

# Raketentreibstoffe I+II - Cheat Sheet

## Basics

Most chemical equations are not valid at high temperatures because of dissociation effects. More dissociation will result in a less released heat during the reaction since energy is needed to break the molecules apart. In general, the following statements are valid during combustion reactions.

**Higher** pressures lead to **less** dissociation.

**Higher** temperatures lead to **more** dissociation.

Thrust	$F$	N
Chamber pressure	$p_c$	Pa
Nozzle exit pressure	$p_e$	Pa
Ambient pressure	$p_0$	Pa
Oxidizer fuel ratio	ROF	-
Initial mass	$m_0$	kg
Burnout mass	$m_b$	kg

Ziolkowski equation  $\Delta v = I_{sp} \cdot g_0 \cdot \ln\left(\frac{m_0}{m_b}\right)$

Total impulse  $I_T = \int_0^{t_e} F dt$

Specific vacuum impulse  $I_{sp} = \frac{F}{\dot{m}g}$

Thrust equation  $F = \dot{m} \cdot c_e + A_e \cdot (p_e - p_0)$

Thrust coefficient  $c_F = \frac{F}{A_t p_c}$

Characteristic length  $L^* = V_c / A_t$

Characteristic speed  $c^* = \frac{p_c A_t}{\dot{m}}$

Characteristic speed  $c^* = \frac{\sqrt{\kappa R T_c}}{\kappa \sqrt{\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}}}$

Efficiency of combustion  $\eta_{c^*} = \frac{c_{real}^*}{c^*}$

## Thermodynamics

Degrees of Molecular Freedom  $f$  -

Ideal gas equation  $pV = mRT$

Isentropic Coefficient  $\kappa = \frac{f+2}{f}$

Isentropic (adiabatic) expansion  $\frac{T_1}{T_0} = \left(\frac{p_1}{p_0}\right)^{\frac{\kappa-1}{\kappa}}$

Ideal gas constant  $R_m = 8.314 \frac{\text{kg m}^2}{\text{s mol K}}$

## Chemical Equations

Massfraction  $\mu_i = \frac{m_i}{m}$

Molefraction  $\nu_i = \frac{n_i}{n}$

Molemass  $M_i = \frac{m_i}{n_i}$

Average mole mass  $\bar{M} = \frac{m}{n} = \sum M_i \cdot \nu_i$

Mole to Mass fraction  $\mu_i = \frac{M_i}{\bar{M}} \nu_i$

Oxygen balance  $W_{ox} = -1600(2x + y/2 - z)/M$  with  $C_x H_y O_z$

## Assumptions of NASA CEA

Adiabatic combustion chamber.

Isentropic Expansion.

Homogenous mixing.

Thermochemical Equilibrium.

The **frozen** option of CEA will freeze all reaction products after the freezing point, allowing no further reactions in the mixture.

## Geometrics

Sphere volume  $V = \frac{4}{3}\pi R^3$

Sphere surface  $A = 4\pi R^2$

Cylinder Side  $A = 2\pi R \cdot h$

## Calculating solid/hybrid rocket fuels

Pressure Exponent	$n$	-
Fuel Surface	$A_b$	m <sup>2</sup>
Port Area	$A_p$	m <sup>2</sup>
Fuel Density	$\rho_b$	$\frac{\text{kg}}{\text{m}^3}$
Temperature Sensitivity Factor	$\Pi_{\dot{r}}$	-
Constants	$a_{ref}, T_{ref}$	-
Effective Burn Duration	$\Delta t_{AD}$	s

Regressionrate  $\dot{r} = a \cdot p_{c,0}^n = \frac{\dot{m}}{A_b \rho_b}$

with  $a = a_{ref} \cdot e^{\Pi_{\dot{r}}(T - T_{ref})}$

Temp. Sensitivity  $\Pi_{\dot{r}} = \frac{1}{\dot{r}} \left( \frac{d\dot{r}}{dT} \right)_p$

Regressionrate hybrid  $\dot{r} = a \cdot G_{ox}^n = a \cdot \left( \frac{\dot{m}_{ox}}{A_p} \right)^n$

If the pressure exponent  $n$  is greater 1, the combustion chamber is sensible to pressure disturbances and can become in-stable. This leads to a destruction of the motor.

Combustion pressure  $p_c = (c^* \rho_b a \frac{A_b}{A_t})^{\frac{1}{1-n}}$

with  $K = \frac{A_b}{A_t}$  as "clamping".

Charact. Speed  $c^* = \frac{\sqrt{\frac{R_m}{M} T_c}}{\Gamma}$

Gamma Function  $\Gamma = \sqrt{\kappa \cdot \left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}}$

Expansion Ratio  $\epsilon = \frac{A_e}{A_t} = \Gamma \sqrt{\frac{\kappa-1}{2\kappa}} \frac{\left(\frac{p_e}{p_c}\right)^{-\frac{1}{\kappa}}}{\sqrt{1 - \left(\frac{p_e}{p_c}\right)^{\frac{\kappa-1}{\kappa}}}}$

Spec. Impulse

$I_{sp} = \frac{1}{g} \left[ \sqrt{\frac{2\kappa}{\kappa-1} \frac{R_m}{M} T_c} \left[ 1 - \left(\frac{p_e}{p_c}\right)^{\frac{\kappa-1}{\kappa}} \right] + \frac{(p_e - p_a) A_e}{\dot{m}} \right]$

Effective Thrust  $F_{eff} = \int_{t_A}^{t_D} F \cdot dt / \Delta t_{AD}$

## Solid

- **Good:** High thrust density, storable, low structure mass, no pumps, cheap
- **Bad:** Short burn times, no reignition, moderate specific impulses, sensible to impacts, not throttleable

## Liquid

- **Good:** High specific impulses, reignitable, variable mass flow
- **Bad:** Movement of fuel in tanks, leakage, complex turbo pumps, big temperature range, zero-g fuel supply

## Gel

Gel propellants are mixtures containing at least two phases. A base fluid and a gelator to solidify the base fluid.

- **Good:** easy to store like solids, can handle metal additives without sedimentation, in use similar to liquid propellants due to shear-thinning behaviour
- **Bad:** lower density and thrust density, lower specific impulses, higher operating pressures to transport the gel are necessary

## Hybrid

Hybrid propellants are diffusion limited, which means that the regression rate is not pressure dependent.

- **Good:** Inherently safe because no oxidizer contained in the fuel, can be throttled and reignited
- **Bad:** low regression rates, oxidizer-fuel shift in some fuels during operation, not much experience

It has been shown that Paraffin cores have a higher regression rate (3-5 times) than the classical HTPB cores.

## Green Propellants

- **Good:** Lower toxicity, less environmental hazards, lower costs
- **Bad:** medium specific impulses, not much experience

## Editorial

Created by Christian Mollière.

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