T H E R M O P T I M ®

Spark ignition engine example

JAVA VERSION

VERSION 1.3

CONTENTS

Reciprocating internal combustion engine cycle

Let us study a reciprocating internal combustion engine whose corresponding theoretical cycle takes into account a multi-step combustion process. We shall in this example analyse the spark ignition engine.

After a 0.9 isentropic efficiency compression, start a combustion that unfolds in three phases:

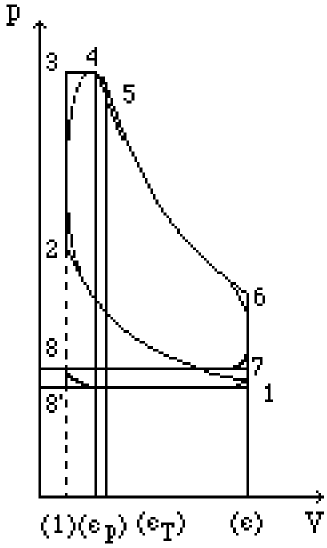
- the first one, at constant volume, allows the pressure to reach its maximum in the cycle,

- the second one, at constant pressure, leads to the maximum temperature

- the end of the combustion takes place at constant temperature.

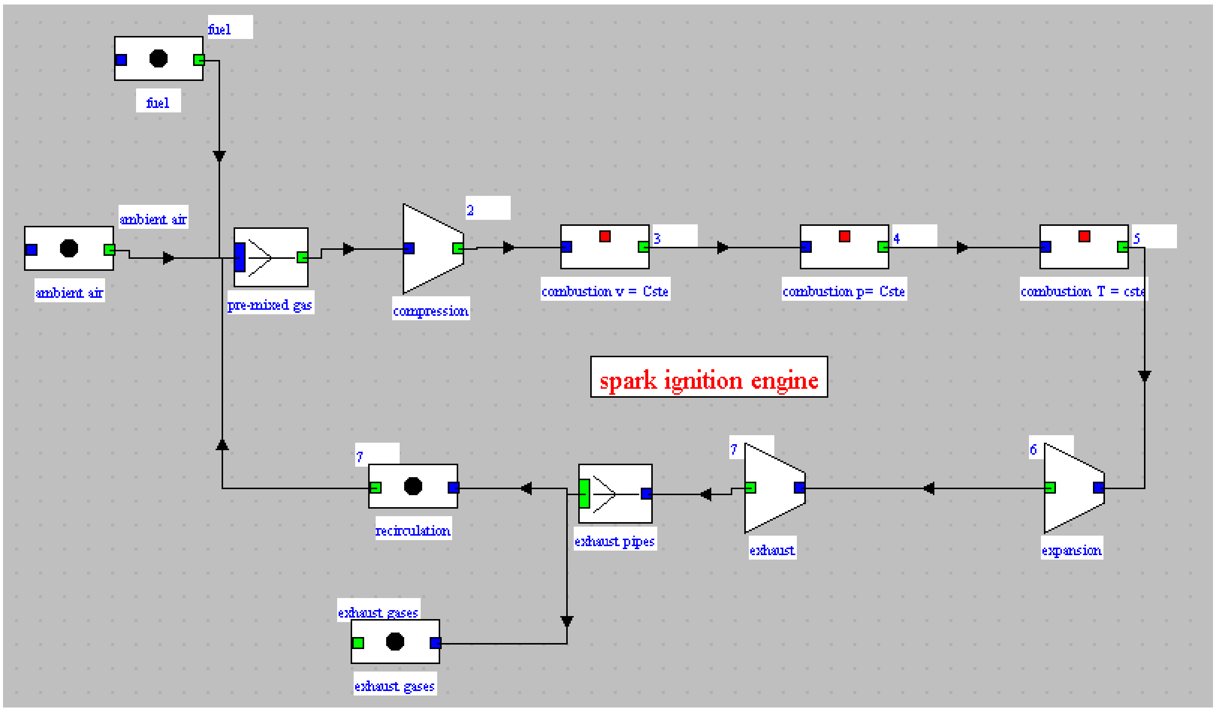
- gases are then expanded to the bottom dead center (bdc), with an expansion isentropic efficiency equal to 0.95

Due to the clearance volume, 3.3% of the burnt gas mass are assumed to recirculate.



