LENI Motors

Numerical Flow Simulation of a Natural Gas Engine Equipped with an Unscavanged Auto-Ignition Prechamber

Background & Objectives

- New **prechamber auto-ignition** combustion concept for cogeneration engines
- **Lower emissions** at comparable efficiencies expected as shown by former studies
- Experimental tests on a mono-cylinder engine
- **Numerical study** with coupled Navier-Stokes & chemical reaction simulations as part of this project with two major objectives:
  - **deeper insight into the ignition conditions** inside the engine (flow, T, P)
  - determining the **location of first ignition**

Numerical simulations

Calculation of the **pure flow field** for investigating the influence of the following three parameters:

- **initial gas temperature**
- **main chamber wall temperature**
- **prechamber wall temperature**

Implentation of chemical reactions in order to determine ignition locations

Model **initial/boundary conditions** (base case):

- Initial gas temperature T_{init} = 460.3 K
- Relative air-to-fuel ratio λ = 1.3
- Compression ratio ε = 13
- Engine speed 1500 rpm
- Simulation from -180 to 180 °CA
- Initial pressure P_{init} = 1.1 bar
- Prechamber wall temperature $T_{wall,pre}$ = 793.2 K
- Main chamber wall temperature $T_{wall,main}$ = 376 K
- Spalart-Allmaras turbulence model
- Hexahedral mesh with 247763 cells
- Dual time stepping with outer time step 0.5 ms and a number of 1000 inner time steps

Implementation of reaction chemistry

Two approaches have been applied to implement the chemical reactions into the simulations using a reaction mechanism containing 55 species and 278 reactions[1]:

Pseudo zero-dimensional approach

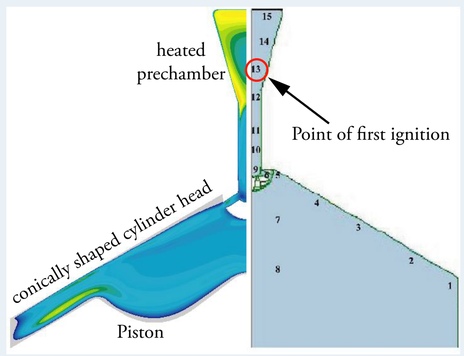
- Based on the pressure-temperature history of particular cells
- Selection of cells based on temperature distribution of base case at TDC
- OH radical concentration used as ignition indicator

Fully coupled approach

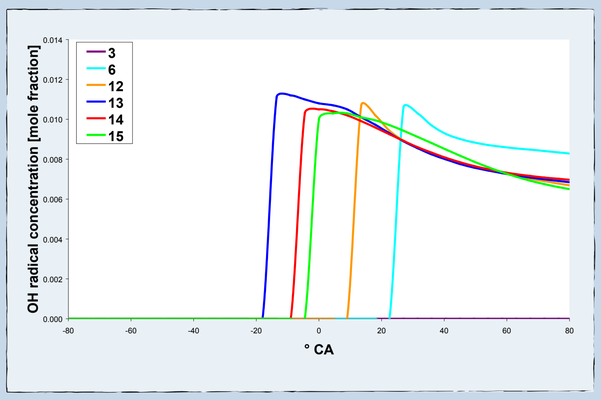
- Solving the flow field and reaction source terms in parallel
- Adaption of the **Navier-Stokes Multiblock Solver** (NSMB) to be able to conduct simulations under turbulent flow conditions
- Reaction chemistry only activated when temperature reaches a threshold value of 850 K.

