

Formuleblad Thermodynamica 2, versie 18-4-2011

Ideale Gaswet $pV = nRT$ en dus $pv = RT$

Constantes $R = 8.314472 \text{ J mol}^{-1} \text{ K}^{-1}$ $N_{AV} = 6.02214 \cdot 10^{23}$ moleculen/mol

1^{ste} HW gesloten systeem $dU = \delta Q - \delta W$

Reversibele arbeid $W = \int_{v_1}^{v_2} p dV$

1^{ste} HW open systeem $\frac{dE_{CV}}{dt} = \dot{Q}_{CV} - \dot{W}_{CV} - \dot{m}_2 \left(h_2 + \frac{c_2^2}{2} + gz_2 \right) + \dot{m}_1 \left(h_1 + \frac{c_1^2}{2} + gz_1 \right)$. Hierin

wordt de uitgaande stroom aangeduid met "2" en de ingaande stroom met "1".

2^{de} HW gesloten systeem $dS = \frac{\delta Q}{T} + \delta S$ met $\delta S \geq 0$

2^{de} HW open systeem $\frac{dS_{CV}}{dt} = \frac{\dot{Q}_{CV}}{T^{trans}} - \dot{m}_2 s_2 + \dot{m}_1 s_1 + \dot{\sigma}_{CV}$ met $\dot{\sigma}_{CV} \geq 0$ waarbij het warmtetransport plaatsvindt bij temperatuur T^{trans}

Thermodynamische potentialen $H = U + pV$ $F = U - TS$ $G = U - TS + pV$

Veranderingen van U, H, F, G

$$dU = TdS - pdV + \mu dN \quad dH = TdS + Vdp + \mu dN$$

$$dF = -SdT - pdV + \mu dN \quad dG = -SdT + Vdp + \mu dN$$

Partiële afgeleiden voor $f(x,y)$

$$df = \left(\frac{\partial f}{\partial x} \right)_y dx + \left(\frac{\partial f}{\partial y} \right)_x dy = M dx + N dy \quad \text{dus} \quad M = \left(\frac{\partial f}{\partial x} \right)_y \quad \text{en} \quad N = \left(\frac{\partial f}{\partial y} \right)_x$$

Maxwell relatie voor $f(x,y)$

$$\text{Indien } df = M dx + N dy \quad \text{dan} \quad \left(\frac{\partial M}{\partial y} \right)_x = \left(\frac{\partial N}{\partial x} \right)_y \quad \text{oftewel} \quad \frac{\partial}{\partial x} \left[\left(\frac{\partial f}{\partial y} \right)_x \right]_y = \frac{\partial}{\partial y} \left[\left(\frac{\partial f}{\partial x} \right)_y \right]_x$$

Integreren

$$f(x_2, y_1) = f(x_1, y_1) + \int_{x_1}^{x_2} \left(\frac{\partial f}{\partial x} \right)_y dx$$

Min 1 regel

$$\left(\frac{\partial x}{\partial y} \right)_z \left(\frac{\partial z}{\partial x} \right)_y \left(\frac{\partial y}{\partial z} \right)_x = -1$$

Definitie warmtecapaciteit

$$C_v = \left(\frac{\partial U}{\partial T} \right)_{v,N} = T \left(\frac{\partial S}{\partial T} \right)_{v,N} \quad \text{en} \quad C_p = \left(\frac{\partial H}{\partial T} \right)_{p,N} = T \left(\frac{\partial S}{\partial T} \right)_{p,N}$$

Departure Gibbs energy

$$\ln \frac{f}{p} = \ln \varphi = \frac{\mu - \mu^{IG}}{RT} = \int_0^p \frac{Z(p) - 1}{p} dp$$

Clapeyron equation

$$\left(\frac{dp}{dT} \right)_{sat} = \frac{s_g - s_f}{v_g - v_f} = \frac{h_g - h_f}{T(v_g - v_f)}$$

Clausius-Clapeyron equation

$$\left(\frac{d \ln P}{dT} \right)_{sat} = \frac{h_g - h_f}{RT^2}$$

Carnot efficiency

$$\eta_{Carnot} = 1 - \frac{T_L}{T_H}$$

Thermal power cycle efficiency (I-law efficiency)

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$$

Isentropic process for an ideal gas

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^\gamma = \left(\frac{v_1}{v_2} \right)^{\gamma-1} \quad \text{met} \quad \gamma = \frac{C_p}{C_v}$$

Entropy change of an ideal gas with temperature and pressure and constant c_p

$$s(T_2, p_2) - s(T_1, p_1) = c_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}$$

Isentropic efficiencies for compression and expansion

$$\eta_{is,exp} = \frac{h_1 - h_2}{h_1 - h_{2,is}}, \quad \eta_{is,compr} = \frac{h_{2,is} - h_1}{h_2 - h_1}$$

COP (coefficient of performance)

$$COP_{cooling} = \frac{Q_C}{Q_H - Q_C} = \frac{T_C}{T_H - T_C}, \quad COP_{heating} = \frac{Q_H}{Q_H - Q_C} = \frac{T_H}{T_H - T_C}$$

Exergy: specific flow exergy and balances

$$ex_f = h - h_0 + \frac{v^2}{2} + gz - T_0 (s - s_0)$$

$$\frac{dEx}{dt} = \dot{E}x_{f,1} - \dot{E}x_{f,2} + (h_0 - T_0 s_0)(\dot{M}_1 - \dot{M}_2) + \left(1 - \frac{T_0}{T_b}\right) \dot{Q} + \dot{W} + \dot{E}x_d$$

$$\dot{M} (ex_{f,1} - ex_{f,2}) = - \left(1 - \frac{T_0}{T_b}\right) \dot{Q} + \dot{W} + \dot{E}x_d$$