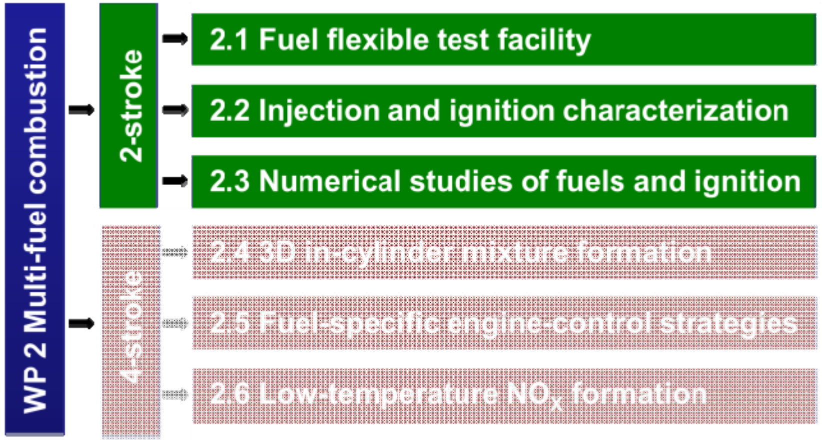
Objectives

- Further improve fuel flexibility of marine engines
- Increase understanding of injection, ignition, combustion and emissions formation for novel and mixed fuels → efficient operation
- Develop experimental and numerical tools required to exploit alternative fuels in marine engines:
  - Experimental facilities with optical access
  - Development of numerical tools
  - Development of novel control strategies

Partners: MAN, Lund University, DTU, Technische Universität München, Politecnico Milano 1863

WP Leaders: Johan Hult/Christian Kunkel

Structure: subprojects, partners, roles



MAN Energy Solutions 2-stroke [2.1-2.3]

- Coordination, fuel-flexible facility, optical test engine, engine tests, CFD, CFD validation data

Danish Technical University: Dept. of Chemical Engineering (Prof. Glarborg) [2.3]

- Detailed chemical kinetic models, experimental validation of mechanisms

Lund University: Division of Combustion Physics (Prof. Mattias Richter) [2.2]

- Development of optical techniques, optical engine tests

Lund University: Division of Fluid Mechanics (Prof. Xue-Song Bai) [2.3]

- Dual-fuel CFD: cell clustering for detailed chemistry

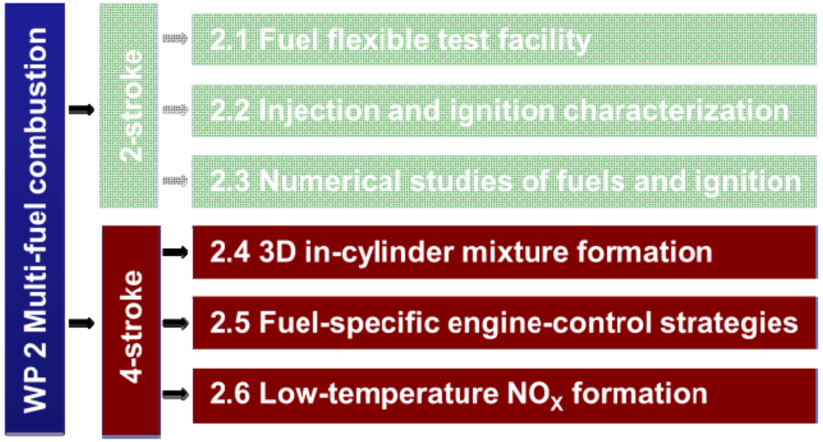
Politecnico di Milano: Department of Energy (Prof. Onorati) [2.3]

- Dual-fuel CFD: mesh motion handling, charge preparation, tabulated chemistry

WPx: Title of Work Package

WP Leaders: Johan Hult/Christian Kunkel

Structure: subprojects, partners, roles



MAN Energy Solutions 4-stroke [2.4-2.6]

- Coordination, optical test engine, tracer seeding system, engine tests on full scale engine and on single cylinder engine, spray investigations, fuel specific control strategy

Technical University of Munich: IC Engines (Prof. Wachtmeister) [2.4]

- Optical cylinder head concept, development of optical techniques, optical engine tests

