Formelsammlung Solartechnik / Formulary Solar Technology

Wintersemester 24/25 / Winter term 24/25

Grundlagen solarer Strahlung / Fundamentals of Solar Radiation

Winkelbeziehungen / Angular relationships

Deklination / Declination
$$\delta = 0.39795 \cdot \cos(0.98563 \cdot (N - 173)) \tag{1}$$

Höhenwinkel / Altitude angle
$$\sin\gamma = \cos\delta \cdot \cos\Omega_s \cdot \cos\varphi + \sin\delta \cdot \sin\varphi \tag{2}$$

Azimuthwinkel / Azimuth angle
$$\sin\alpha_s = \begin{cases} 180° - \frac{\cos\delta \cdot \sin\Omega_s}{\cos\gamma}, & \text{wenn / if } \cos\Omega_s < \frac{\tan\delta}{\tan\varphi} \\ \frac{\cos\delta \cdot \sin\Omega_s}{\cos\gamma}, & \text{sonst / otherwise} \end{cases} \tag{3}$$

mit / with

Stundenwinkel / Hour angle	Ω_s
Breitengrad / Latitude	φ
Fortlaufende Nummerierung der Tage / Day of year	N

Plancksches Strahlungsgesetz / Planck's radiation law
$$E_{\lambda,S}(\lambda, T) = \frac{2\pi hc^2}{\lambda^5 (e^{\frac{hc}{\lambda k_B T}} - 1)} \tag{4}$$

Wiensches Verschiebungsgesetz / Wien's displacement law
$$\lambda_{\max} T = 2897.8\,\mu\text{m}\,\text{K} \tag{5}$$

Stefan-Boltzmann-Gesetz / Stefan-Boltzmann law
$$E = \sigma A T^4 \tag{6}$$

Transmissionsgesetz / Transmission law
$$I = I_0 \cdot e^{-\epsilon \cdot s} = I_0 \cdot \tau_G \qquad \text{mit / with} \quad \tau_G = \tau_{RS} \cdot \tau_{MS} \cdot \tau_A \tag{7}$$

Snellius Gesetz / Snellius' law
$$\frac{\sin\alpha}{\sin\beta} = \frac{n_2}{n_1} = \frac{c_1}{c_2} \tag{8}$$

Strahlungsintensität / Radiant intensity
$$L = \frac{d^2E}{dA_{\text{proj}}\, d\Omega} = \frac{d^2E}{\cos\theta\, dA\, d\Omega} \tag{9}$$

mit / with $d\Omega = \sin\theta \, d\theta \, d\varphi$ (Raumwinkel / Solid angle)

Strahlungsfluss / Radiant flux

$$q = \int_0^{2\pi} \int_0^{\pi} L \cos\theta \sin\theta \, d\theta \, d\varphi \tag{10}$$

Etendue / Etendue

$$U := \iint N^2 \cos\theta \, dA \, d\Omega \tag{11}$$

Konzentration solarer Strahlung / Concentration of Solar Radiation

Brennfleck Paraboloid / Focal Spot of Paraboloid

$$r_{1,B} = r_{t,\alpha D} = \frac{d_B}{2} \cdot \alpha_D \tag{12}$$

$$r_{2,B} = \frac{r_t \cdot \alpha_D}{\cos(\phi)} \tag{13}$$

$$A = \pi r_t^2 \sin(\phi)^2 \tag{14}$$

$$A' = \pi r_t^2 \frac{\sin(\Theta)^2}{\cos(\phi)^2} \tag{15}$$

Brennrechteck Parabolrinne / Focal rectangle of parabolic trough

$$r_B = \frac{r_t \cdot \alpha_D}{\cos(\phi)} - \frac{d_B}{2} \tag{16}$$

$$A = 2 \cdot l \cdot r_t \sin(\phi) \tag{17}$$

$$A' = l \cdot r_t \frac{\sin(\Theta)}{\cos(\phi)} \tag{18}$$

Maximale Temperatur / Maximum temperature

$$T_{\text{abs, max}} = \sqrt[4]{\frac{I_0}{\sigma} C} = T_S \sqrt[4]{\frac{C}{C_{\mathbf{max}}}} \tag{19}$$

Thermische Kollektoren / Thermal Collectors

Parabolrinnenkollektoren / Parabolic Trough Collectors

Optischer Wirkungsgrad / Optical efficiency

$$\eta_{\text{opt}} = \rho_{\text{refl}} \cdot \tau_{\text{rec}} \cdot \alpha_{\text{rec}} \cdot IC \tag{20}$$

Wirkungsgradgleichung / Efficiency equation

$$\eta_{\text{coll}} = \eta_{\text{opt}} \cdot \kappa(\theta) - c_1 \cdot T_m^* - c_2 \cdot G_b \cdot T_m^{*2} \tag{21}$$

mit / with $T_m^* = \dfrac{T_{\text{fluid}} - T_U}{G_b}$ and $G_b = DNI \cdot \cos\theta$

Einfallswinkel-Modifikator / Incidence Angle Modifier (IAM)

$$\kappa(\theta) = b_0 + b_1 \cdot \theta + b_2 \cdot \theta^2 \tag{22}$$

Kollektorausrichtung / Collector orientation

N-S Ausrichtung / N-S orientation $\cos\theta = \sqrt{1 - \cos^2\gamma \cdot \cos^2\alpha_s}$ (23)

O-W Ausrichtung / E-W orientation $\cos\theta = \sqrt{1 - \cos^2\gamma \cdot \sin^2\alpha_s}$ (24)

