Thermodynamica 1

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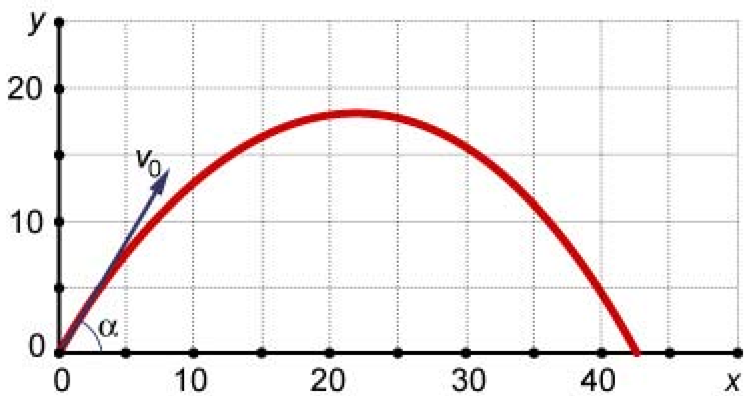
college 6 – boek hoofdstuk 1

Delft University of Technology

Water raket wedstrijd 25 maart, 2011
Mekelpark (voor de faculteit)

- Plastic cola fles (0.5 liter)
- Rubber stop of kurk
- Fiets pomp
- Prijs: 100 Euro voor grootste afstand (mits > 50 meter)
- 1 poging per deelnemer (team)



summary lecture 5

- ideal gas model
- universal gas constant
- real gases
- Joule's experiment
- specific heat: c_v and c_p (for an ideal gas)
- enthalpy
- quasi-static processes for an ideal gas

processes

ideal gas: $\delta q = c_{\mathrm{v}}\, dT + p\, d\mathrm{v}$ (quasi-static process)

isotherm: $dT = 0 \rightarrow q_{12} = w_{12} = \int_1^2 p dv = \int_1^2 \frac{RT}{v} dv = RT \ln \frac{v_2}{v_1}$

isobar: $p_2 = p_1 \rightarrow w_{12} = (p_2 v_2 - p_1 v_1) = R(T_2 - T_1); q_{12} = c_p (T_2 - T_1)$

processes

ideal gas: $\delta q = c_v\, dT + p\, d\text{v}$ (quasi-static process)

isochor: $q_{12} = c_v (T_2 - T_1)$ $\quad w_{12} = 0$

isobar: $q_{12} = c_p (T_2 - T_1)$ $\quad w_{12} = R(T_2 - T_1)$

isotherm: $q_{12} = RT \ln(\text{v}_2/\text{v}_1)$ $\quad w_{12} = q_{12}$

adiabatic: $q_{12} = 0$ $\quad w_{12} = -\, c_v (T_2 - T_1)$

Poisson relation: $p\text{v}^n = \text{constant}$, $\quad n = c_p / c_v$

IC-engine

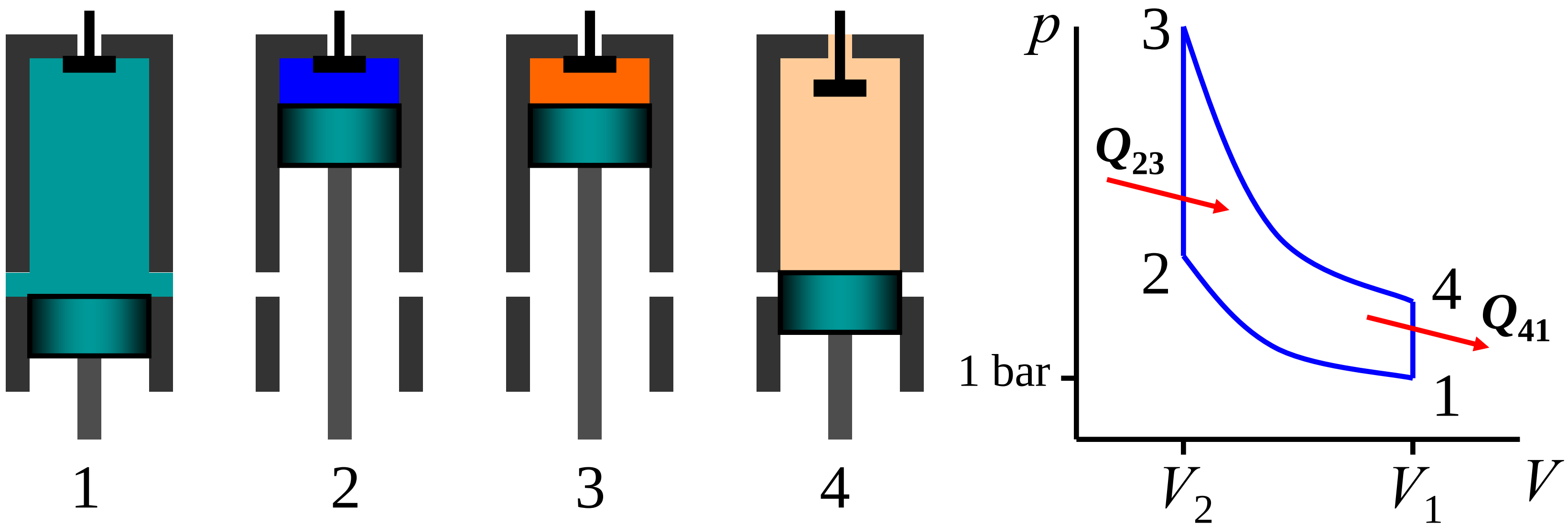
1→2 Adiabaat

2→3 Isochor

3→4 Adiabaat

4→1 Isochor

the Otto cycle



Efficiency

$$1 \Rightarrow 2: \quad 0 = C_v dT + pdV \Rightarrow \Delta_{12}W = C_v(T_1 - T_2)$$

$$2 \Rightarrow 3: \quad \delta Q = \mathrm{C_v} dT \Rightarrow \Delta Q_{23} = C_v(T_3 - T_2)$$

$$3 \Rightarrow 4: \quad 0 = \mathrm{C_v} dT + pdV \Rightarrow \Delta_{34}W = C_v(T_3 - T_4)$$

