Combustion in rocket engine depending on air-fuel equivalence ratio

Computational method in combsution

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Contents

1 Introduction

The aim of the project was to show relation between oxidizer/fuel ratio and parameters of gas in combustion chamber using library "Cantera" in Python. Cantera has implemented reaction mechanism called GRI-Mech 3, which contains 53 chemicals compunds and great number of reactions. This mechanism is used for homogenous reactions and it might be widely-used for engineering calculations.

2 Model

Combustion in real rocket engine is extremly complex process which depends on huge number of factors. In this simulation the following assumption were adopted:

- constant mass flow rate from oxidizer and fuel tank to combustion chamber,
- fuel is injested as gas,
- combustion chamber is zero dimensional reservoir (Cantera‘s restriction),
- flow thorugh nozzle is isentropic.

Calculation are performed on an engine with following parameters:

- Fuel - methane ($T = 293K, p = 40atm$)
- Oxidizer - oxygen ($T = 293K, p = 40atm$)
- Combustion chamber virtual volume $= 0,0005m^3$
- Ignition caused by injection small dose of free hydrogen radicals.

The stiochometric reaction of complete combustion of propane in oxygen as follows:

$$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$$

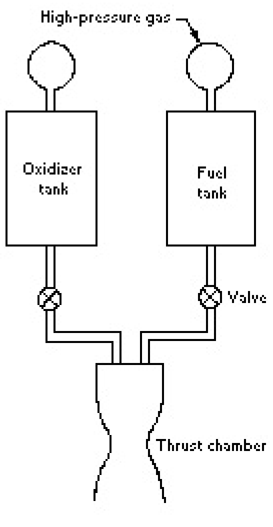


Figure 1: Simplified engine diagrame

3 Programm structure

In the beginning the programm creates reactants and define their pressure, temperature and chemical composition. Next there is place for necessary function which compute the coefficient k that is used for setting pressure difference between reservoir. This function is based on critical flow in nozzle or hole, despite in which place is used. In consequence the mass flow between reservoir depends only on area of throat.

$A_{CH4\ injector} = 4e^{-5}\ m^2$ - area of methane injector

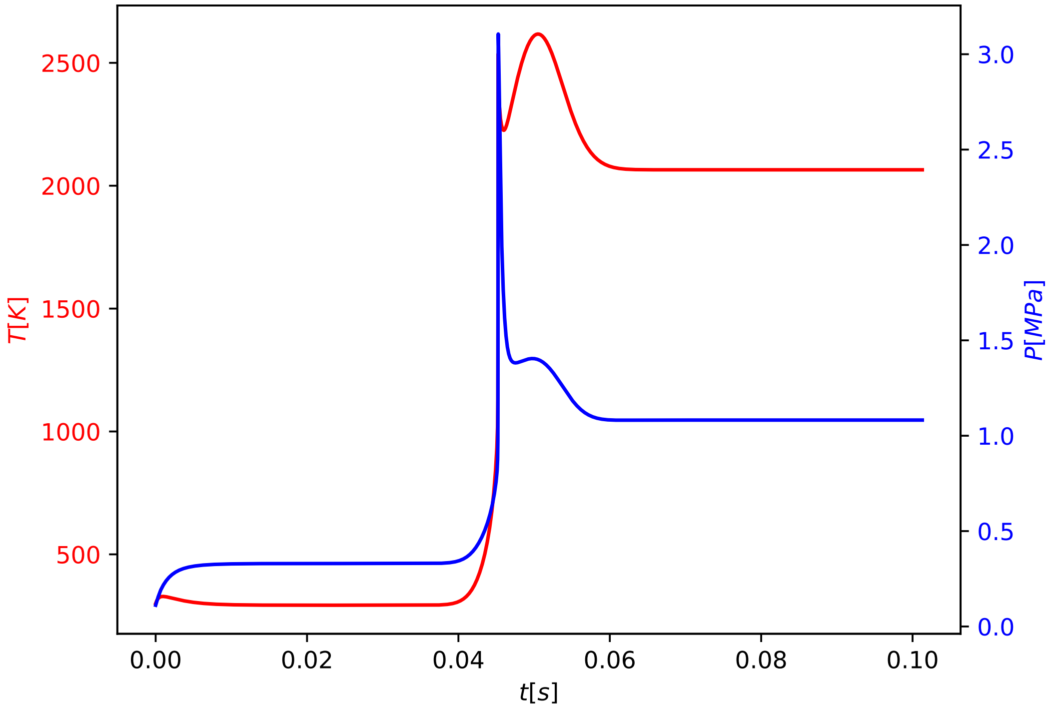
$A_{O2\ injector} = 4e^{-5}\ m^2$ - area of oxygen injector