[1] J. Huang, W.K. Bushe, Combust. Flame 144 (2006) 74-88

Zero-dimensional approach

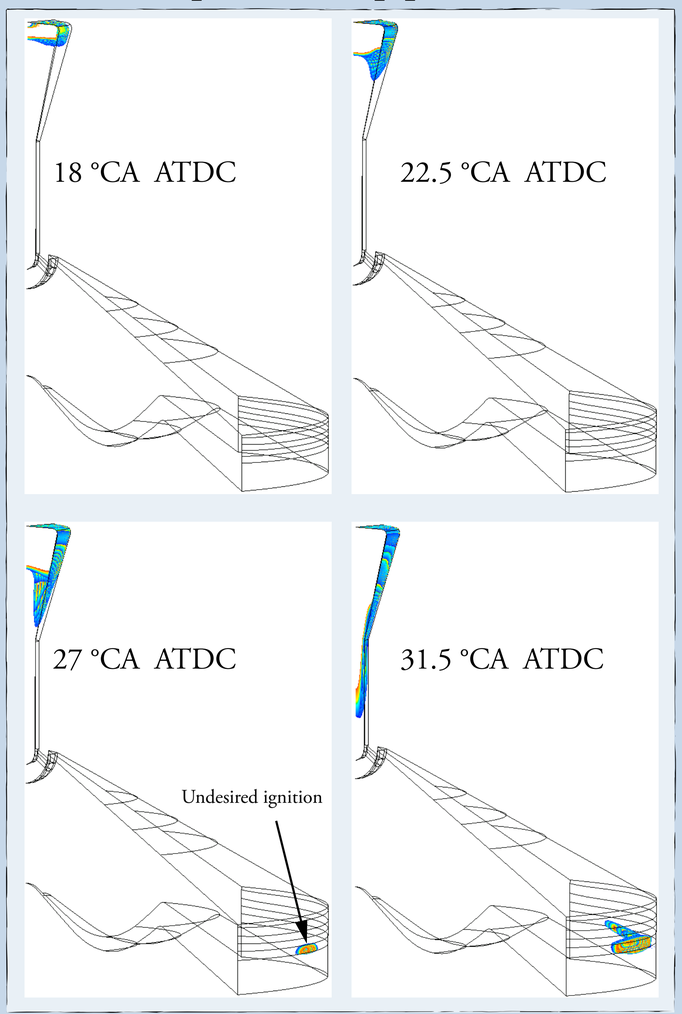


Cells selected for evaluation



OH radical concentration for 0D approach

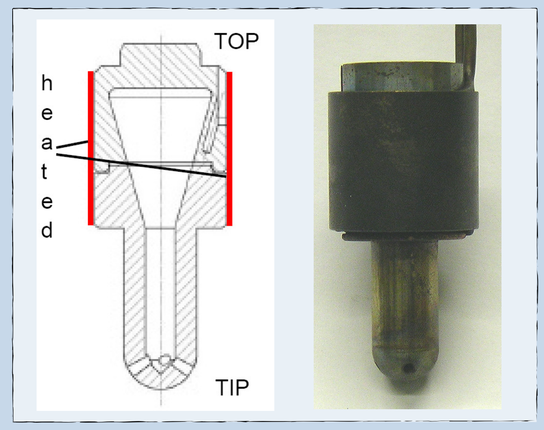
Coupled approach



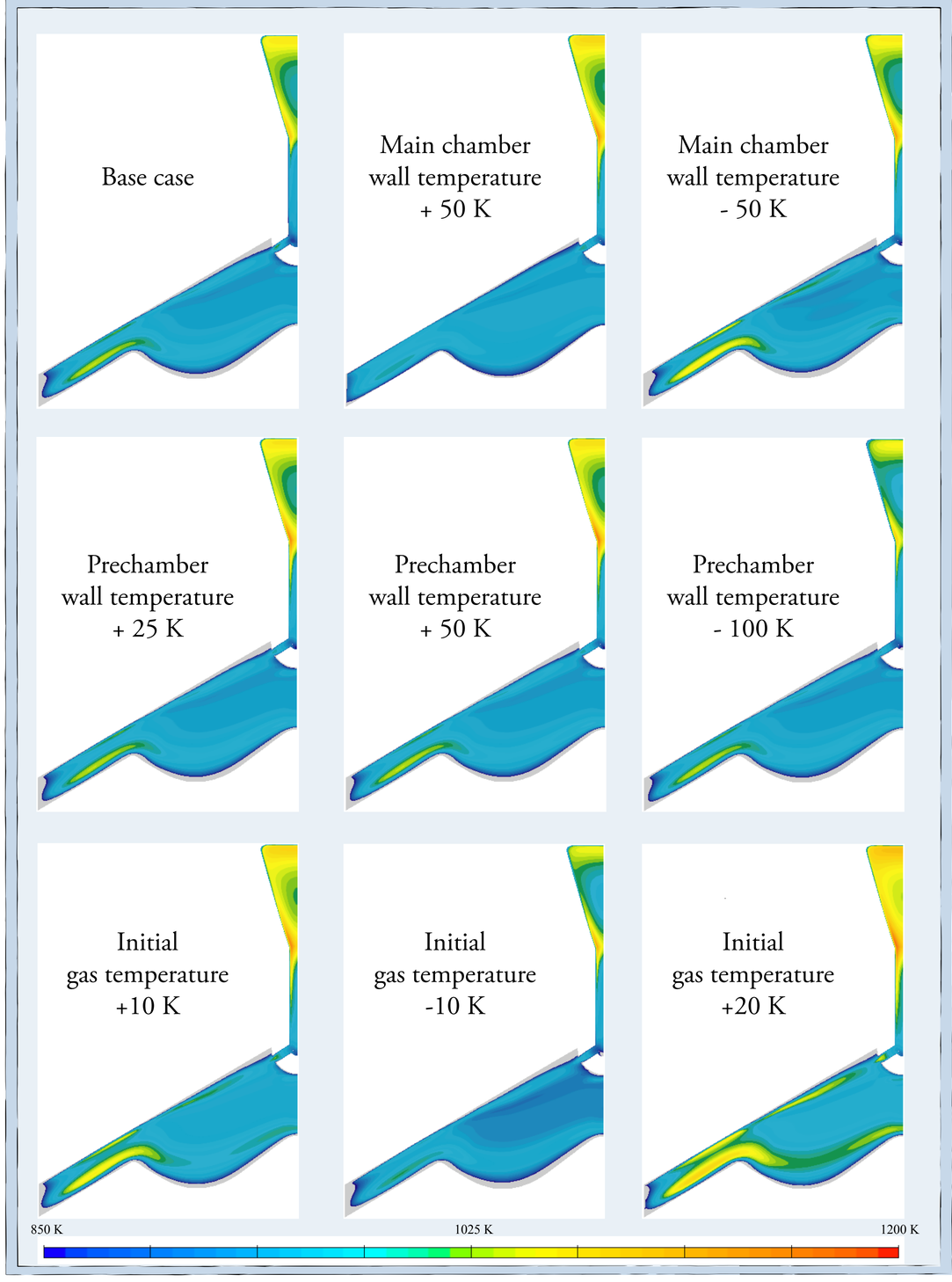
OH radical concentration for coupled simulation

Heated Prechamber

- Heating power up to 160 W ($T_{max,wall}$ ≈ 640 °C)
- Thermocouple for wall temperature measurement
- four holes connecting the prechamber to the main chamber
- 10° inclination of the holes to create a swirl motion inside the prechamber in order to increase the heat transfer from the walls



Temperature profiles CFD only



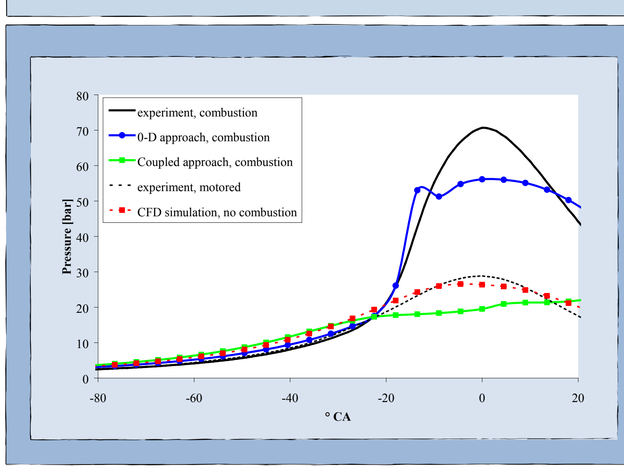
Results & Conclusions

The simulations clearly indicated:

- **First ignition inside the prechamber**
- Risk of **undesired ignition in the main chamber**
- **Prechamber wall temperature effective control** for ignition timing
- Initial gas temperature most influencing factor

Further steps in improving the modelling will be:

- Taking into account the **valve geometry and flow**
- Further improvement of the coupled approach
- **Experimental validation** of the model
- Investigation of the **mixture formation inside the prechamber** and its influence on the ignition timing



Pressure curves comparing simulations and experiment

Comparison of the two approaches

- Both approaches only valid until ignition
- Zero-dimensional approach in good agreement with experimental ignition time, but limited in spatial resolution
- Low calculation time of 0D approach advantageous for rapid evaluation
- Coupled approach shows delayed ignition, but numerical improvement needed
- A reduction of the chemical mechanism necessary to reduce calculation time to acceptable ranges

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