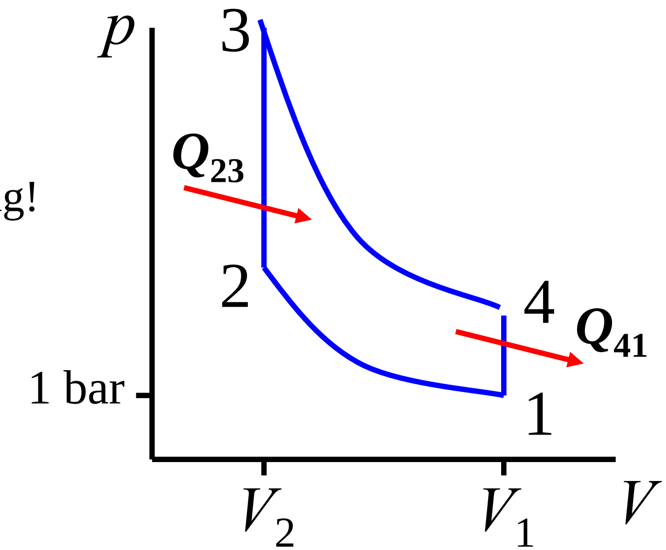
$$4 \Rightarrow 1: \quad \delta Q = \mathrm{C_v} dT \Rightarrow \Delta Q_{41} = C_v(T_4 - T_1)$$

$$W_{cycle} = \Delta_{34}W + \Delta_{12}W$$

$$\eta = \frac{W_c}{Q_{in}} = \frac{C_v[(T_3 - T_4) + (T_1 - T_2)]}{C_v(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

$T_3 - T_2 \Rightarrow$ Zo hoog mogelijk maken $\Rightarrow$ warme motor!

$T_4 - T_1 \Rightarrow$ Zo laag mogelijk maken $\Rightarrow$ koude omgeving!

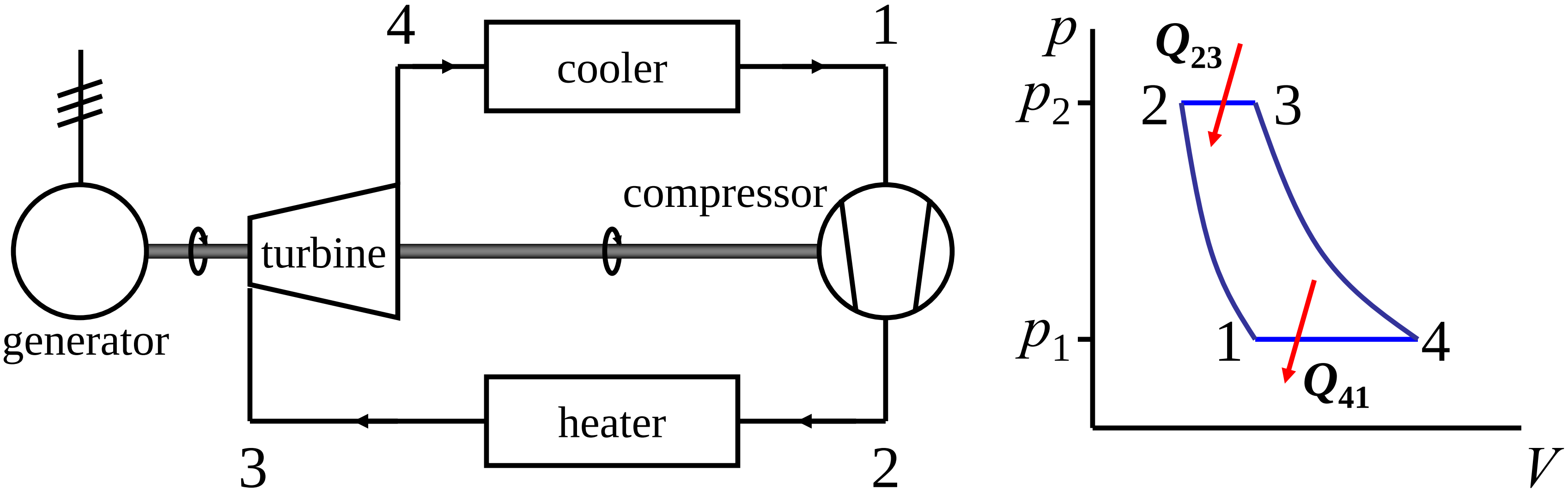


T3-T2 is gelimiteerd door?