$A_{throat} = 1e^{-3}\ m^2$ - area of nozzle‘s throat

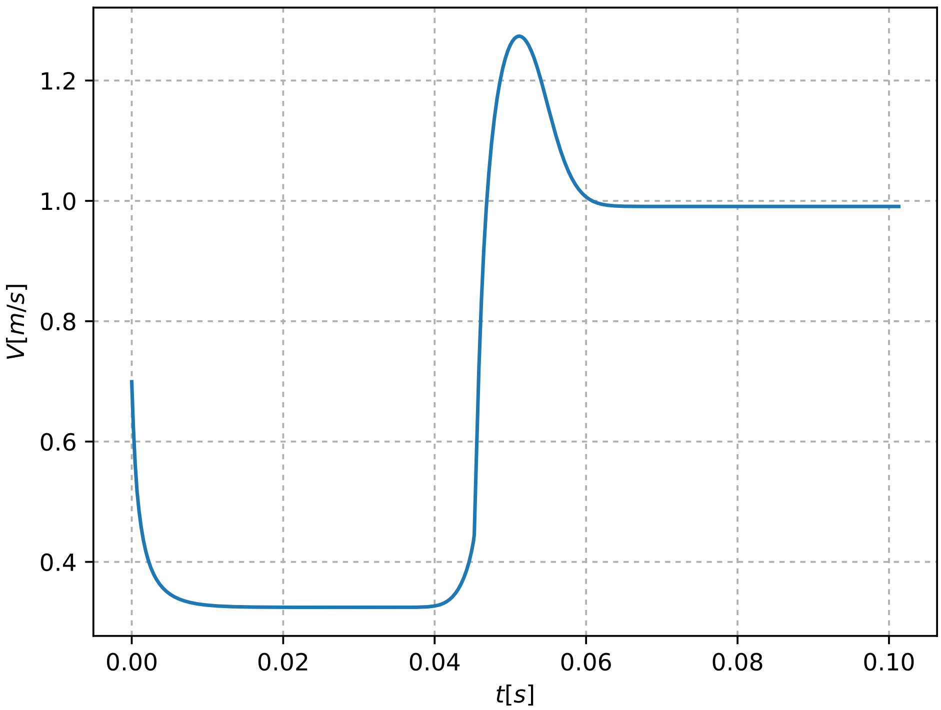
All state parameters in combustion are computed in cantera. The velocity of exaust gasesa are caluclated from:

$$v_2 = \sqrt{(2 * (\frac{kR}{k-1} T_0 (1 - (\frac{p_2}{p-0})^{\frac{k-1}{k}})))}$$