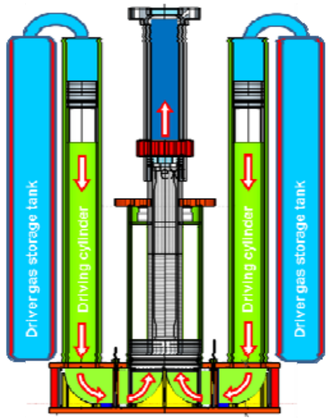
Technical University of Munich: Thermodynamic (Prof. Sattelmayer) [2.6]

- Low temperature NOx formation, development and validation of models

WP Leaders: Johan Hult/Christian Kunkel

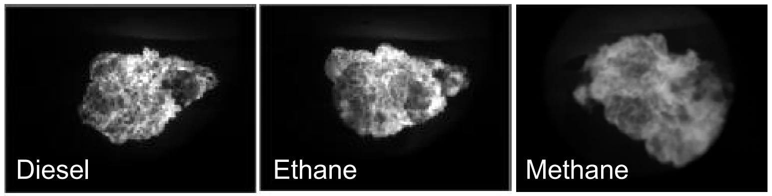
Outline of work performed

- A fuel-flexible test facility for controlled studies of fuel injection, ignition and combustion under realistic conditions designed.



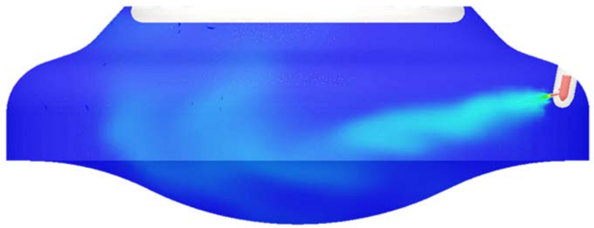
Fuel-flexible test facility concept

- Optical tests on several fuels (Diesel, LNG, Ethane, LPG) performed on the 4T50ME-X engine. Optical methods for multi-camera 3D imaging, lube-oil visualisation and schlieren prepared.



Optical imaging of different fuels on test engine

- Detailed chemical kinetic models for alternative fuels developed. CFD of single and multi-fuel combustion performed.


CFD of dual-fuel combustion on low-speed engine

WP Leaders: Johan Hult/Christian Kunkel

Outline of work performed

- Realisation and successful testing of a concept to measure 3D in-cylinder mixture formation on a dual fuel medium speed single cylinder engine.

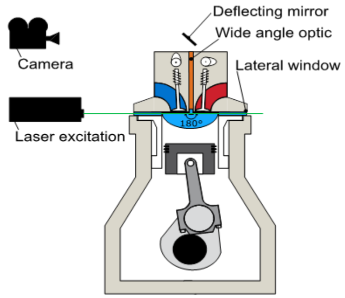


Fig.1: Design for vertical and horizontal accesses

- Fuel-specific engine-control strategy developed on a single cylinder engine and successfully validated on a MAN-ES medium speed full scale dual fuel engine.

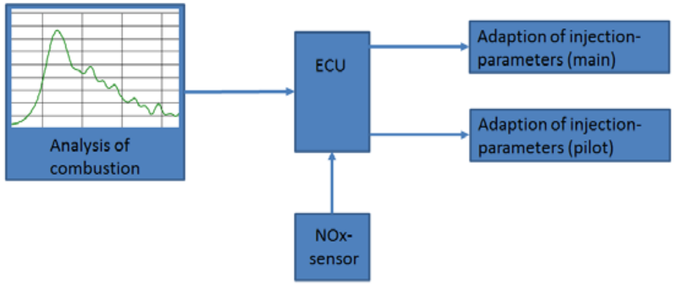


Fig.2: Illustration concept for a fuel flexible engine

- Development and validation of an efficient numerical model to predict NO_2 formation in a dual fuel medium speed engine.

