I. Eigenschappen van zuivere stoffen/Properties of pure substances

1 Algemeen/General

- $H \stackrel{\text{def}}{=} U + PV$, $\quad h = u + Pv$
- $c_V \stackrel{\text{def}}{=} \left(\frac{\partial u}{\partial T}\right)_V$, $c_P \stackrel{\text{def}}{=} \left(\frac{\partial h}{\partial T}\right)_P$, $k \stackrel{\text{def}}{=} \frac{c_P}{c_V}$

2 Vaste stoffen en onsamendrukbare vloeistoffen/Solids and incompressible liquids

- $v = \text{constant}$
- $c_P = c_V = c$
- $\Delta u = c\Delta T$
- $\Delta h = c\Delta T + v\Delta P$
- $\Delta s = s_2 - s_1 = c \ \ln\frac{T_2}{T_1}$

3 Samengedrukte vloeistof/Compressed liquid

- $v = v_f(T)$, $u = u_f(T)$, $s = s_f(T)$, $h = h_f(T)$

4 Verzadigde vloeistof-damp mengsels/ Saturated liquid-vapor mixtures

- $x \stackrel{\text{def}}{=} \frac{m_g}{m_f + m_g}$
- $v = x\, v_g + (1-x)v_f = v_f + x\left(v_g - v_f\right) = v_f + x\, v_{fg}$
  (idem voor u, h en s/same for u, h and s)
- Verzadigde vloeistof/Saturated liquid: $x = 0$,
  Verzadigde damp/Saturated vapor: $x = 1$

5 Oververhitte damp/Superheated vapor

Tabel/Table A6 (water) en/and A13 (R134a)

6 Ideale gassen/Ideal gases

- **Ideale gaswet/Ideal gas law**:
  1) $PV = n\bar{R}T$
     met/with $\bar{R} = 8{,}314 \frac{\mathrm{J}}{\mathrm{mol}\,K}$ onafhankelijk van het gas/independent of the gas
  2) $Pv = RT$
     met/with $R = \frac{\bar{R}}{M}$ afhankelijk van het gas/dependent on the gas
- $c_P = c_V + R$
- u en h enkel functie van T/ u and h only a function of T:
  $c_V = \frac{du}{dT}$ en/and $c_P = \frac{dh}{dT}$

Polytrope toestandsveranderingen/Polytropic state changes

- $Pv^n = \text{constant}$
- $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \left(\frac{v_2}{v_1}\right)^{1-n}$ en/and $\frac{P_2}{P_1} = \left(\frac{v_2}{v_1}\right)^{-n}$

Toestandsveranderingen bij constante c_V en c_P/State changes with constant c_V and c_P

- $\Delta u = c_V \Delta T$
  $\Delta h = c_P \Delta T$
- $\Delta s = c_P \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1} = c_V \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1}$
- Isentroop = polytroop met $n = k$/
  Isentrope = polytrope with $n = k$

II. Gesloten systemen/Closed Systems

1 Algemeen/General

- Behoud van massa/Conservation of mass: $\dot{m}_{in} = \dot{m}_{out} = 0$
- 1ste hoofdwet (Behoud van Energie)/
  1st law of thermodynamics (Conservation of energy):
  $$\Delta E = Q - W$$

  Q: warmte opgenomen door het systeem vanuit de omgeving/heat absorbed by the system from the environment

  W: arbeid geleverd door het system op de omgeving/work done by the system on the surroundings
- 2de hoofdwet (Entropiebalans)/
  2nd law of thermdynamics (Entropy balance)
  $$\Delta S = \sum_k \frac{Q_k}{T_k} + S_{gen} \quad (\text{met/with } S_{gen} \geq 0)$$

  Q_k: warmte uitgewisseld bij temperatuur T_k/heat exchanged at temperature T_k

  S_{gen}: gegenereerde entropie (altijd niet-negatief)/generated entropy (always non-negative)

2 Reversibele processen/Reversible processes

- Volumearbeid of expansiearbeid/Boundary work:
  $$W_{1\to 2} = \int_1^2 P dV$$
- Polytroop proces van ideaal gas/Polytropic process of an ideal gas:
  $$W_{1\to 2} = \frac{P_2V_2 - P_1V_1}{1-n} \quad (n \neq 1)$$
  $$W_{1\to 2} = P_1V_1 \ln\frac{V_2}{V_1} \quad (n = 1)$$

- Isotherm proces/Isothermal process: $Q = T\Delta S$

III. Stationaire open systemen/ Steady-state open systems

1 Algemeen/General

- Behoud van massa/Conservation of mass:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

- 1ste hoofdwet/1st law of thermodynamics:

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_k \dot{m}_{in_k}\theta_k = \dot{Q}_{out} + \dot{W}_{out} + \sum_k \dot{m}_{out_k}\theta_k$$

$$\theta = h + \frac{\mathrm{v}^2}{2} + gz$$

- 2de hoofdwet/2nd law of thermodynamics:

$$\sum_k \frac{\dot{Q}_k}{T_k} + \sum_k \dot{m}_{in_k}s_k - \sum_k \dot{m}_{out_k}s_k + \dot{S}_{gen} = 0$$

$$(\text{met/with } \dot{S}_{gen} \geq 0)$$

2 Inwendig reversibele processen/ Internally reversible processes ($\dot{S}_{gen}$ = 0)

- $w = -\int v\,dp + \frac{\mathrm{v}_i^2 - \mathrm{v}_e^2}{2} + g(z_i - z_e)$
- isotherm proces/isothermal process:

$$q = T\Delta s$$

- polytroop proces/polytropic process:

$$\int v\,dp = \begin{cases} \dfrac{n}{n-1}(P_2v_2 - P_1v_1) & (n \neq 1) \\ P_1v_1 \ln\left(\dfrac{P_2}{P_1}\right) & n = 1 \end{cases}$$

IV. Systemen met onregelmatige stroming/ Unsteady-flow systems

- Behoud van massa/Conservation of mass:

$$m_{in} - m_{out} = \Delta m = m_2 - m_1$$

- 1ste hoofdwet/1st law of thermodynamics:

$$\left[Q_{in} + W_{in} + \sum_k m_{in_k}\theta_k\right] - \left[Q_{out} + W_{out} + \sum_k m_{out_k}\theta_k\right] = m_2 e_2 - m_1 e_1$$

$$\theta = h + \mathrm{ke} + \mathrm{pe},\ \ e = u + \mathrm{ke} + \mathrm{pe}$$

- 2de hoofdwet/2nd law of thermodynamics:

$$\sum_k \frac{Q_k}{T_k} + \sum_k m_{in_k} s_{in} - \sum_k m_{out_k} s_{out} + S_{gen} = (S_2 - S_1)_{CV}$$

V. Warmtetransport/Heat transfer

1 Conductie/Conduction

- Wet van Fourier/Fourier's law of conduction:

$$\dot{Q} = \frac{k.A}{L}\Delta T$$

- Thermische weerstand/Thermal resistance:

$$R = \frac{L}{k.A}$$

2 Convectie/Convection

- Wet van Newton voor afkoeling/Newton's law of cooling:

$$\dot{Q} = h_{conv}.A.\Delta T$$

- Thermische weerstand/Thermal resistance:

$$R = \frac{1}{h.A}$$

3 Straling/Radiation

- Stefan-Boltzmann wet/Stefan-Boltzmann law:

$$\dot{Q} = \varepsilon.\sigma.A.T^4$$

$$\sigma = 5{,}67.10^{-8}\ W/m^2K^4$$

$$h_{rad} = \varepsilon.\sigma(T^2 + T_{surr}^2)(T + T_{surr})$$

- Netto stralingswarmtetransport/Net radiation heat transfer:

$$\dot{Q} = \varepsilon.\sigma.A(T^4 - T_{surr}^4)$$

- Thermische weerstand/Thermal resistance:

$$R = \frac{1}{h.A}$$

Formularium stromingsmechanica
Formulary fluid mechanics

1 Fluidum statica / Fluid statics

$$P = P_o + \rho g h = P_o + \rho g y \sin\theta$$

$$F_R = \int_A P dA = \int_A (P_o + \rho g y \sin\theta) dA = (P_o + \rho g y_C \sin\theta) A \text{ met/with } y_c = \frac{1}{A}\int_A y dA$$

$$y_P F_R = \int_A y P dA = P_o \int_A y dA + \rho g sin\theta \int_A y^2 dA = P_o y_c A + \rho g sin\theta I_{xx,O} \text{ met/with } I_{xx,O} = I_{xx,C} + y_C^2 A$$

$$F_B = \rho_f g \mathcal{V}$$

2 Bernoulli

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} + g z_1 = \frac{p_2}{\rho} + \frac{V_2^2}{2} + g z_2$$

3 Momentum analyse / Momentum analysis

$$\frac{dN_{sys}}{dt} = \frac{d}{dt}\int_{CV} \rho\eta d\mathcal{V} + \int_{CS} \rho\eta \vec{V} \cdot d\vec{A}$$

Behoud van massa / Conservation of mass:

$$\frac{d}{dt}\int_{CV} \rho d\mathcal{V} + \int_{CS} \rho \vec{V} \cdot d\vec{A} = 0$$

