

## A HYBRID SEMI IMPLICIT SOLVER USING REAL-GAS THERMODYNAMICS APPLICABLE TO A WIDE RANGE OF MACH NUMBERS

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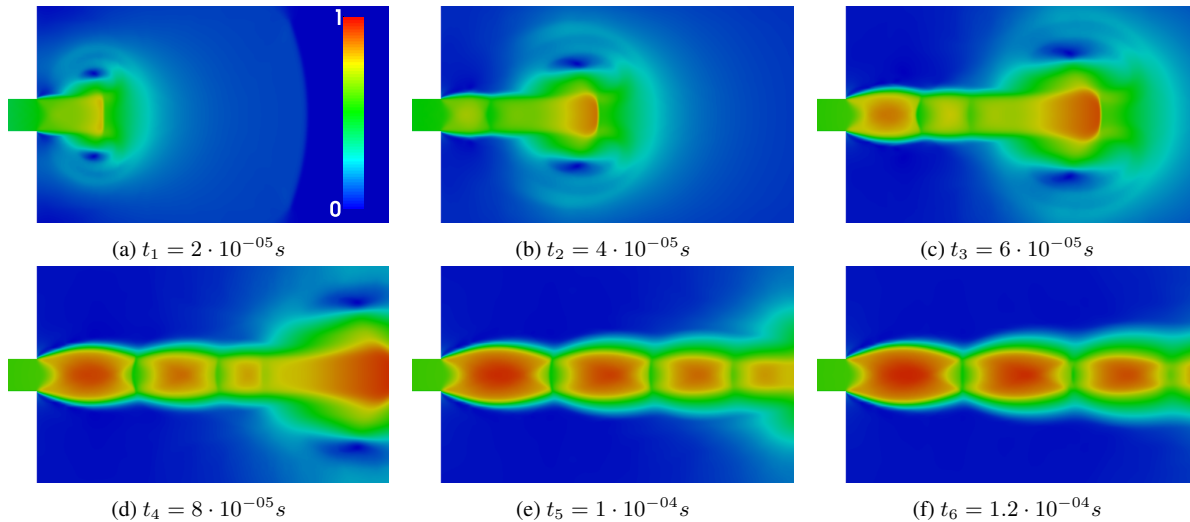
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High pressure gas injectors in internal combustion engines operate at pressures well above the critical state of the used fluids. For these operating points the ideal-gas assumption is not valid anymore. Instead real-gas thermodynamic effects need to be considered. Furthermore during the process of expansion in the injector and in the combustion chamber the pressure and temperature values decrease and get close to or drop below the critical point, which needs a special numerical treatment.

This work considers the development of a compressible pressure-based solver which can be used for a wide range of Mach numbers typical for an injection process. While the standard Pressure Implicit with Splitting of Operators (PISO) method is used for the coupling between velocity and pressure, a high-resolution non-oscillatory central scheme established by Kurganov and Tadmor calculates the convective fluxes. A blending function based on the local Mach- and CFL-number switches between the compressible and incompressible regimes of the developed model [1]. The source code for the hybrid solver was extended such that the pressure dependence of the compressibility  $\psi$  is taken into account. The thermophysical models on the basis of the Peng-Robinson equation of state [2] were implemented. A localized artificial diffusivity [3] regulated with the gradient of the compressibility factor  $Z$  works effectively on reducing numerical oscillations due to the large temperature and density gradients at the transcritical state of the fluid.

Simulations were performed using different fluids, pressure ratios, absolute pressure and temperature values and nozzle geometries. Following preliminary results are extracts from the ongoing work. Figure 1 shows the transient high pressure nitrogen  $N_2$  injection into medium at rest of a simple two-dimensional nozzle with a diameter of  $d_{nozzle} = 1$  mm for different time steps  $t_{1..6}$ . The total pressure at the injector inlet is  $p_{in,tot} = 500$  bar with a pressure ratio of  $\Pi = p_{in,tot}/p_{out} = 5$ .



**Figure 1: Normalized velocity plots for a transient high pressure gas injection**

A comparison of the normalized pressure profile along the centerline for two different fluids after an injection time of  $t = 1$  ms can be seen in figure 2. While nitrogen  $N_2$  is a common fluid for experiments in test facilities, methane  $CH_4$  is the principal component in natural gas used in gaseous-fuel engines. The position of the Mach disks as well as the absolute values change due to the thermophysical properties of the distinct fluids.

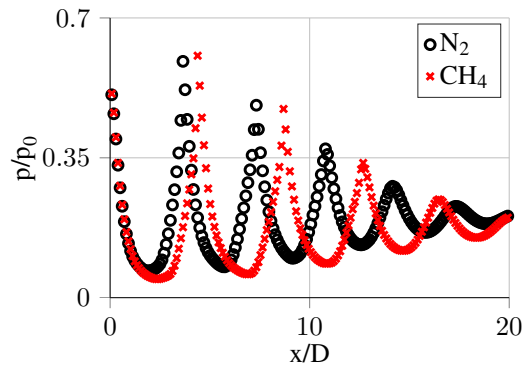


Figure 2: Normalized pressure profile along centerline

## References

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