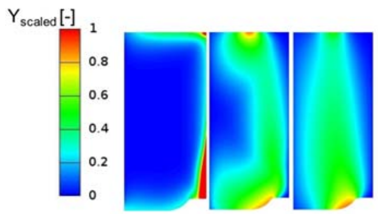


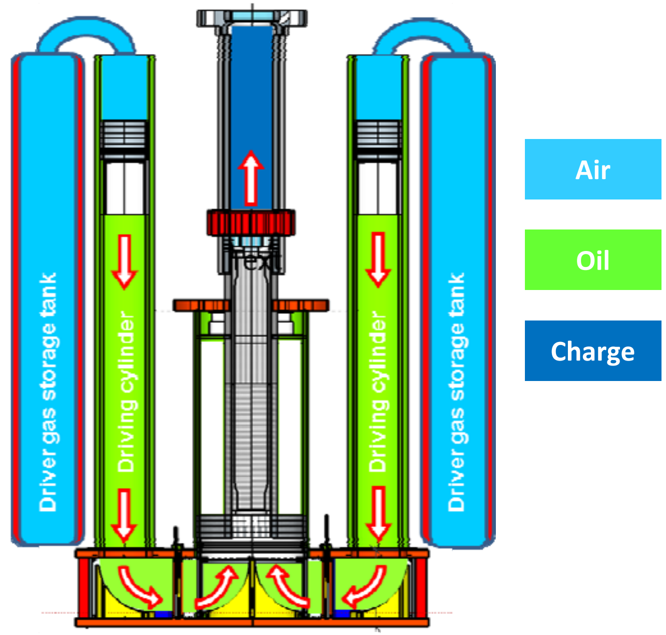
Fig.3: Simulated concentration in combustion chamber at BDC of CH4, NO2, NO (from left to right)

WP Leaders: Johan Hult/Christian Kunkel

Final results & Achievements

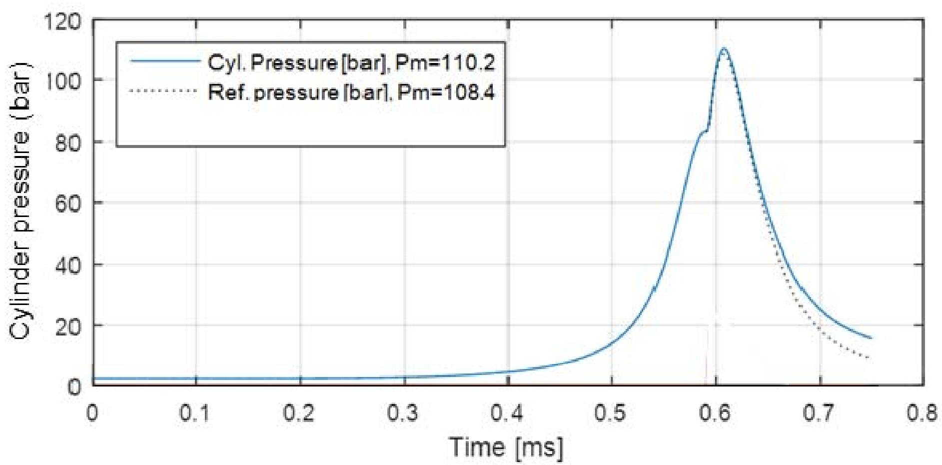
Fuel flexible test facility:

- ➢ Concept evaluation → finished
- ➢ Design specifications → finished
- ➢ Building specifications → finished
- ➢ Detailed design work, purchasing & construction → postponed (limited engineering capability)



Fuel-flexible test facility pneumatic-hydraulic drive concept

- Hydraulic drive
- Ø 500 mm
- Optical access
- Expansion
- Height:~5 m
- Footprint:~2×3 m