Behoud van momentum / Conservation of momentum:

$$\sum \vec{F} = \frac{d}{dt}\int_{CV} \rho \vec{V} d\mathcal{V} + \int_{CS} \rho \vec{V}\vec{V} \cdot d\vec{A}$$

$$\sum \vec{F} = \frac{d}{dt}\int_{CV} \rho \vec{V} d\mathcal{V} + \sum_{out} \beta \dot{m} \vec{V}_{avg} - \sum_{in} \beta \dot{m} \vec{V}_{avg}$$

4 Inwendige stroming / Internal flow

Navier-Stokes:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + \nu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

Reynoldsgetal / Reynolds number:

$$Re = \frac{VD}{\nu} = \frac{\rho V D}{\mu}$$

Stroming in buis / Pipe flow:

$$u(r) = -\frac{R^2}{4\mu}\left(\frac{dP}{dx}\right)\left(1 - \frac{r^2}{R^2}\right)$$

$$Q = -\frac{\pi R^4}{8\mu}\frac{\partial P}{\partial x}$$

Plaatstroming / Plate flow:

$$u(x) = \frac{1}{2\mu}\frac{dP}{dx}y^2 + \left[\frac{U_p}{a} - \frac{1}{2\mu}\frac{dP}{dx}a\right]y$$

Major/Minor losses:

$$\Delta P = f\frac{L}{D}\frac{\rho V_{avg}^2}{2} + \sum_i K_i\frac{\rho V_{avg}^2}{2}$$

Laminaire stroming / laminar flow:

$$f = \frac{64}{Re}$$

Turbulente stroming / turbulent flow:

$$\frac{1}{\sqrt{f}} \cong -2.0\log\left(\frac{\epsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

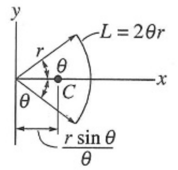
Krachtwerking / fluid forces:

$$C_D = \frac{F_D}{(\rho V^2/2)A}$$

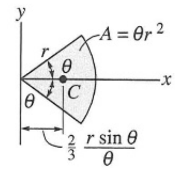
$$C_L = \frac{F_L}{(\rho V^2/2)A}$$

Geometrische eigenschappen van lijn- en oppervlakte-elementen

Plaats van het zwaartepunt	Plaats van het zwaartepunt	Traagheidsmoment van oppervlak



