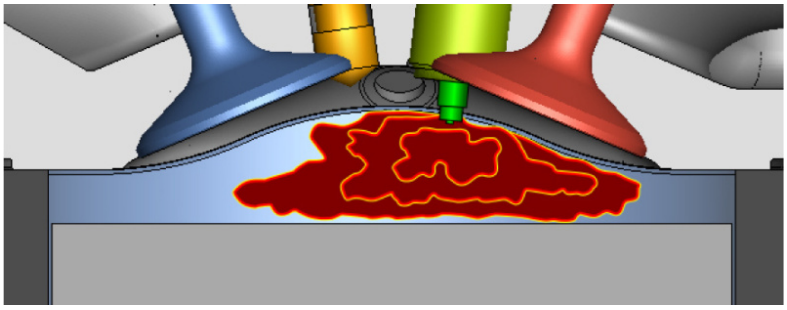
Numerical Simulation of Flame-Wall-Interaction



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Introduction

In most of the technical combustion systems the chemical reaction approaches the enclosing walls termed as flame-wall-interaction (FWI). A typical example is the final stage of the chemical reaction within an internal combustion engine as illustrated in Fig. 1, but also within aero engines or gas turbines used in power plants FWI is part of the process. In order to control the thermal load, the temperature of the walls is kept significantly below the flame temperature, usually by active cooling. Accordingly, a heat flux from the flame towards the wall is initiated which removes the activation energy required to sustain the chemical reaction. The result is an incomplete consumption of the fuel coming along with pollutants and power losses. In order to increase the efficiency and to reduce the pollutant formation FWI becomes an even more severe and restricting factor within future developments. Typical examples are the downsizing of internal combustion engines and the use of lean premixed combustion within aero engines. The overall process is determined by the interaction of fluid mechanics, heat transfer and chemical reaction embedded in a turbulent environment yielding huge demands onto its computation.

Methods

This project aims at computing this interaction for both, developing the numerical method to accurately describe the process as well as to gain inside into the underlying physics. The first steps currently conducted consist of a detailed investigation of suited approaches within one- and two-dimensional simplified geometries. At this, two approaches are applied to profit from the knowledge gained mutually. Within the first one, the process is highly accurately described by the direct computation of the reaction kinetics [1] while the second one uses efficient reduction techniques to lower the computational costs.[2] This reduction should finally enable the computation of realistic geometries within the next stages of the project. We implemented both approaches into the academic code Fastest which enables a very detailed comparison.

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Results

Within other projects, we extend the codes capability to compute full scale reacting systems. A hybrid MPI-openMP parallelization is employed to obtain parallelization efficiency for reaction kinetics. Figure 2 shows one of the first results obtained so far. The three snapshots illustrated here represent a two-dimensional simulation mimicking the spherical expanding flame of an engine approaching a piston wall (as in Fig. 1). In the top the flame is still propagating undisturbed as visualized by the reaction layer which precedes the hot gases being intact. The two following instances show the weakening of this reaction zone closer to the wall and finally total quenching still leaving a thin layer of unreacted gases above the piston.

Outlook

The first steps of this research have been conducted within a numerical framework that established for reacting systems in the past [3]. A detailed assessment is ongoing to identify the necessary numerical and modeling developments required for the FWI-simulation. As an intermediate step towards real applications, the simulation of well characterized experiments featuring three dimensional laminar and turbulent FWI is planned.

Figures

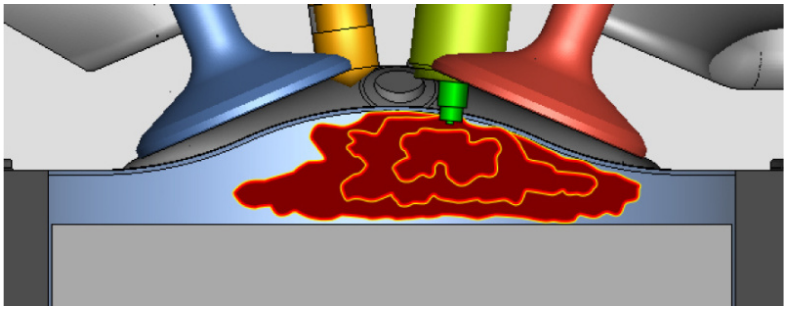

Fig. 1: Illustration of the flame propagation within an internal combustion engine leading to FWI.

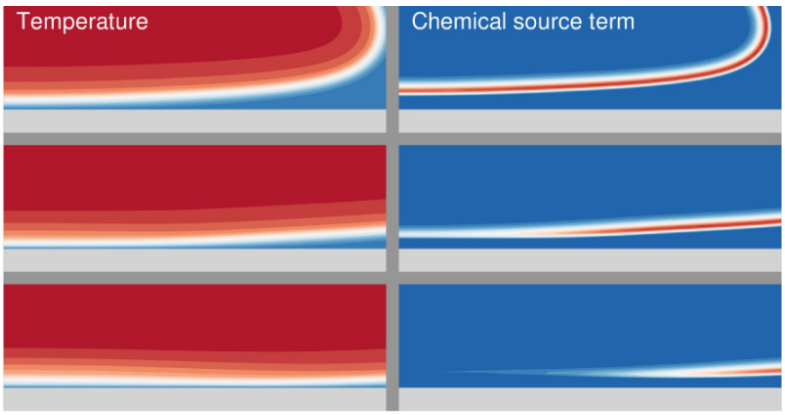

Fig. 2: 3 timesteps of a 2D simulation showing the impact of a flame onto the piston.

Reference

[1] T. Meier, G. Kuenne, A. Ketelheun, and J. Janicka (2013), Numerische Abbildung von Verbrennungsprozessen mit Hilfe detaillierter und tabellierter Chemie. VDI Berichte, 2161: 643-652, Deutscher Flammentag 26.

[2] A. Ketelheun, G. Kuenne, and J. Janicka (2013): Heat Transfer Modeling in the Context of Large Eddy Simulation of Premixed Combustion with Tabulated Chemistry. Flow Turbulence and Combustion, Vol 91(4): 867-893. https://doi.org/10.1007/s10494-013-9492-6

[3] G. Kuenne, A. Ketelheun, and J. Janicka (2011): LES modeling of premixed combustion using a thickened flame approach coupled with FGM tabulated chemistry. Combustion and Flame, Vol. 158(9): 1750-1767. https://doi.org/10.1016/j.combustflame.2011.01.005

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