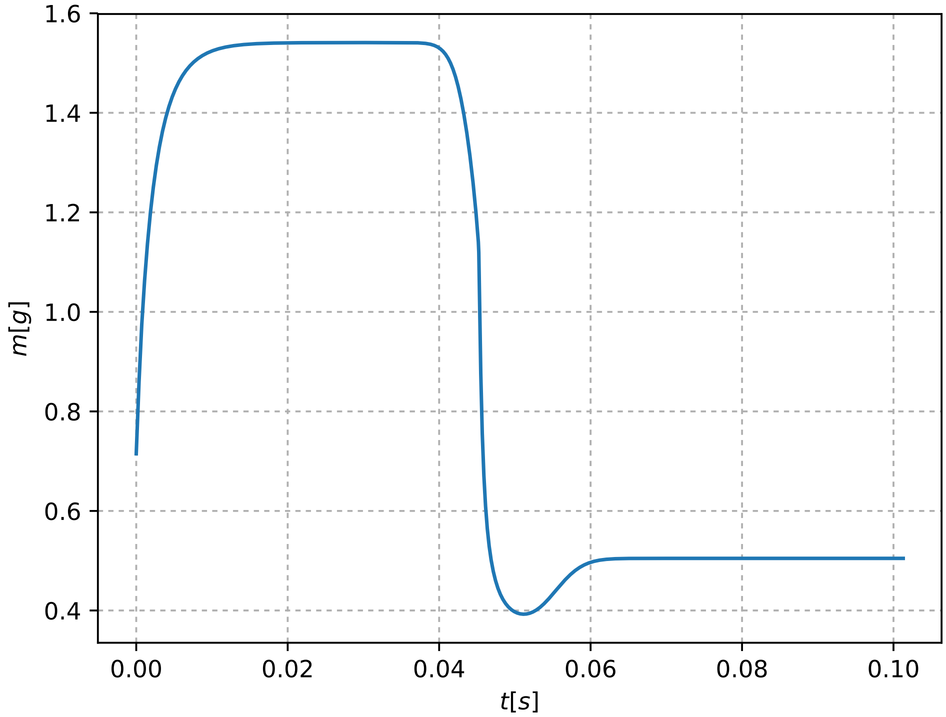
4 Results



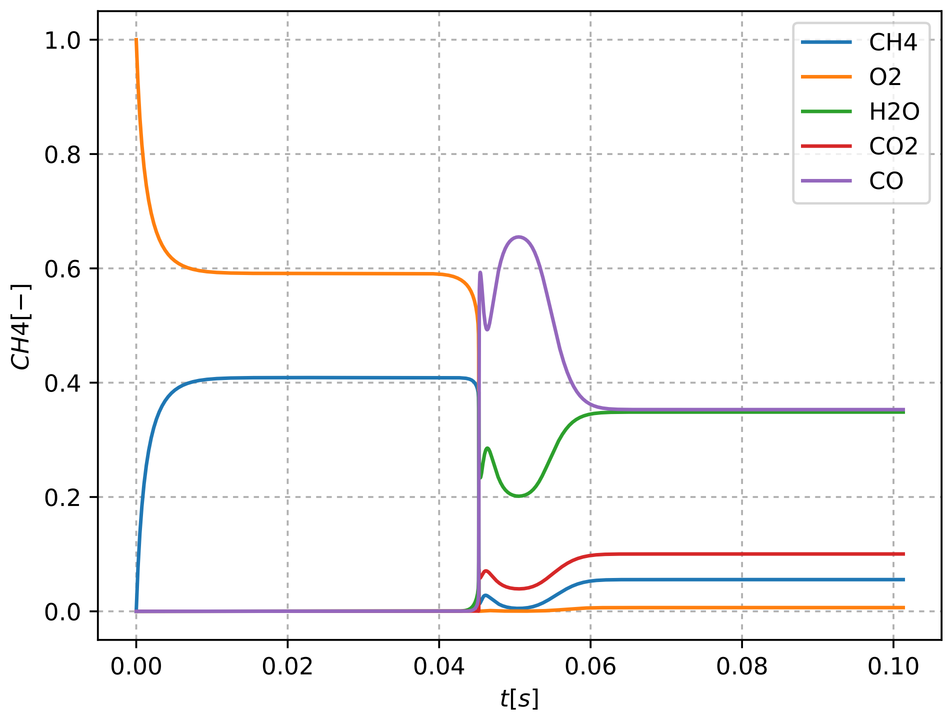
(a) Total temperature and pressure in combustion camber



(b) Velocity in outlet of nozzle



(c) Mass of reagents in combustion camber



(d) Mass of reagents in combustion camber

Figure 2: All plots are in function of time

5 Summary

Peak of pressure in 0,5s is due to ignition and start of combustion and critical flow in nozzle. Last plot (Figure 2d) shows that in exhaust gases there are methane and carbon monoxide. This is consequence of partial combstion. This study of working a rocket engine is simplified, however it may be starting point for later analysis.

References

[1] $http://www.cantera.org/docs/sphinx/html/cython/examples/reactors_combustor.html$