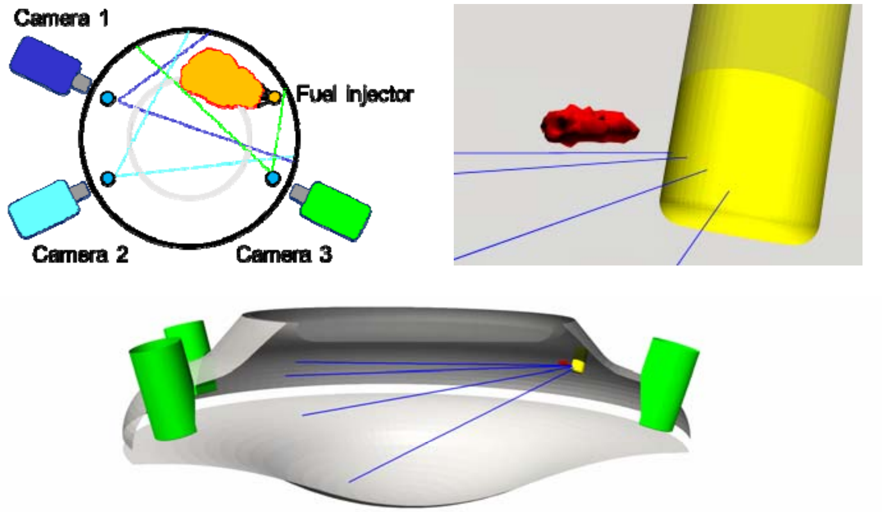


Simulated TCC performance compared to engine

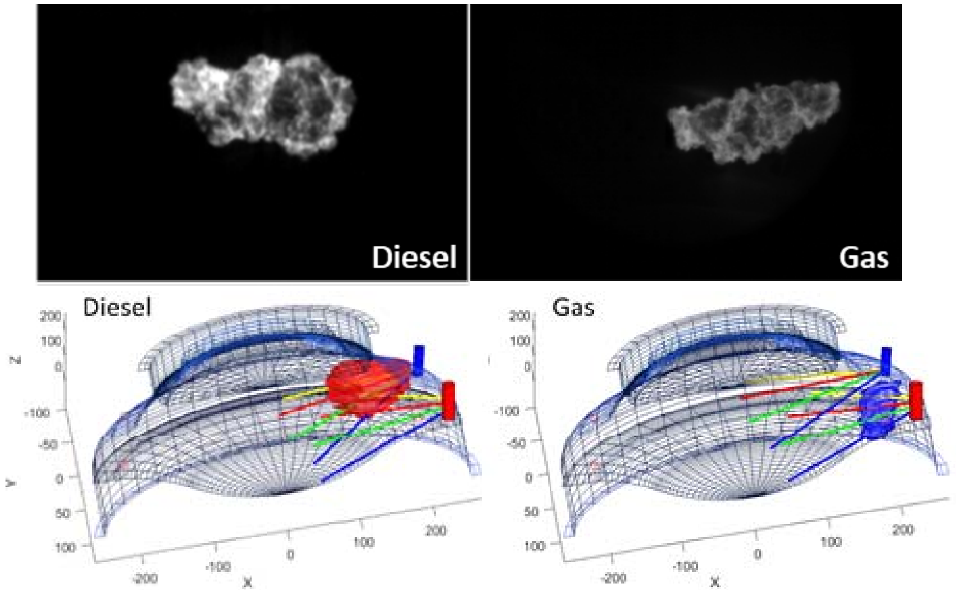
Final results & Achievements

Injection and ignition characterization:

- Tests on alternative fuels on 4T50ME-X engine instead of fuel flexible test facility
- Engine tests: Diesel, LNG, ethane, LPG
- Optical techniques prepared:
  - Tri-camera imaging
  - High-speed Schlieren
  - Lubrication oil visualisation
- Non-optical studies
  - LPG
  - Early gas injection
  - Gas hydrate formation