Turmkraftwerk / Solar tower power plant

Realer Wirkungsgrad / Real efficiency

$$\eta_{\text{th}} = \frac{\dot{Q}}{A_{\text{Ap}} \cdot C \cdot DNI \cdot \eta_{\text{hel}}} \tag{25}$$

Receiver Bilanz / Receiver balance

$$\dot{Q} = A_{\text{ap}} \left[\alpha \cdot C \cdot DNI \cdot \eta_{\text{hel}} - \epsilon \cdot \sigma T_{\text{abs}}^4 - U_L \cdot (T_{\text{abs}} - T_{\text{amb}})\right] = A_{\text{abs}} \cdot U_I \cdot (T_{\text{abs}} - T_{\text{fluid}}) \tag{26}$$

Kraftwerksschaltungen / Power Plant Circuits

Thermische Kreisprozesse / Thermal cycles

Ideal thermischer Wirkungsgrad Brayton / Ideal Brayton cycle efficiency

$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}} \quad \text{mit / with} \quad \kappa = \frac{c_p}{c_v} \tag{27}$$

Isentrope Zustandsänderung / Isentropic process

$$\eta_{s,V} = \frac{h_{2,s} - h_1}{h_2 - h_1} \quad \text{und / and} \quad \eta_{s,T} = \frac{h_3 - h_4}{h_3 - h_{4,s}} \tag{28}$$

Photovoltaik / Photovoltaics

PV Zellen / PV cells

Planck-Einstein Relation / Planck-Einstein relation

$$E_\lambda = \frac{hc}{\lambda} \tag{29}$$

Shockley-Gleichung / Shockley equation

$$I_D = I_S\left(e^{\frac{U_D}{nU_T}} - 1\right) \tag{30}$$

Strom-Spannungskennlinie / Current-voltage characteristic

$$I = I_{\text{ph}} - I_D = c_0 E - I_S \cdot \left(e^{\frac{U_D}{nU_T}} - 1\right) \tag{31}$$

$$FF = \frac{P_{\text{MPP}}}{U_L \cdot I_K} < 1 \tag{32}$$

Wirkungsgrad / Efficiency

$$\eta = \frac{P_{\text{el}}}{P_{\text{solar}}} = \frac{P_{\text{MPP}}}{E_{\text{solar}} \cdot A_{\text{cell}}} \tag{33}$$

Konzentrationsabhängigkeit / Concentration dependence

$$U_L^C = U_L^1 + m\,U_T \ln(C) \tag{34}$$

$$I_K^C = C \cdot I_K^1 \tag{35}$$

Energiespeicher / Energy Storage

Speicherkapazität / Storage capacity

$$Q = f_{\text{usage}} \cdot m \cdot \overline{c_p} \cdot (T_{\max} - T_{\min}) \tag{36}$$

mit / with $f_{\text{usage}} = \dfrac{Q_{\text{storage,real}}}{Q_{\text{storage,ideal}}}$

Katalytische Reaktionen / Catalytic reactions

$$A + B + \Delta^R H^* \rightleftharpoons C + D \tag{37}$$

Thermische Dissoziationsreaktionen / Thermal dissociation reactions

$$\text{AB}_{(s/l)} + \Delta^R H^* \rightleftharpoons \text{A}_{(s/l)} + \text{B}_{(g)} \tag{38}$$

Solare Wasserstofferzeugung - Solar hydrogen production

Allgemeine Reaktionsgleichung / General reaction equation

$$\text{C}_n\text{H}_m\text{O}_x + o\text{H}_2\text{O} \rightleftharpoons (n-(o+x))\text{C} + (o+x)\text{CO} + \left(\frac{m}{2} + o\right)\text{H}_2 \tag{39}$$

Ideale Gasgleichung / Ideal gas law

$$pV = nRT \tag{40}$$

Konstanten / Constants

Lichtgeschwindigkeit im Vakuum / Speed of light in vacuum

$$c_0 = 2.998 \times 10^8 \, \frac{\mathrm{m}}{\mathrm{s}} \tag{41}$$

Planck-Konstante / Planck's constant

$$h = 6.626 \times 10^{-34} \, \mathrm{J\,s} \tag{42}$$

Elementarladung eines Elektrons / Electronvolt

$$1 \, \mathrm{eV} = 1.602 \times 10^{-19} \, \mathrm{J} \tag{43}$$

Ideale Gaskonstante / Ideal gas constant

$$R = 8.314 \, \frac{\mathrm{J}}{\mathrm{mol\,K}} \tag{44}$$

Boltzmann-Konstante / Boltzmann's constant

$$k_B = 1.381 \times 10^{-23} \, \frac{\mathrm{J}}{\mathrm{K}} \tag{45}$$

Stefan-Boltzmann-Konstante / Stefan-Boltzmann constant

$$\sigma = 5.67 \times 10^{-8} \, \frac{\mathrm{W}}{\mathrm{m^2\,K^4}} \tag{46}$$

Bandlücken / Band Gaps

Table 1: Bandlücken

Material	E_G [eV]
Ge	0.70
$CuInSe_2$	1.00
c−Si	1.13
GaAs	1.42
CdTe	1.45
AlSb	1.55
$CuGaSe_2$	1.70
$a-Si_{(amorph)}$	1.70
$Al_{0\cdot 85}Ga_{0\cdot 15}As$	1.90
GaP	2.30
CdS	2.45