# Formularium Thermodynamica

2009-'10

## 1 Eigenschappen van zuivere stoffen

verzadigd mengsel: $y_{\mathrm{avg}} = y_{\mathrm{f}} + x y_{\mathrm{fg}}$

samengedrukte vloeistof: $\begin{cases} h_T \approx h_{\mathrm{f},T} + v_{\mathrm{f},T}(P - P_{\mathrm{sat},T}) \\ y_T \approx y_{\mathrm{f},T} \end{cases}$

ideale gassen:

$$PV = mRT$$

reële gassen:

$$z = \frac{Pv}{RT} \text{ met } z = \frac{v_{\mathrm{actual}}}{v_{\mathrm{ideal}}}$$

$z \approx$ cte voor alle gassen bij eenzelfde $T_R$ en $P_R$ :

$$T_R = \frac{T}{T_{\mathrm{cr}}} \text{ en } P_R = \frac{P}{P_{\mathrm{cr}}}$$

$$v_R = v_{\mathrm{actual}} \frac{P_{\mathrm{cr}}}{RT_{\mathrm{cr}}}$$

$$\left(P + \frac{a}{v^2}\right)(v - b) = RT \qquad \text{(Van der Waals)}$$

## 2 Arbeid en energie

$$h = u + Pv$$

$$W_{\mathrm{b}} = \int_1^2 P \, \mathrm{d}V$$

$$\Delta H = \Delta U + W_{\mathrm{b}}$$

$$\Delta E_{\mathrm{sys}} = E_{\mathrm{in}} - E_{\mathrm{uit}}$$

Polytroop proces:

$$\frac{P}{v^{-n}} = \mathrm{cte}$$

Warmtecapaciteit:

$$c_v = \left(\frac{\delta u}{\delta T}\right)_v \qquad c_P = \left(\frac{\delta h}{\delta T}\right)_P$$

Ideale gassen:

$$c_P = c_v + R$$
$$k = \frac{c_P}{c_v}$$
$$\Delta u \approx c_{v,\text{avg}}\,(T_2 - T_1)$$
$$\Delta h \approx c_{P,\text{avg}}\,(T_2 - T_1)$$

Vaste stoffen en vloeistoffen:

$$c_P = c_v = c$$
$$\Delta u \approx c_{,\text{ avg}}\,(T_2 - T_1)$$
$$\Delta h = \Delta u + v\Delta P$$

## 3 Stroming van massa en energie

$$\dot{m} = \rho v A \qquad \text{waarin } v = \text{snelheid} \qquad \text{incompressible flow: } \rho = \text{cte}$$
$$\frac{\mathrm{d}m_{\text{sys}}}{\mathrm{d}t} = \dot{m}_{\text{in}} - \dot{m}_{\text{uit}}$$
$$\Theta = h + e_{\text{kin}} + e_{\text{pot}} \qquad (\text{kJ/kg})$$
$$E_{\text{mass flow}} = m\Theta$$
$$\text{Steady flow: } \begin{cases} E_{\text{sys}} = \text{cte} \\ m_{\text{CV}} = \text{cte} \end{cases}$$

## 4 Tweede hoofdwet

Cyclus (warmtemotor):

$$\eta_{\text{th}} = \frac{W_{\text{net, uit}}}{Q_{\text{in}}}$$
$$Q_{\text{in}} - Q_{\text{uit}} - W_{\text{net,uit}} = 0$$
$$\text{Reversibele processen: } \frac{Q_{\text{L}}}{Q_{\text{H}}} = \frac{T_{\text{L}}}{T_{\text{H}}}$$

Warmtepomp:

$$\text{COP}_{\text{HP}} = \frac{Q_{\text{uit}}}{W_{\text{net,in}}}$$

Koelinstallatie (refrigerator):

$$\text{COP}_{\text{R}} = \frac{Q_{\text{in}}}{W_{\text{net,in}}}$$

## 5 Entropie

$$\Delta S = S_{\text{in}} - S_{\text{uit}} + S_{\text{gen}}$$

Gibbs-vergelijkingen:

$$\begin{aligned} T\,\mathrm{d}s &= \mathrm{d}u + P\,\mathrm{d}v \\ &= \mathrm{d}h - v\,\mathrm{d}P \end{aligned}$$

Ideale gassen:

$$\begin{aligned} s_2 - s_1 &= s_2^0 - s_1^0 - R\ln\frac{P_2}{P_1} \\ &= c_{P,\text{avg}}\ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1} \\ &= c_{v,\text{avg}}\ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1} \end{aligned}$$

Vaste stoffen en vloeistoffen:

$$\Delta s = c_{\text{avg}}\ln\frac{T_2}{T_1}$$

Isentrope processen:

$$\begin{aligned} \left(\frac{T_2}{T_1}\right)_S &= \left(\frac{v_1}{v_2}\right)^{k-1} \\ &= \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \\ \left(\frac{P_2}{P_1}\right)_S &= \left(\frac{v_1}{v_2}\right)^{k} \end{aligned}$$

$$\left(\frac{v_2}{v_1}\right)_S = \frac{v_{\text{r}2}}{v_{\text{r}1}} \qquad v_{\text{r}} = \frac{T}{P_{\text{r}}}$$

$$\left(\frac{P_2}{P_1}\right)_S = \frac{P_{\text{r}2}}{P_{\text{r}1}}$$

## 6 Gascycli

Compressieverhouding:

$$r = \frac{V_{\text{max}}}{V_{\text{min}}} = \frac{V_{\text{BDC}}}{V_{\text{TDC}}}$$

Mean effective pressure:

$$\text{MEP} = \frac{W_{\text{net}}}{\Delta V} = \frac{W_{\text{net}}}{V_{\text{BDC}} - V_{\text{TDC}}}$$

Carnot-cyclus:

$$\eta_{\text{th}} = 1 - \frac{T_{\text{L}}}{T_{\text{H}}}$$

Otto-cyclus:

$$\eta_{\text{th}} = 1 - \frac{1}{r^{k-1}}$$

Stirling & Ericsson-cycli:

$$\eta_{\text{th}} = 1 - \frac{T_{\text{L}}}{T_{\text{H}}}$$

Diesel-cyclus:

$$\eta_{\text{th}} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_{\text{c}}^k - 1}{k\,(r_{\text{c}} - 1)}\right] \qquad \text{met } r_{\text{c}} = \frac{v_{\text{na verbranding}}}{v_{\text{voor verbranding}}} \text{ (= cutoff verhouding)}$$