Speed of Chapman - Jouguet detonation wave as a function of initial parameters: temperature, pressure and equivalence ratio for ethylene - oxygene mixture

Malgorzata Grzmiaczka

June 8, 2017

Major:	Lotnictwo i Kosmonautyka
Course:	Metody Komputerowe w Spalaniu

1 Introduction

Chapman-Jouguet theory defines detonation wave as a shock wave with energy release inside the wave front. In line with this theory the speed of detonation wave is constant and defined for each material.

The Chapman-Jouguet condition is a state when reaction products are assumed to flow at a locally sonic speed relative to the shock.

The objective of this work is to establish the relationship between detonation wave velocity and initial parameters of temperature, pressure and equivalence ratio, as well as the general physical state of it.

2 Mathematical model

To obtain the dependence between C-J wave speed and initial parameters of the process, certain calculation models are used, though the analytical solution is not possible.

In this work, an approach presented in paper [1] is going to be used as the mathematical model that enables us to find C-J detonation speed.

On the assumption that the heat capacities of the reactants and products are constant, it is possible to obtain energy equation in the following form:

$$\frac{1}{2}u_1^2 + q + c_{p1}T_1 == \frac{1}{2})u_2^2 + c_{p2}T_2$$

After transformation we arrive at an equation for C-J detonation wave velocity:

$$s = \sqrt[2]{2(\gamma_2^2 - 1)(q + c_{p1}T_!)}$$

3 Results

3.1 Relationship between C-J detonation speed and initial temperature

Calculations of speed and detonation parameters were made for:
p = 101325 Pa
$\phi = 1.0$

Relationship of C-J speed and T_{in} is shown on Figure 1.

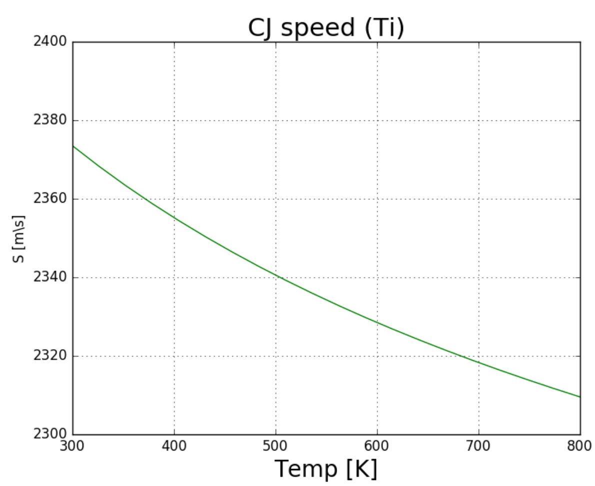

Figure 1: Relationship between C-J speed and initial temperature

As can be seen the C-J detonation wave velocity falls with the increasing initial temperature.