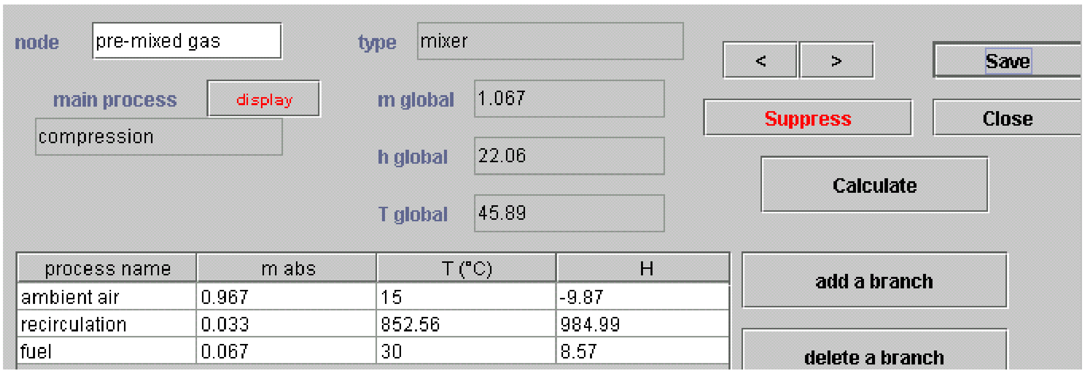
ε compression ratio
ε_P isobaric cutoff ratio
ε_T isothermal cutoff ratio

This cycle corresponds to the following diagram which can easily be built in the graphical editor:



Solution of the problem

The approach is very close to that of the diesel engine, to which the reader should refer, the main difference coming from that the intake mass initially comprises the fuel, and that therefore ulterior combustion is made without other fuel addition. In these conditions, the mixer is comprised of three fluids: the recycled gases, the ambient air, and the fuel. After some iterations, one gets, for example, the project below.

