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 $\Delta v = I_{\text{sp}} \cdot g_0 \cdot \ln(\frac{m_0}{m_b})$

Total impulse $I_T = \int_0^{t_e} F dt$
Specific vacuum impulse $I_{\text{sp}} = \frac{F}{\dot{m} g}$

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

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

Thermodynamics

Degrees of Molecular Freedom	f	-

Ideal gas equation $pV = mRT$

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

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

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 $\mu_i = \frac{M_i}{M} \nu_i$
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 $A = 4\pi R^2$

Calculating solid rocket fuels

Pressure Exponent	n	-
Fuel Surface	A_b	m^2
Fuel Density	ρ_b	$\frac{\text{kg}}{\text{m}^3}$
Temperature Sensitivity Factor	$\Pi_{\dot{r}}$	-
Constants	a_{ref}, T_{ref}	-
Effective Burn Duration	Δt_{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 $\Pi_{\dot{r}} = \frac{1}{\dot{r}}(\frac{d\dot{r}}{dT})_p$

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

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

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

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

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 throttable

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 thrustdensity, 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

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