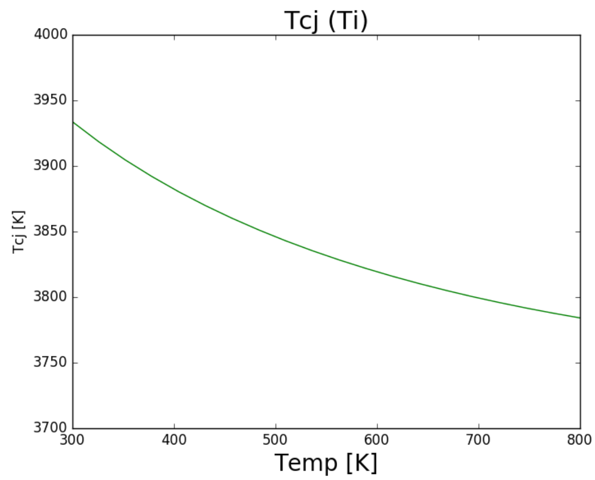

Figure 2: Influence of initial temperature on detonation temperature

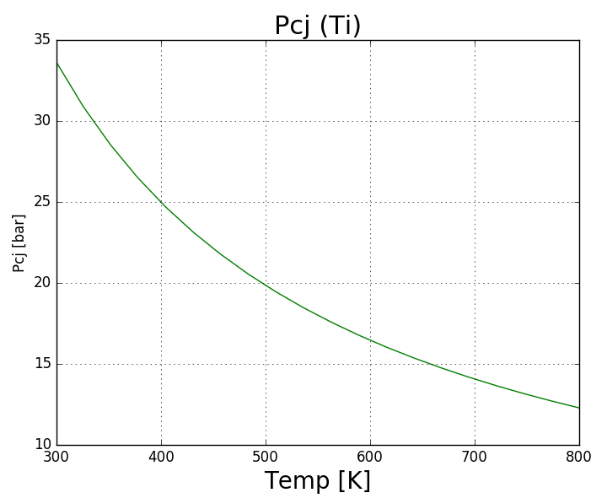

Figure 3: Influence of initial temperature on detonation pressure

According to Figures 2,3 and 4 all of the parameters o C-J detonation wave drop nonlinear with the increase of initial temperature.

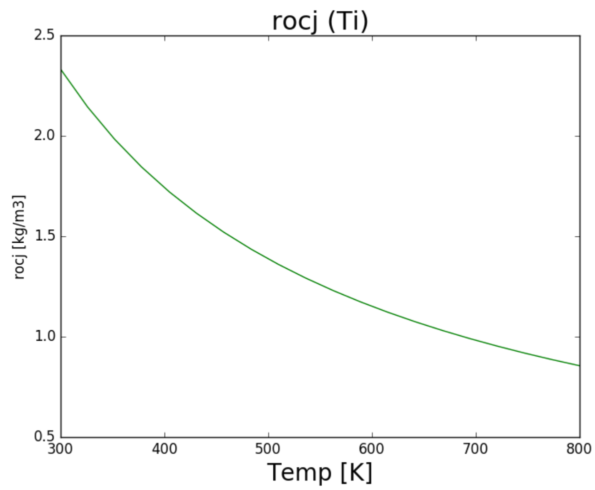

Figure 4: Influence of initial temperature on detonation mixture density

3.2 Relationship between C-J detonation speed and initial pressure

Calculations of speed and detonation parameters were made for:
T = 300 K
$\phi = 1.0$

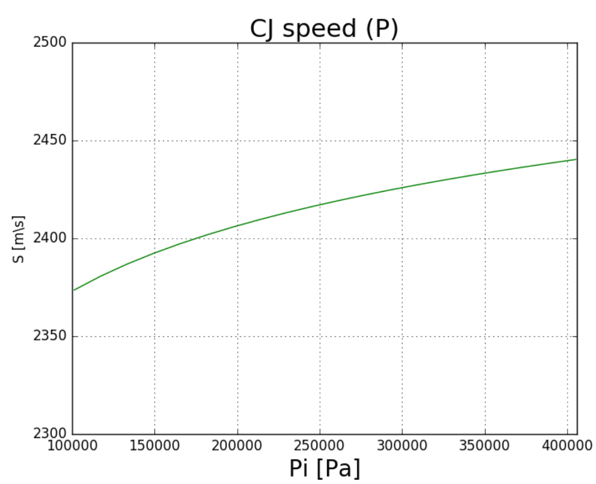

Figure 5: Relationship between C-J speed and initial pressure

As it is shown on Figure 5 along with growth of initial pressure, C-J detonation speed increase as well.