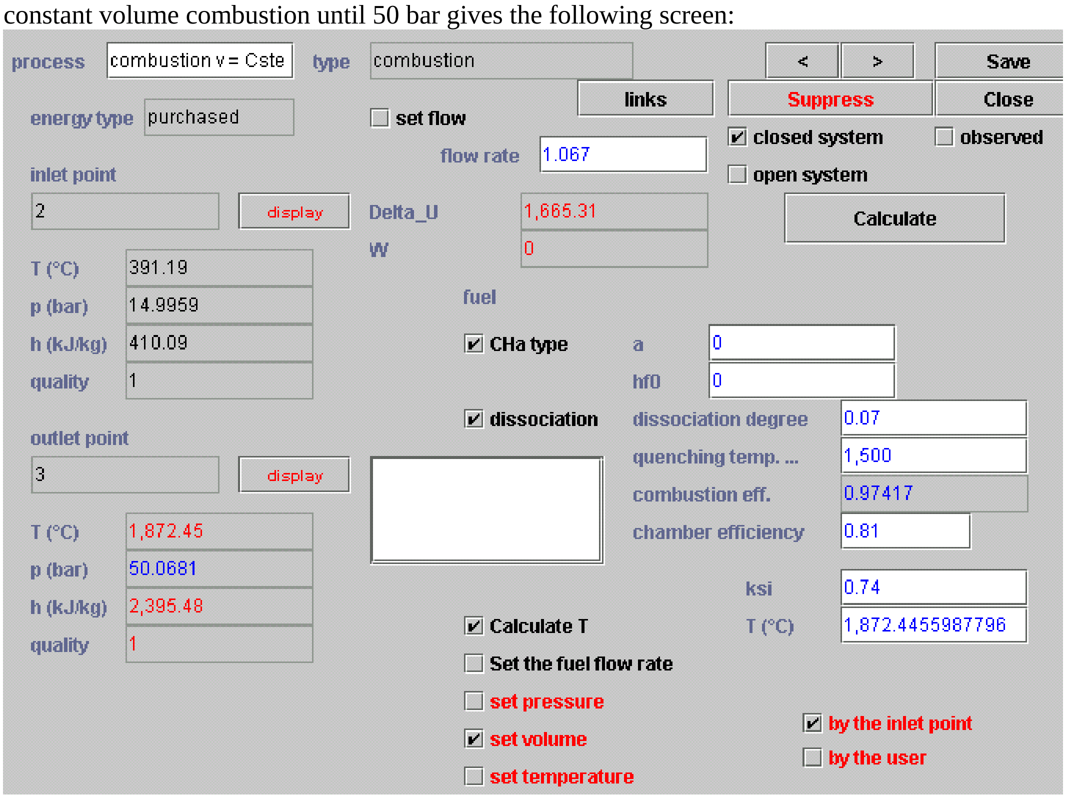


The intake fuel mix (close to the stoichiometric mix) has for these conditions the following composition (one keeps the same chemical formula for the fuel as in the diesel engine example):

component name	molar fraction	mass fraction
N2	0.7644739	0.7072499
Ar	0.008809558	0.01162292
O2	0.1992529	0.2105633
CO2	0.002901183	0.004216664
H2O	0.003545039	0.002109145
CO	0.001442814	0.00133467
H2	0.0005033247	0.00003350868
C7,2H13,42 `carb	0.01907133	0.06286994

The presence of CO and H2, in tiny quantities, comes from the recirculation of exhaust gases.

After the compression (volumetric ratio equal to 8, e.g. smaller than that of the diesel to avoid detonation), the constant volume combustion until 50 bar gives the following screen:



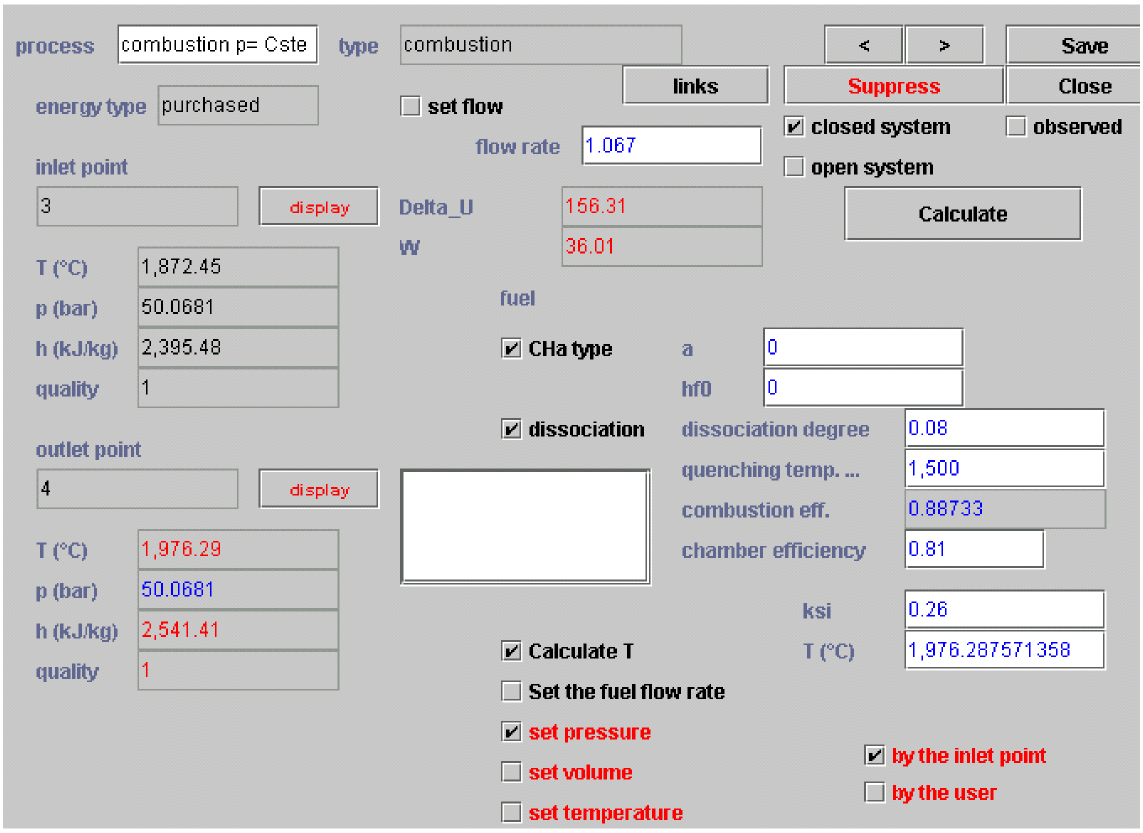
As it is clear, in this case, that the notion of air factor λ loses its meaning, this parameter is used to represent the burnt fraction of the reactants ξ. If ξ < 1, one considers that only a fraction x of the mix has reacted, and that (1-ξ) has not reacted. Combustion gases are then considered as a dual mix gas: there are the reaction products, including inert gases, and the fraction of the initial mix that has not reacted.

