Formula Sheet AE1105 (Sustainable Development)

Wind:

Energy flow: $\frac{1}{2}\rho U^3 A$ [W] — U: incoming wind speed, A: πr^2, swept area

Power coeff.: $C_P = \frac{P}{\frac{1}{2}\rho U^3 A}$ — $C_{P,drag} < 0.15$, $C_{P,lift} \approx 0.45$, maximum $= \frac{16}{27}$

Power: $P = D_{plate} \cdot (U - V)$ — V: travelling speed of blades

Produced energy: $E_{produced} = C_f \cdot P_{rated} \cdot 8760 \cdot T$ — C_f: capacity factor, 8760: hrs/year, T: lifetime (= 20)

Tip speed: $U = \Omega R = \frac{2\pi RN}{60}$ — Ω: angular veloc., R: radius, N: rpm

T.S. ratio: $\lambda = \frac{U}{V} = \frac{\Omega R}{V}$ — U: tip speed, V: free stream velocity

Cost/kWh: $g = C\frac{R}{E} + M$, $M = K\frac{C}{E}$ — C: capital cost, R: capital recovery factor, E: annual energy output, M: maintenance costs, K: factor (= 0,025)

R: $R = \frac{x}{1-(1+x)^{-n}}$ — x: required annual rate of return, n: years to recover investm.

Life Cycle Analysis

Energy Intensity Rat.: $\eta = \frac{E_{used}}{E_{produed}}$

Energy Payback Ratio: $EPR = \frac{1}{\eta} = \frac{E_{produced}}{E_{used}}$

Energy Payback Time: $EPR \cdot T = \eta \cdot T$

$EPR \cdot T = \eta \cdot \epsilon_{fossil\ fuel} \cdot T$ — T: lifetime (= 20)

Solar:

Avg. solar energy: $E_{in} = (\frac{1}{4})(1-\alpha) \cdot S_0 \cdot (\pi \cdot R^2)$ — $\alpha = 0.3$, $S_0 = 1372 W/m^2$, $R = 6367{,}5 km$.

Avg. outgoing energy: $E_{out} = \sigma \cdot T^4 \cdot 4 \cdot \pi \cdot R^2$ — $\sigma = 5{,}670 \cdot 10^{-8} W/m^2K^4$ (Stefan-Boltzmann), T: temperature of the Earth

Air mass: $\frac{AB}{AC} = \frac{1}{\cos(\theta_i)}$

Declination: $\delta = 23{,}45 \cdot \sin\left(\frac{360}{365}(284+n)\right)$ — n: day of year

Angle of incidence: $\theta_i = (\cos\phi \cdot \cos\beta + \sin\phi \cdot \sin\beta \cdot \cos\gamma)\cos\delta \cdot \cos\omega + \cos\delta \cdot \sin\omega \cdot \sin\beta \cdot \sin\gamma + \sin\delta$ $(\sin\phi \cdot \cos\beta - \cos\phi \cdot \sin\beta \cdot \cos\gamma)$ — γ: azimuth angle (solar panel), β: slope (tilt of solar panel), ϕ: latitude, ω: azimuth angle (Earth), δ: declination

Available solar energy: $I_S \cdot \cos\theta_i \cdot \eta \cdot A$ — I_S: intensity of sunlight, η: efficiency, A: area panel

Sunlight hours: $N = \frac{2}{15}\cos^{-1}(-\tan\delta \cdot \tan\phi)$

Heat transfer:

Conduction (Fourier): $Q = -k \cdot A \cdot \frac{\Delta T}{\Delta t}$ — Q: heat, k: const. thermal cond., T: temp, t: thickness

k: $k = k_0\left(1 + \beta(T - T_0)\right)$ — k_0: k_{T_0}, β: for (g) $\beta > 0$, for (s)/(l) $\beta < 0$.

Thermal diffusivity: $\alpha = \frac{heat\ conducted}{heat\ stored} = \frac{k}{\rho \cdot C_P}$ — C_P: specific heat, $\rho \cdot C_P$: heat capacity

Thermal resistance: $R = \frac{t}{k}$, $R_{tot} = R_1 + R_2 + \cdots + R_n$ — t: thickness

Composed wall: $\frac{\dot{Q}}{A} = \dot{q} = \frac{\Delta T_{tot}}{R_{tot}}$

Convection: $\dot{Q} = h \cdot A \cdot \Delta T$ — h: local heat transfer coeff, A: area

Thermal resistance: $R = \frac{1}{h}$, $R_{tot} = R_1 + R_2 + \cdots + R_n$

Heat trans. in general: $q = U \cdot \delta T$

U: $U = \frac{1}{\frac{1}{h_A} + \frac{t_1}{k_1} + \frac{1}{c} + \frac{t_2}{k_2} + \frac{1}{h_B}}$

Radiation (coeff's): $\rho' + \alpha' + \tau = 1$ — ρ': reflectivity c., α': absorptivity c., τ: transmittivity c.

Alternative aviation fuels:

Change in Eq. surf. T: $\Delta T = \lambda \cdot \Delta F$ — λ: climate sensitivity (= 0,8), ΔF: radiative forcing

F: $\Delta F = \frac{\Delta solar\ energy \cdot (1-\alpha)}{4}$

Fischer-Tropsch: $(2n+1)H_2 + nCO \rightarrow C_nH_{2n+2} + nH_2O$ + catalyst

Bram Peerlings – October 24, 2010