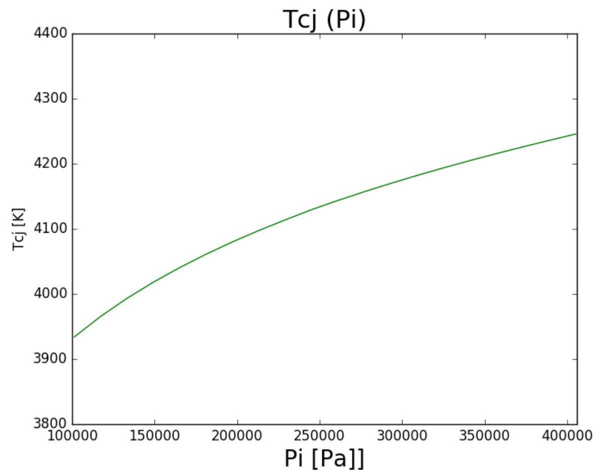

Figure 6: Influence of initial pressure on detonation temperature

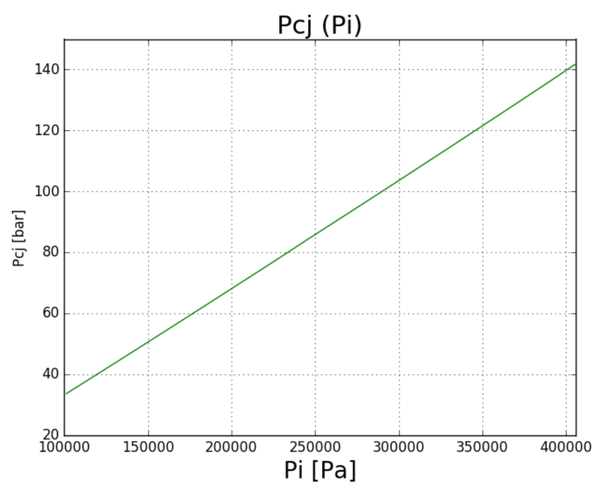

Figure 7: Influence of initial pressure on detonation pressure

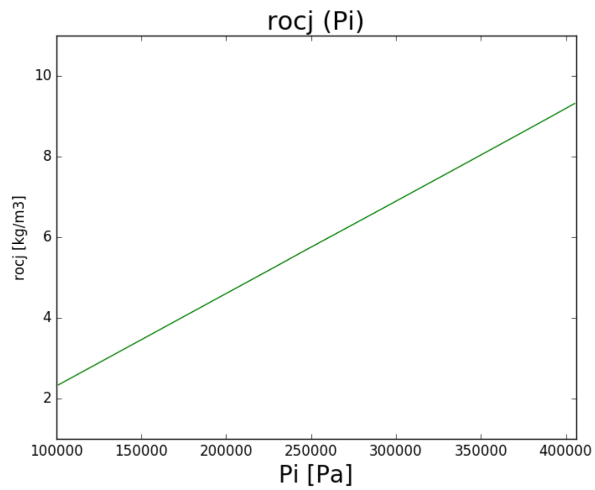

Figure 8: Influence of initial pressure on detonation mixture density

Figures 6, 7, 8, that represent detonation wave parameters, show that initial pressure's increase conduce to growth of detonation's temperature, pressure and density.

3.3 Relationship between C-J detonation speed and initial equivalence ratio

Calculations of speed and detonation parameters were made for:
p = 101325 Pa
T= 300 K

Calculations where conducted for equivalence ratios in the range between 0.2 and 1.5. The minimum value of C-J speed total approximately $1689\frac{m}{s}$ and maximum about $2581\frac{m}{s}$ (Figure 5).

Based on Figure 9, it might be observed that along with increasing equivalence ratio C-J speed goes up as well.

As it can be seen on Figures 10 and 11 the growth of initial equivalence ratio causes increase of detonation temperature and pressure.
There can be observed a slight drop of detonation temperature at high equivalence ratios. It results from worse burning mixture properties.

However, when it comes to detonation medium density, the higher initial equivalence ratio, the lower ρ.

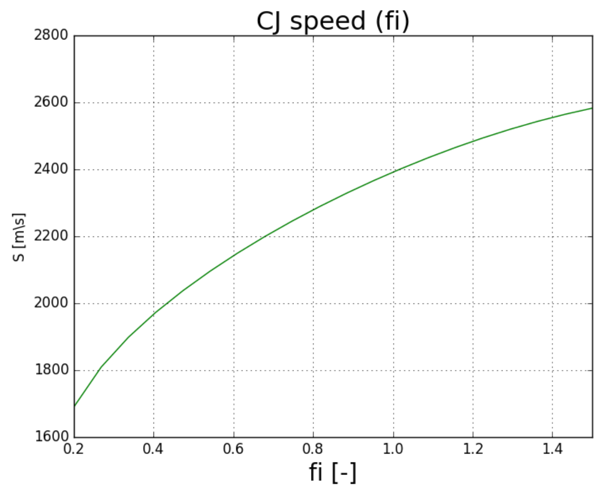

Figure 9: Relationship between C-J detonation speed and initial equivalence ratio