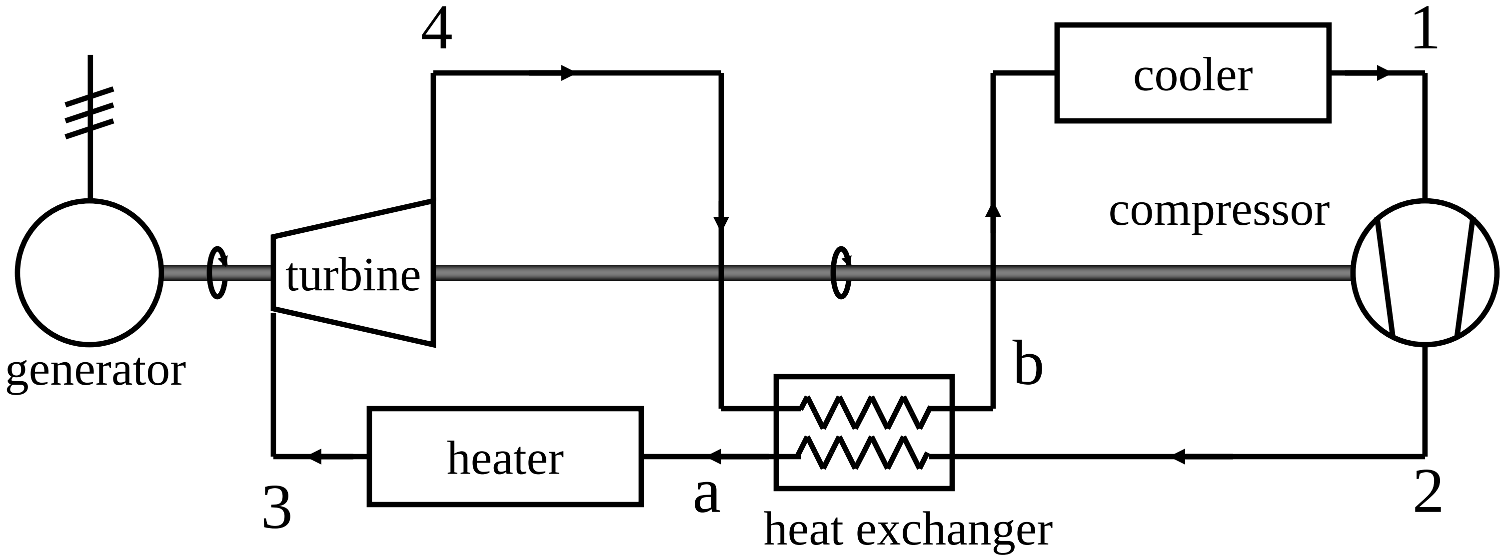
T4-T1 is gelimiteerd door?