Multi-camera imaging for spatial location of flames



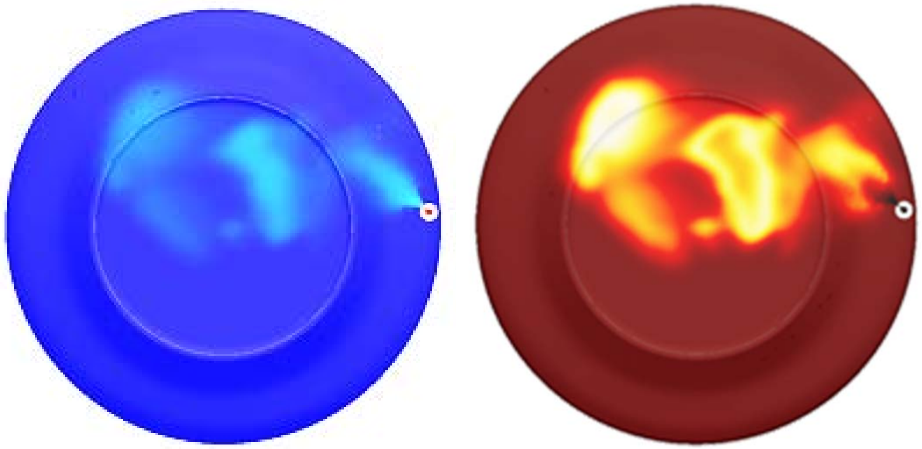
Diesel vs. LNG

WP Leaders: Johan Hult/Christian Kunkel

Final results & Achievements

Numerical studies of fuels and ignition:

- Detailed chemical kinetic models for new gaseous fuels completed and experimentally validated: LNG, ethane, methanol, LPG (propane/butane).
- Strategies for reducing mechanisms
- Tools for ignition delay and flame speed
- Develop CFD for dual-fuel operation, focusing on LNG:
  - Mesh motion handling for fast and robust CFD
  - Charge preparation
  - tabulated chemistry
  - cell clustering for direct chemistry integration



Mixture fraction and temperature for dual-fuel low-speed engine (tabulated chemistry)

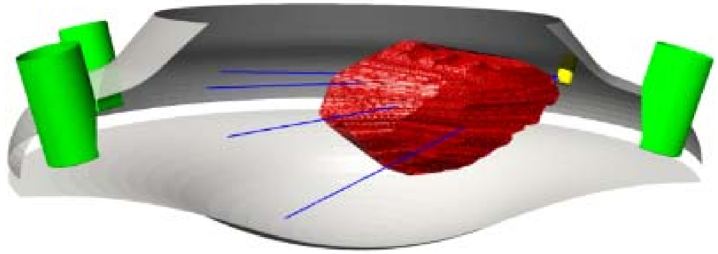
Dual-fuel injection and combustion in low-speed engine (cell clustering)

WP Leaders: Johan Hult/Christian Kunkel

Conclusions

Injection and ignition characterization

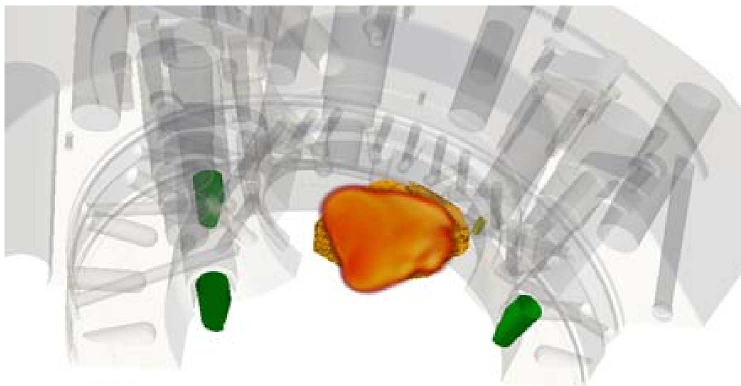
Optical tools can be useful for studies of ignition concepts and phenomena for new fuels. Multi-camera imaging useful tool for spatially locating events inside the cylinder → continued work.



Spatial mapping of flame using multi-camera imaging

Numerical studies of fuels and ignition

Now have chemical model for all alternative fuels we use. Extensions of CFD tools required for dual-fuel simulations have been developed and implemented. Feasibility of dual-fuel simulations demonstrated → continued work. Optical data is being used for CFD validation (diesel&LNG).



Optical data for CFD validation

WP Leaders: Johan Hult/Christian Kunkel

Final results & Achievements

Concept for 3D in-cylinder mixture formation:

- Concept with lateral and vertical optical access successfully tested up to full-load. No mechanical problems detected after more than 70 operating hours.
- The usable resolution with the vertical access is about 140mm (bore: 350mm).
- Mixing device for gas-tracer successfully designed and tested.
- Mixing device for air-tracer successfully installed and tested.
- The fuel distribution inside the combustion chamber was measured successfully.