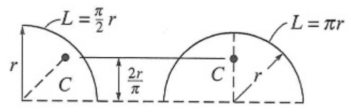
Segment van een cirkelboog



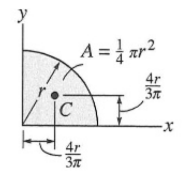
Segment van een cirkelvlak

$I_x = \frac{1}{4} r^4(\theta - \frac{1}{2}\sin 2\theta)$

$I_x = \frac{1}{4} r^4(\theta + \frac{1}{2}\sin 2\theta)$



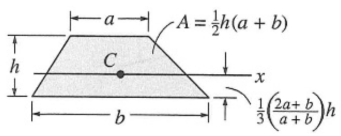
Kwart en halve cirkelboog



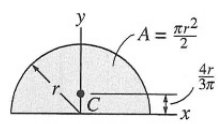
Kwart cirkelvlak

$I_x = \frac{1}{16}\pi r^4$

$I_y = \frac{1}{16}\pi r^4$



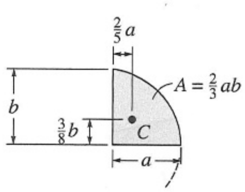
Het vlak van een trapezoïde



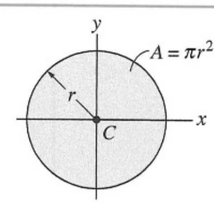
Half cirkelvlak

$I_x = \frac{1}{8}\pi r^4$

$I_y = \frac{1}{8}\pi r^4$



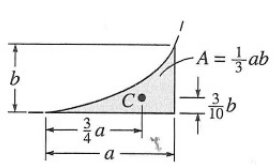
Half paraboolvlak



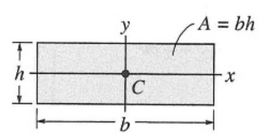
Cirkelvlak

$I_x = \frac{1}{4}\pi r^4$

$I_y = \frac{1}{4}\pi r^4$



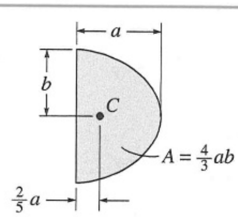
Exparaboolvlak



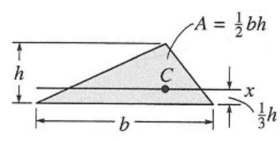
Rechthoekig vlak

$I_x = \frac{1}{12}bh^3$

$I_y = \frac{1}{12}hb^3$



Paraboolvlak



Driehoekig vlak

$I_x = \frac{1}{36}bh^3$

Integralen

$$\int x^n\,dx = \frac{x^{n+1}}{n+1} + C, \quad n \neq -1$$

$$\int \frac{dx}{a+bx} = \frac{1}{b}\ln(a+bx) + C$$

$$\int \frac{dx}{a+bx^2} = \frac{1}{2\sqrt{-ba}}\ln\left[\frac{a+x\sqrt{-ab}}{a-x\sqrt{-ab}}\right] + C, \quad ab < 0$$

$$\int \frac{x\,dx}{a+bx^2} = \frac{1}{2b}\ln(bx^2+a) + C,$$

$$\int \frac{x^2\,dx}{a+bx^2} = \frac{x}{b} - \frac{a}{b\sqrt{ab}}\tan^{-1}\frac{x\sqrt{ab}}{a} + C, \quad ab > 0$$

$$\int \frac{dx}{a^2-x^2} = \frac{1}{2a}\ln\left[\frac{a+x}{a-x}\right] + C, \quad a^2 > x^2$$

$$\int \sqrt{a+bx}\,dx = \frac{2}{3b}\sqrt{(a+bx)^3} + C$$

$$\int x\sqrt{a+bx}\,dx = \frac{-2(2a-3bx)\sqrt{(a+bx)^3}}{15b^2} + C$$

$$\int x^2\sqrt{a+bx}\,dx = \frac{2(8a^2-12abx+15b^2x^2)\sqrt{(a+bx)^3}}{105b^3} + C$$

$$\int \sqrt{a^2-x^2}\,dx = \frac{1}{2}\left[x\sqrt{a^2-x^2} + a^2\sin^{-1}\frac{x}{a}\right] + C, \quad a > 0$$

$$\int x\sqrt{a^2-x^2}\,dx = -\frac{1}{3}\sqrt{(a^2-x^2)^3} + C$$

$$\int x^2\sqrt{a^2-x^2}\,dx = -\frac{x}{4}\sqrt{(a^2-x^2)^3} + \frac{a^2}{8}\left(x\sqrt{a^2-x^2} + a^2\sin^{-1}\frac{x}{a}\right) + C, a > 0$$

$$\int \sqrt{x^2 \pm a^2}\,dx = \frac{1}{2}\left[x\sqrt{x^2 \pm a^2} \pm a^2\ln(x+\sqrt{x^2 \pm a^2})\right] + C$$

$$\int x\sqrt{x^2 \pm a^2}\,dx = \frac{1}{3}\sqrt{(x^2 \pm a^2)^3} + C$$

$$\int x^2\sqrt{x^2 \pm a^2}\,dx = \frac{x}{4}\sqrt{(x^2 \pm a^2)^3} \mp \frac{a^2}{8}x\sqrt{x^2 \pm a^2} - \frac{a^4}{8}\ln(x+\sqrt{x^2 \pm a^2}) + C$$

$$\int \frac{dx}{\sqrt{a+bx}} = \frac{2\sqrt{a+bx}}{b} + C$$

$$\int \frac{x\,dx}{\sqrt{x^2 \pm a^2}} = \sqrt{x^2 \pm a^2} + C$$

$$\int \frac{dx}{\sqrt{a+bx+cx^2}} = \frac{1}{\sqrt{c}}\ln\left[\sqrt{a+bx+cx^2} + x\sqrt{c} + \frac{b}{2\sqrt{c}}\right] + C, c > 0$$

$$= \frac{1}{\sqrt{-c}}\sin^{-1}\left(\frac{-2cx-b}{\sqrt{b^2-4ac}}\right) + C, c > 0$$

$$\int \sin x\,dx = -\cos x + C$$

$$\int \cos x\,dx = \sin x + C$$

$$\int x\cos(ax)\,dx = \frac{1}{a^2}\cos(ax) + \frac{x}{a}\sin(ax) + C$$

$$\int x^2\cos(ax)\,dx = \frac{2x}{a^2}\cos(ax) + \frac{a^2x^2-2}{a^3}\sin(ax) + C$$

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax} + C$$

$$\int xe^{ax}\,dx = \frac{e^{ax}}{a^2}(ax-1) + C$$

$$\int \sinh x\,dx = \cosh x + C$$

$$\int \cosh x\,dx = \sinh x + C$$