gas turbine cycle

the Joule cycle

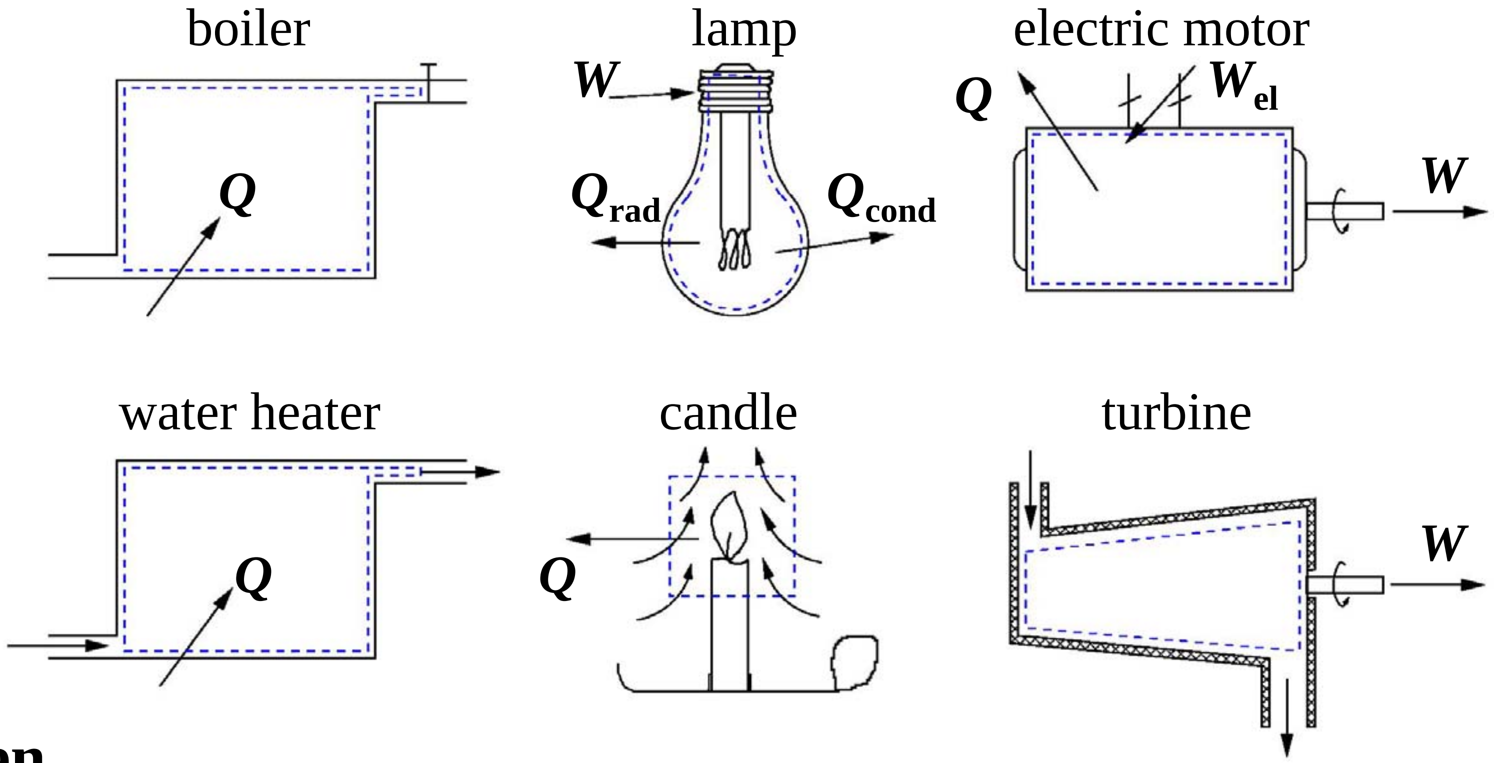


gas turbine


4
1
cooler
compressor
turbine
generator
b
heater
3
a
heat exchanger
2

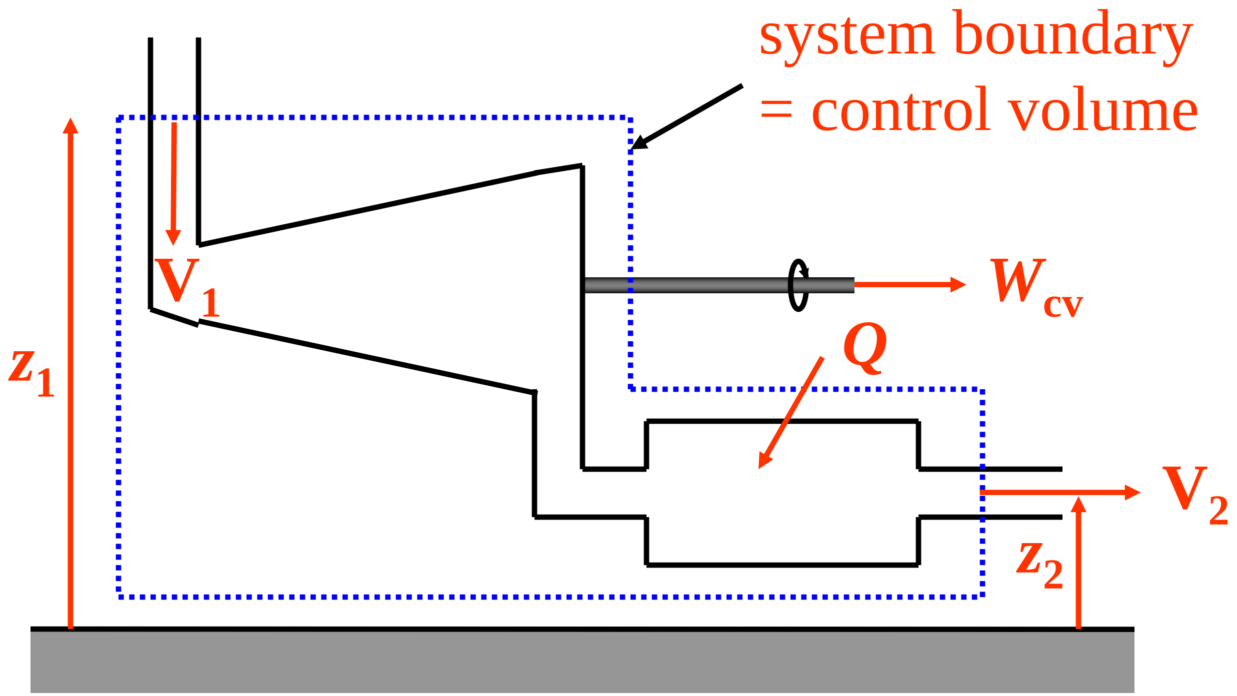
systems

closed



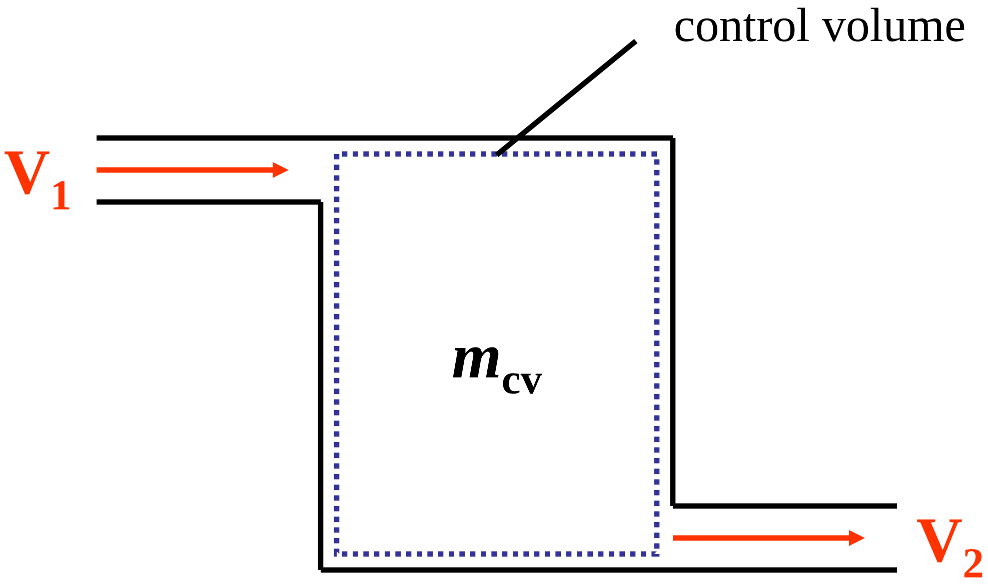
open

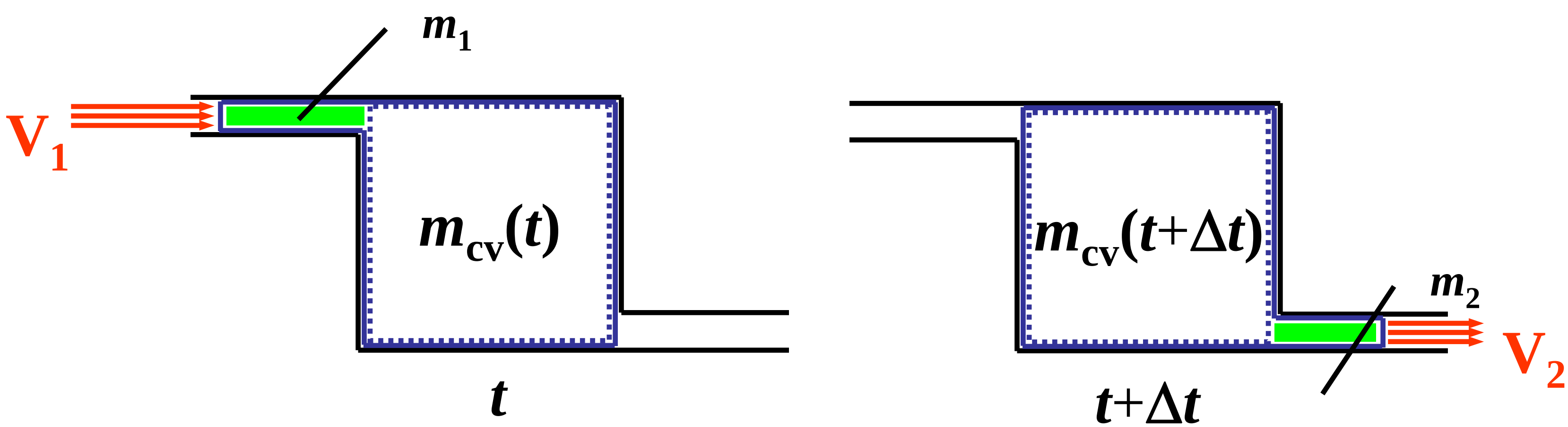
open system



mass balance for an open system

Let op de snelheid vector V en volume ook V





conservation of mass for a closed system:

$$m_{cv}\left(t+\Delta t\right)+m_2 = m_{cv}\left(t\right)+m_1$$

over a time interval Δt:

$$\frac{m_{cv}\left(t+\Delta t\right)-m_{cv}\left(t\right)}{\Delta t} = \frac{m_1}{\Delta t}-\frac{m_2}{\Delta t}$$

limit for $\Delta t \rightarrow 0$: (mass per second = mass flow rate)

$$\boxed{\frac{dm_{cv}}{dt} = \dot{m}_1 - \dot{m}_2}$$

mass flow rate for 'flat' velocity profile: $\dot{m} = \rho A V = AV / v$

Som 4.8

- A fixed volume with one inlet (1) and one outlet (2) :
  - → find the mass flow rate
  - → the area A2