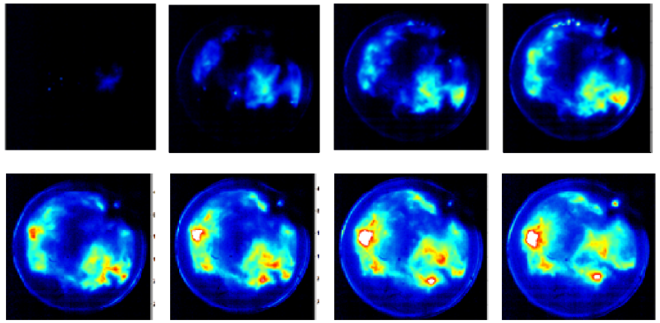


Fig.1: Measurement of flame luminescence with vertical access

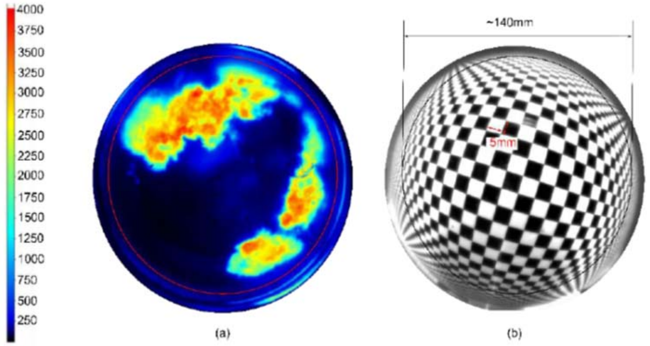


Fig.2: flame luminescence (le.) and test image of checkerboard for image quality estimation (ri.).

WP2: Multi-Fuel Combustion

WP Leaders: Johan Hult/Christian Kunkel

Final results & Achievements

Fuel specific engine control strategy:

- Different fuels were tested in the spray chamber and on the single cylinder engine.
- Fuel properties influencing combustion and emission behaviour were defined.
- Negative impacts of HFO-like fuels (compared to DMA) concerning combustion and emission behaviour could be partly compensated by an appropriate injection strategy.
- A fuel specific control strategy was defined on the base of the single cylinder engine data.
- The control strategy was successfully tested on a medium speed full scale DF-engine.

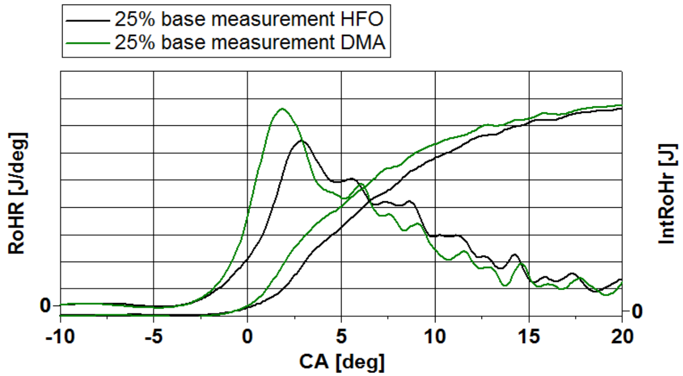


Fig.1: Load 25%: Comparison RoHR DMA vs. HFO under same boundary conditions

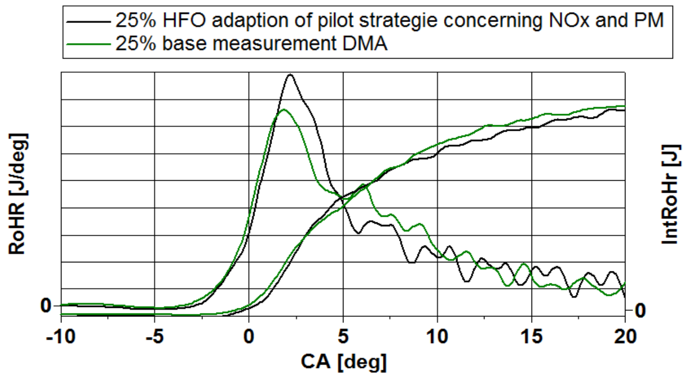


Fig.2: Load 25%: RoHR after Optimization of the pilot-injection strategy with HFO

WP Leaders: Johan Hult/Christian Kunkel

Final results & Achievements

Low temperature NOx-formation

- The boundary conditions leading to NO_2-formation are now well understood.
- A purposeful approach was to split the engine model into an exhaust duct model and an in-cylinder model.
- An appropriate model for the exhaust duct was built up and successfully validated.
- The in-cylinder NO_2-formation model was built up and validated.
- To improve the results of the in-cylinder model further improvements concerning the combustion model have to be made.