Here, one has adjusted ξ to obtain p = 50 bar.

The burnt gas composition, considering the dissociation, becomes:

component name	molar fraction	mass fraction
N2	0.7388013	0.7076713
Ar	0.008513715	0.01162985
O2	0.05006601	0.05477908
CO2	0.09762823	0.1469139
H2O	0.09414534	0.05799332
CO	0.004769617	0.004568156
H2	0.001283761	0.00008848855
C7,2H13,42 `carb	0.004792029	0.01635592

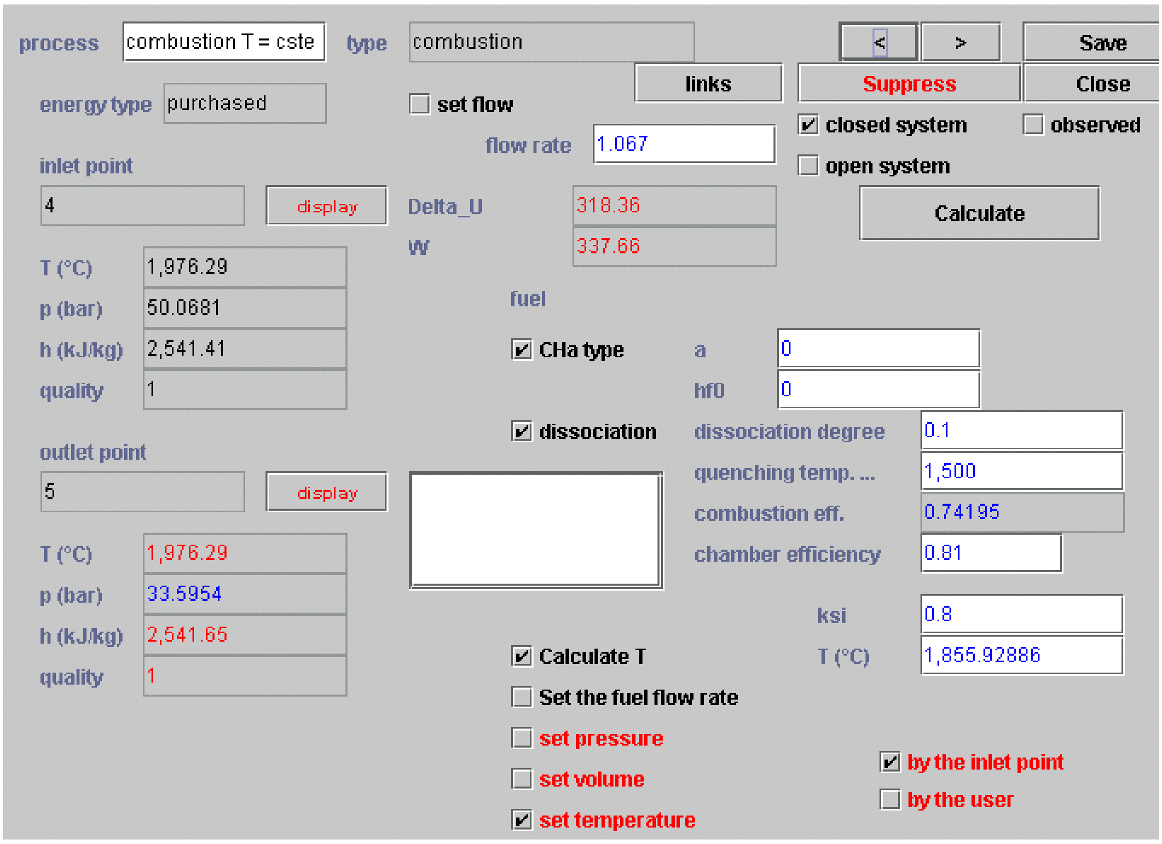
The combustion continues at constant pressure, until it reaches a temperature of 2250 K:



The burnt gas composition becomes:

component name	molar fraction	mass fraction
N2	0.7365418	0.7101736
Ar	0.008487677	0.01167097
O2	0.03693553	0.04067985
CO2	0.1011109	0.1531612
H2O	0.1006522	0.06241166
CO	0.009916998	0.009560945
H2	0.002819611	0.0001956389
C7,2H13,42 `carb	0.003535256	0.01214618

Finally, the constant temperature combustion gives, with $\xi = 0.8$ that takes into account the presence of non burnt gases:



Exhaust gases contain some fuel and oxygen, as well as carbon monoxide and hydrogen.

component name	molar fraction	mass fraction
N2	0.7314482	0.7284202
Ar	0.00842898	0.01197083
O2	0.007336021	0.00834501
CO2	0.08714399	0.1363388
H2O	0.1064837	0.06819569
CO	0.04333837	0.04315434
H2	0.01511856	0.001083447
C7,2H13,42 `carb	0.0007021616	0.002491651

The expansion phase can be represented. It takes place between points 5 and 6, of similar composition. The volumetric expansion rate ρ_{56} is calculated. THERMOPTIM assumes that the volume v_6 at the bottom dead center (bdc) is known. If one calls V_i and m_i the total volume of the cylinder and the mass in the cylinder at point i, one has the following relationships:

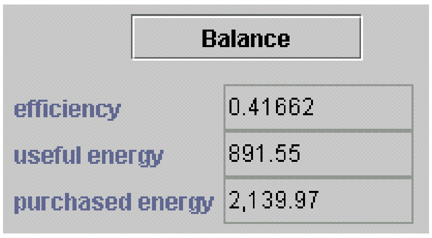
$\rho_{56} = V_6/V_5 = (m_6\, v_6)/(m_5\, v_5) \quad = v_6/v_5$ since $m_6 = m_5$

Furthermore $\rho = V_6/V_2 = (m_6\, v_6)/(m_2\, v_2) = (m_5\, v_6)/(m_2\, v_2)$, and $\rho = V_1/V_2$

$v_6 = \rho\, (m_2\, v_2)/m_5 = v_1\, m_1/m_5 = v_1$ since $m_1 = m_5$

The specific volume at the bdc is therefore equal to that of point 1. It therefore correspondingly has to be modified manually in order to take into account this phenomenon.

Finally, the indicated efficiency of the cycle is less than that of the diesel engine:



After correction with the thermal efficiency (0.81) and the sweeping cycle, it has a value of 33.7 %.

The project file is "gasoline.prj" and the diagram file "gasoline.dia".

It should be noted that the automatic recalculation cannot be fully automated here. The reason is that the combustion in the motor cylinder is represented as a sequence of three closed system combustions: first constant volume, second constant pressure and third constant temperature. This corresponds to very specific parameter settings which are not taken into account by the calculation process, as for instance the setting of ξ to get the right pressure or temperature or the update of v_6.

Viewing the point state values in the diagram editor

The results obtained may be displayed on the diagram (the values differ slightly from those shown above as the initial settings were not exactly the same):