$P_1 = 8bar$

$V_1 = 40m/s$

$T_1 = 600K$

$A_1 = 20cm^2$

$P_1 = 2bar$

$V_1 = 350m/s$

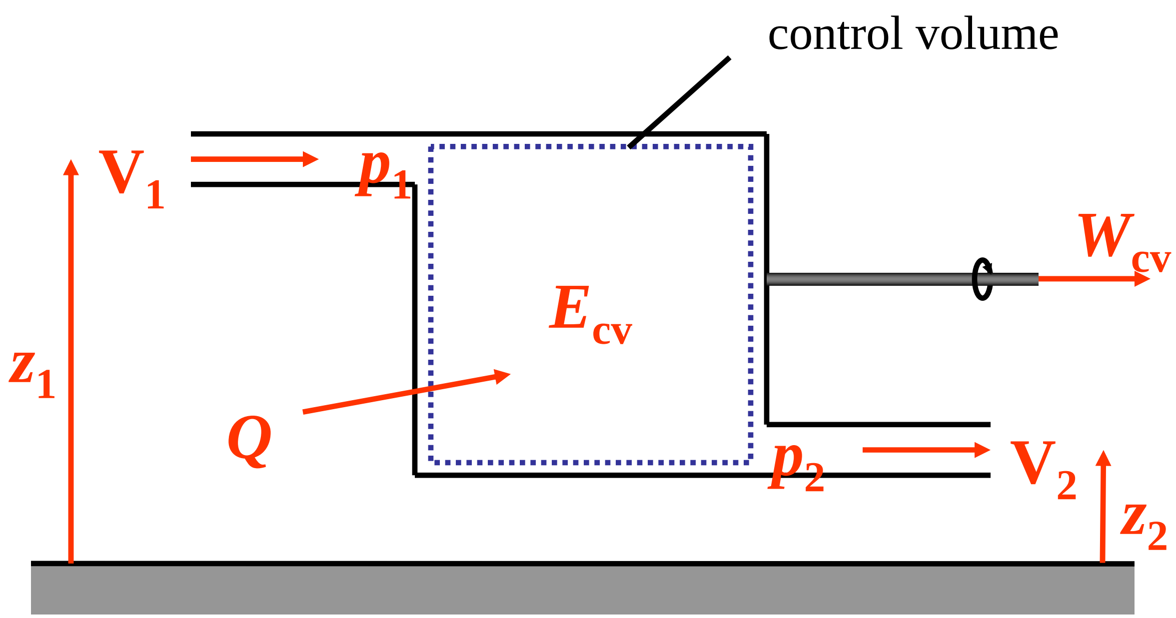
$T_1 = 400K$

$A_1 = ?\,cm^2$

$m_2 = 0.372kg/s$

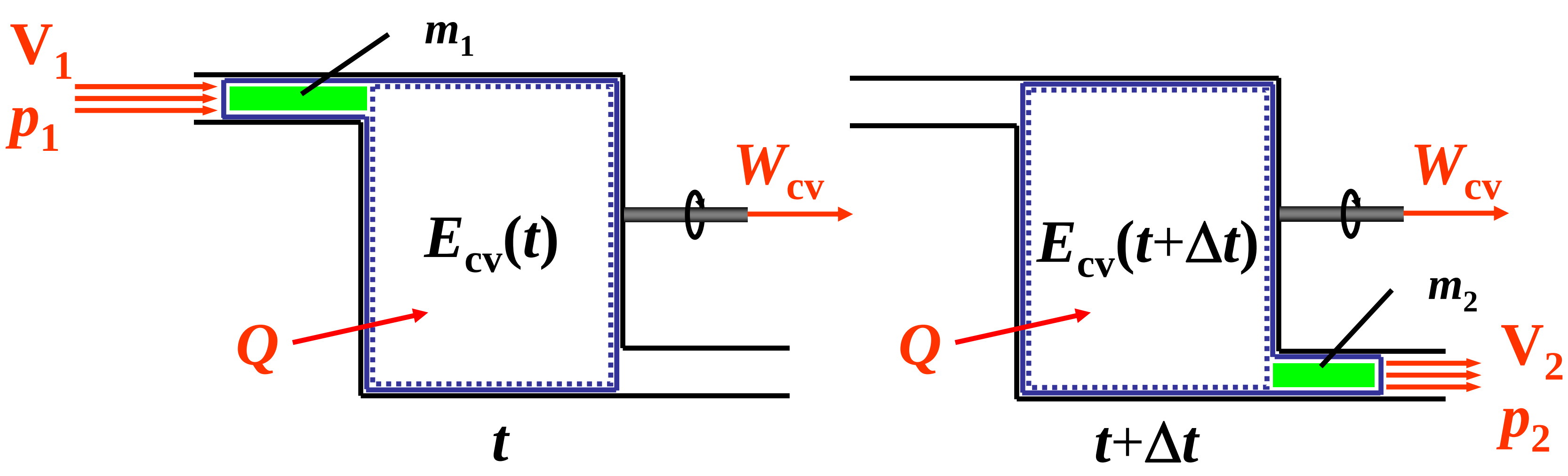
$A_2 = 6.1cm^2$

energy balance for an open system



total specific energy of a mass element: $e = u + \frac{1}{2}\mathrm{V}^2 + gz$

total system energy: $E = \int_V \rho e dV$



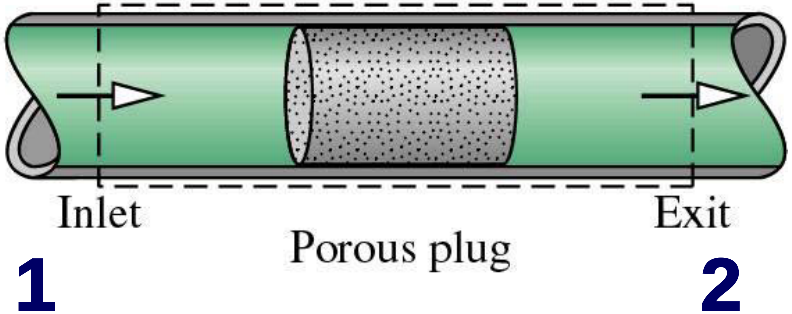
First Law of Thermodynamics for a closed system:

$$Q = \underbrace{\left(E_{cv}(t+\Delta t) + m_2 e_2\right)}_{E(t+\Delta t)} - \underbrace{\left(E_{cv}(t) + m_1 e_1\right)}_{E(t)} + \underbrace{W_{cv}}_{\text{technical work}} + \underbrace{p_2\left(m_2 \mathrm{v}_2\right) - p_1\left(m_1 \mathrm{v}_1\right)}_{\text{flow work}}$$

with: $\mathrm{e} = u + \tfrac{1}{2}\mathrm{V}^2 + gz$

$$Q = E_{cv}(t+\Delta t) - E_{cv}(t) + W_{cv} + m_2\left(u_2 + p_2\mathrm{v}_2 + \tfrac{1}{2}\mathrm{V}_2^2 + gz_2\right) - m_1\left(u_1 + p_1\mathrm{v}_1 + \tfrac{1}{2}\mathrm{V}_1^2 + gz_1\right)$$

Flow work



$$\dot{W}_{12} = \frac{F\Delta s}{\Delta t} = F \cdot V$$

$$F \cdot V = (P_2 A - P_1 A)V = (P_2 - P_1)AV$$

$$\dot{m} = \frac{AV}{v}$$

$$\dot{W}_{12} = \dot{m}v(P_2 - P_1)$$

Note: $V = Velocity$ and $v = specific\ volume$

with specific enthaply $h = u + p\mathrm{v}$:

$$Q = E_{\mathrm{cv}}(t+\Delta t) - E_{\mathrm{cv}}(t) + W_{\mathrm{cv}} + m_2\left(h_2 + \tfrac{1}{2}\mathrm{V}_2^2 + gz_2\right) - m_1\left(h_1 + \tfrac{1}{2}\mathrm{V}_1^2 + gz_1\right)$$