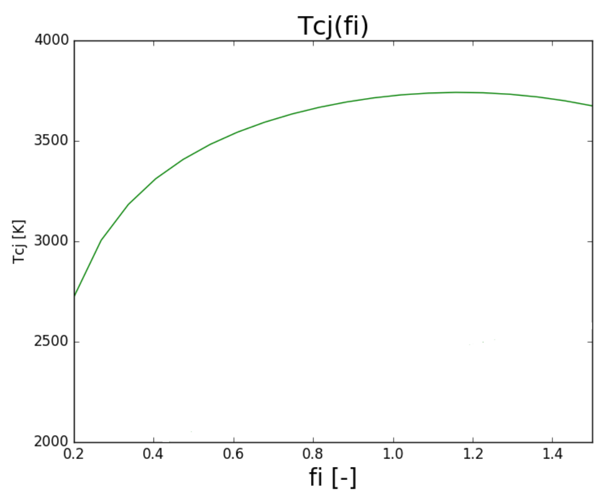

Figure 10: Influence of initial equivalence ratio on detonation temperature

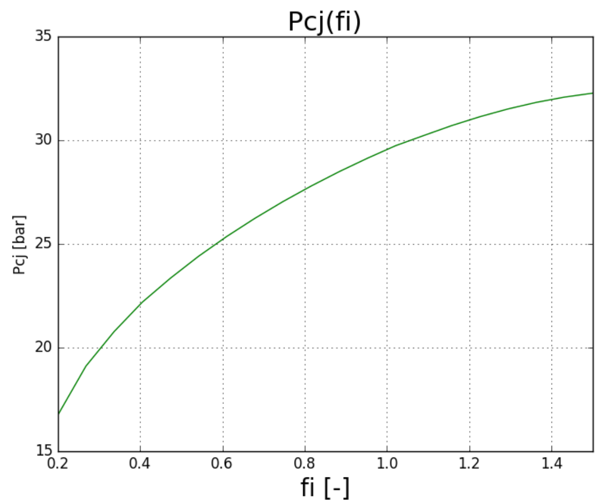

Figure 11: Influence of initial equivalence ratio on detonation pressure

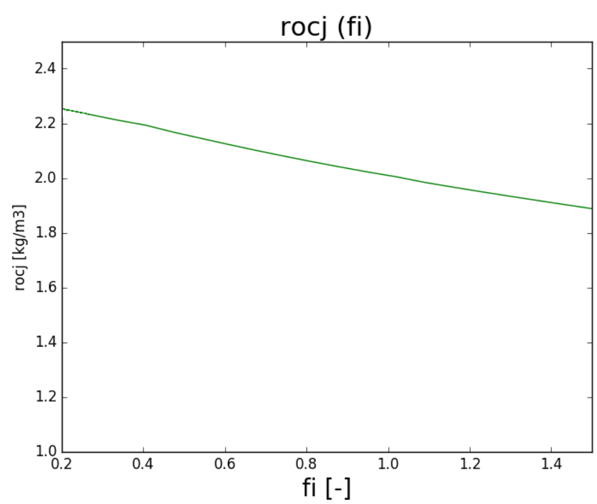

Figure 12: Influence of initial equivalence ratio on detonation mixture density

4 Summary

Calculations were made using SDToolbox software. Results, presented in this work, of computed relationships between Chapman-Jouguet detonation speed and initial parameters: temperature, pressure and equivalence ratio are only approximation of reality. Their not analytical solutions. Despite that fact, obtained charts reflect expected values, tendencies and reality with sufficient accuracy.

5 References

1. *A combustion wave in a premixed gas, the Chapman-Jouguet detonation wave*, source: https://www.mech.kth.se/courses/5C1219/Hand_ou_PDF/SG2219_NT_Lecture, *[access: 07.06.2017]*

2. N.Robert *History of the basic models of shock and detonations waves*, source: http://hadmernok.hu/2012_2_nagyr.pdf, *[access: 07.06.2017]*

3. http://math.mit.edu/ kasimov/detonation.html, *[access: 07.06.2017]*