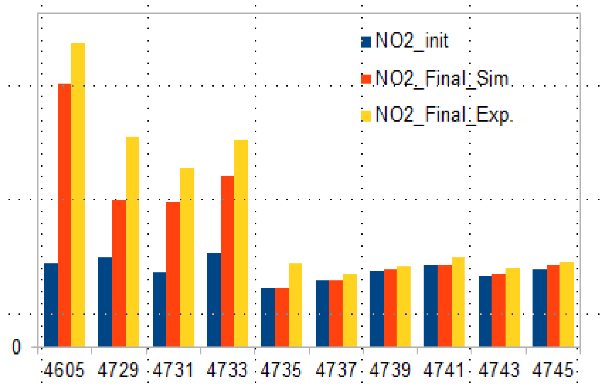


Fig.1: Comparison NO_2: simulation (red) vs. experiment (yellow) [exh. duct model]

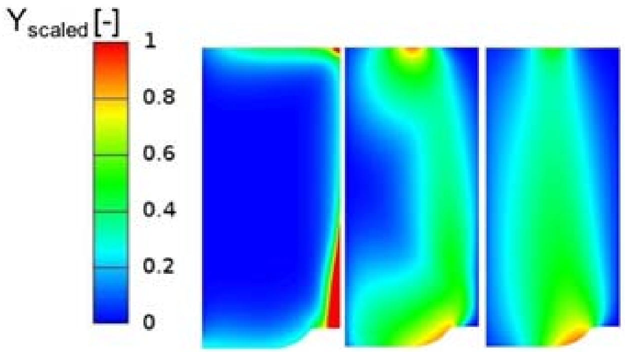


Fig.2: Simulated concentration in combustion chamber at BDC of CH4, NO2, NO (from left to right)

WP Leaders: Johan Hult/Christian Kunkel

Conclusions

<u>Concept for 3D in-cylinder mixture formation:</u>

The concept works in general. The optical distortion makes the preparation and evaluation extremely time-consuming. A Bowditch-concept would lead to higher accuracy.

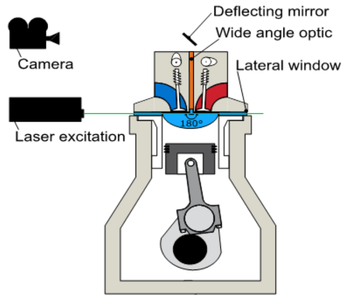


Fig.1: Design for vertical access

<u>Fuel specific engine control strategy:</u>

An appropriate strategy helps to compensate influences of different fuel properties at least partly.

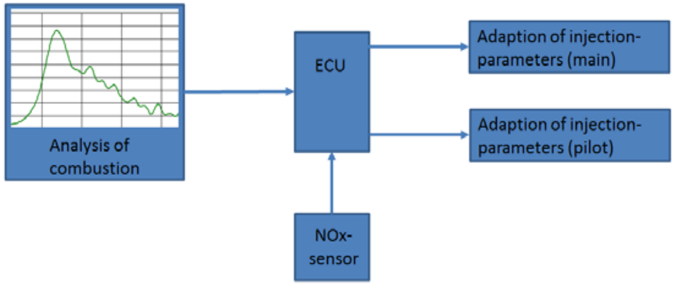


Fig.2: Illustration concept for a fuel flexible engine

<u>Low temperature NOx-formation:</u>

The exhaust duct model works quite accurately. Further improvements have to be made concerning the combustion model to improve the results of the in-cylinder NO_2-model.

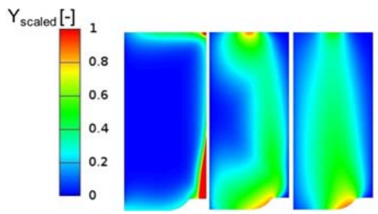


Fig.3: Simulated concentration in combustion chamber at BDC of CH4, NO2, NO (from left to right)