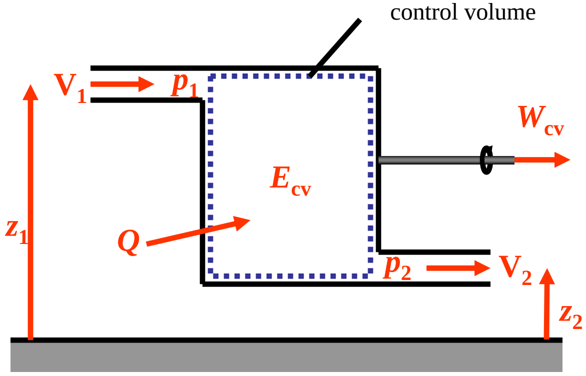
over a time interval Δt :

$$\frac{Q}{\Delta t} = \frac{E_{\mathrm{cv}}(t+\Delta t) - E_{\mathrm{cv}}(t)}{\Delta t} + \frac{W_{\mathrm{cv}}}{\Delta t} + \frac{m_2}{\Delta t}\left(h_2 + \tfrac{1}{2}\mathrm{V}_2^2 + gz_2\right) - \frac{m_1}{\Delta t}\left(h_1 + \tfrac{1}{2}\mathrm{V}_1^2 + gz_1\right)$$

limit for $\Delta t \to 0$: (energy per second = power)

$$\underbrace{\dot{Q}}_{\text{heat flow rate}} = \dot{E}_{\mathrm{cv}} + \underbrace{\dot{W}_{\mathrm{cv}}}_{\text{technical power}} + \underbrace{\dot{m}_2}_{\text{mass flow rate out}}\left(h_2 + \tfrac{1}{2}\mathrm{V}_2^2 + gz_2\right) - \underbrace{\dot{m}_1}_{\text{mass flow rate in}}\left(h_1 + \tfrac{1}{2}\mathrm{V}_1^2 + gz_1\right)$$

1st law for stationary open system



general:

$$\dot{Q} = \dot{E}_{cv} + \dot{W}_{cv} + \dot{m}_2\left(h_2 + \tfrac{1}{2}V_2^2 + gz_2\right) - \dot{m}_1\left(h_1 + \tfrac{1}{2}V_1^2 + gz_1\right)$$

stationary: $\dot{E}_{cv} = 0$ and $\dot{m}_{cv} = 0 \rightarrow \dot{m}_2 = \dot{m}_1 = \dot{m}$

$$\boxed{\dot{Q} = \dot{W}_{cv} + \dot{m}\left[\left(h_2 - h_1\right) + \tfrac{1}{2}\left(V_2^2 - V_1^2\right) + g\left(z_2 - z_1\right)\right]}$$

turbine

1st law for stationary open system:

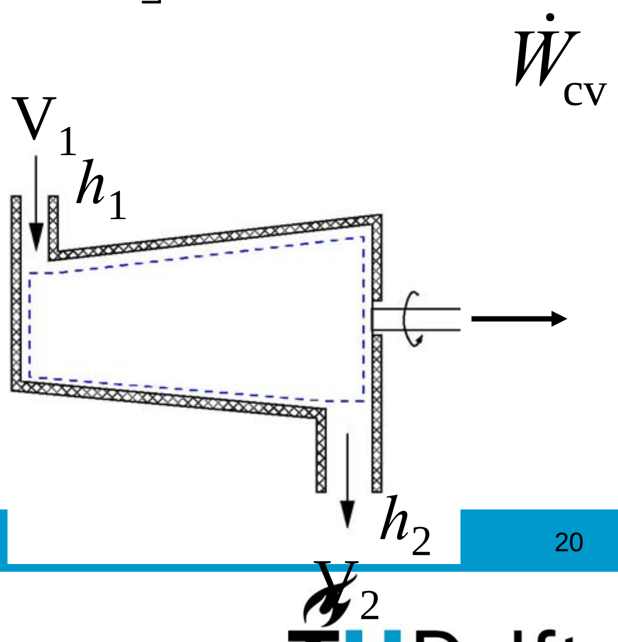
with: $\frac{1}{2}\left(V_2^2 - V_1^2\right) << \left(h_2 - h_1\right)$ and $g\left(z_2 - z_1\right) << \left(h_2 - h_1\right)$

$$\dot{Q} = \dot{W}_{cv} + \dot{m}\left[\left(h_2 - h_1\right) + \tfrac{1}{2}\left(V_2^2 - V_1^2\right) + g\left(z_2 - z_1\right)\right]$$

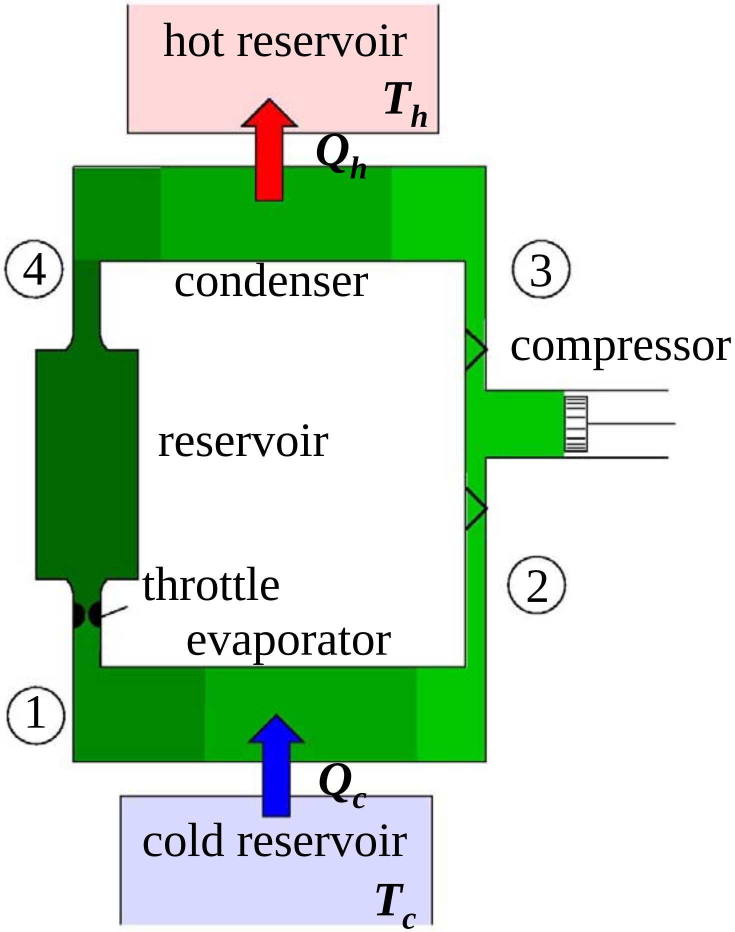
$$\dot{Q} = \dot{W}_{cv} + \dot{m}\left(h_2 - h_1\right)$$

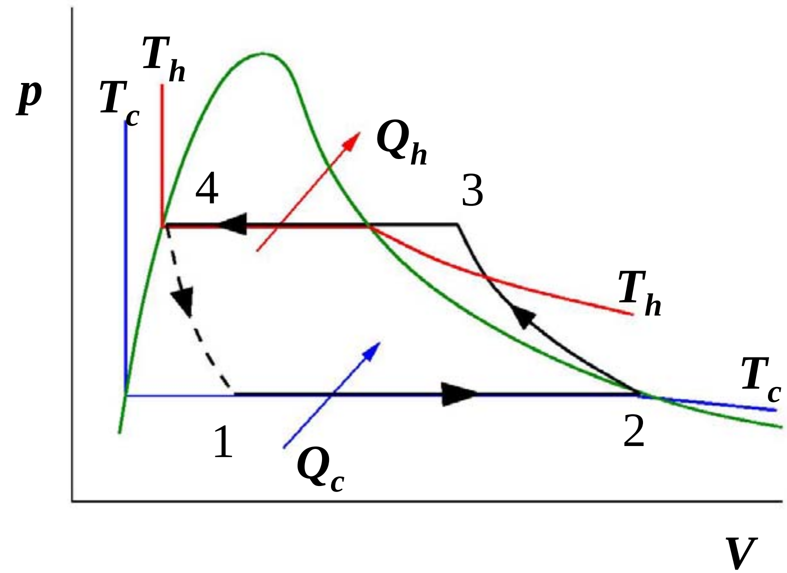
heat insulation:

$$\boxed{\dot{W}_{cv} = \dot{m}\left(h_1 - h_2\right)}$$



Refrigerator met smoorklep





coefficient of performance:

$$COP = \beta = \frac{Q_{\text{cold}}}{W_{\text{cycle}}} = \frac{Q_{\text{cold}}}{Q_{\text{hot}} - Q_{\text{cold}}}$$

TU Delft

Throttle (smoorklep)

1st law for stationary open system:

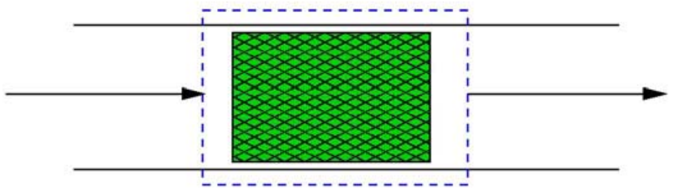
with: $\dot{W}_{cv} = 0$ and $g(z_2 - z_1) << (h_2 - h_1)$ and heat insulation:

$$\dot{Q} = \dot{W}_{cv} + \dot{m}\left[(h_2 - h_1) + \tfrac{1}{2}\left(V_2^2 - V_1^2\right) + g(z_2 - z_1)\right]$$

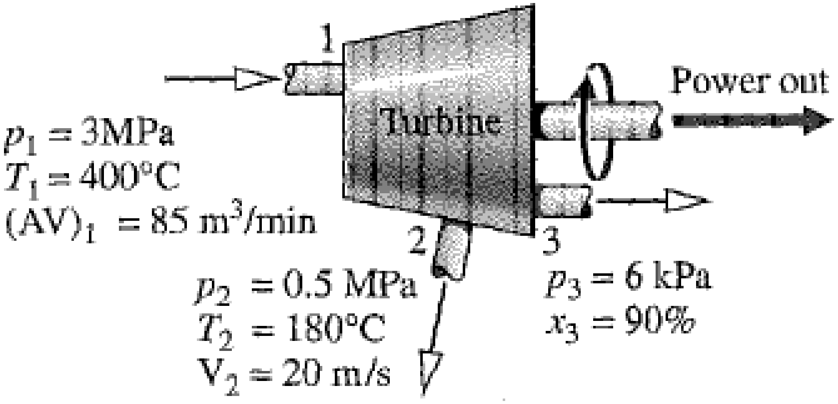
$$h_1 + \tfrac{1}{2}V_1^2 = h_2 + \tfrac{1}{2}V_2^2$$

when additionally: $\tfrac{1}{2}\left(V_2^2 - V_1^2\right) << (h_2 - h_1)$

$$\boxed{h_1 = h_2}$$



Probleem 4.29



▲ **Figure P4.29**

$$\dot{m}_2 = 11088 kg/h$$

$$\dot{m}_3 = 40.2 kg/h$$

$$d_2 = 0.282 m$$