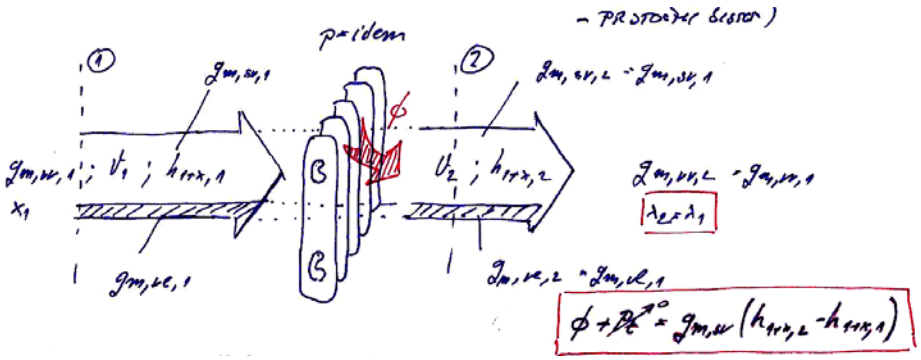
8.3.3 Osnovne promene stanja vlažnog vazduha

8.3.3.1 Izobarsko zagrevanje vlažnog vazduha

- Izobarsko zagrevanje vlažnog vazduha se u tehničkoj praksi izvodi njegovim prestrujavanjem preko zagrejanih površina (cevi, ploča, lamela,...)
- Protočni sistem



- Bilans mase

$$q_{m,\mathrm{vv},2} = q_{m,\mathrm{vv},1}$$

$$q_{m,\mathrm{sv},2} = q_{m,\mathrm{sv},1}$$

$$q_{m,\mathrm{sv}}(1+x_1) = q_{m,\mathrm{sv}}(1+x_2) \;\Rightarrow\; \boxed{x_1 = x_2}$$

- Bilans energije ($p = \mathrm{idem}$)

$$q_{\mathrm{m,sv}} \cdot h_{1+x,1} + \Phi_{\mathrm{zg}} + \cancel{P_{\mathrm{teh}}} = q_{\mathrm{m,sv}} \cdot h_{1+x,2} \;\Rightarrow\; \boxed{\Phi_{\mathrm{zg}} = q_{\mathrm{m,sv}} \cdot (h_{1+x,2} - h_{1+x,1})}$$

- Zatvoren sistem - model izobarskog zagrevanja

$p = \mathrm{idem}$

masa

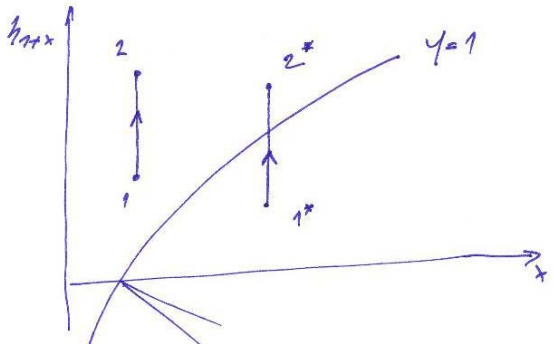
$$\left.\begin{aligned} m_{\mathrm{vl}} &= \mathrm{idem} \\ m_{\mathrm{sv}} &= \mathrm{idem} \end{aligned}\right\} \Rightarrow x = \mathrm{idem}$$

Energija

$$Q_{1-2} + \cancel{W_{\mathrm{teh},1-2}} = H_{\mathrm{vv},2} - H_{\mathrm{vv},1}$$

$$Q_{12} = m_{\mathrm{sv}}\,(h_{1+x,2} - h_{1+x,1})$$

- Prikaz u Molijerovom dijagramu

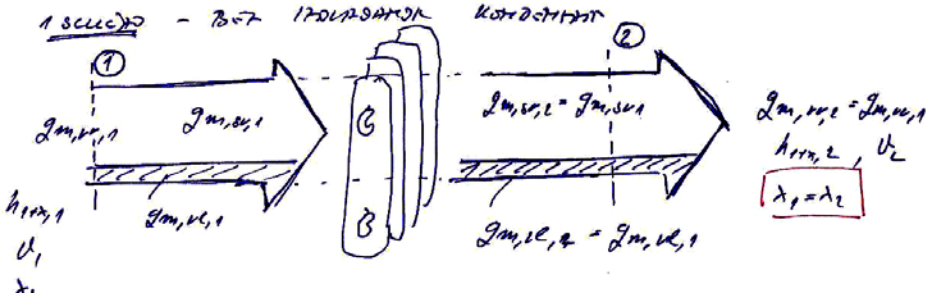


8.3.3.2 Izobarsko hlađenje vlažnog vazduha

- Izobarsko hlađenje vlažnog vazduha se u tehničkoj praksi izvodi njegovim prestrujavanjem preko hladnih površina (cevi, ploča, lamela,...)
- Protočni sistem

- **Model 1 – „površinsko“ hlađenje**

  <u>1. slučaj</u> – bez izdvajanja kondenzata



- Bilans mase

$$q_{m,\mathrm{vv},2} = q_{m,\mathrm{vv},1}$$

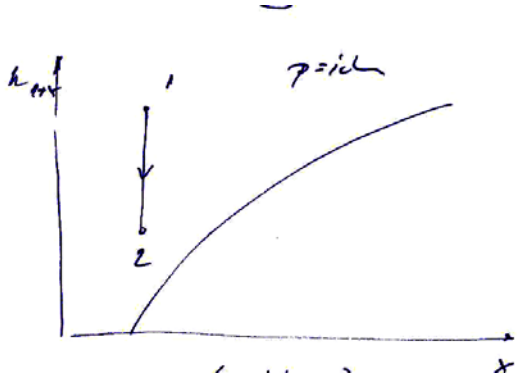
$$q_{m,\mathrm{sv},2} = q_{m,\mathrm{sv},1} = q_{m,\mathrm{sv}}$$

$$q_{m,\mathrm{sv}}(1+x_1) = q_{m,\mathrm{sv}}(1+x_2) \quad \Rightarrow \quad \boxed{x_1 = x_2}$$

- Bilans energije ($p = \mathrm{idem}$)

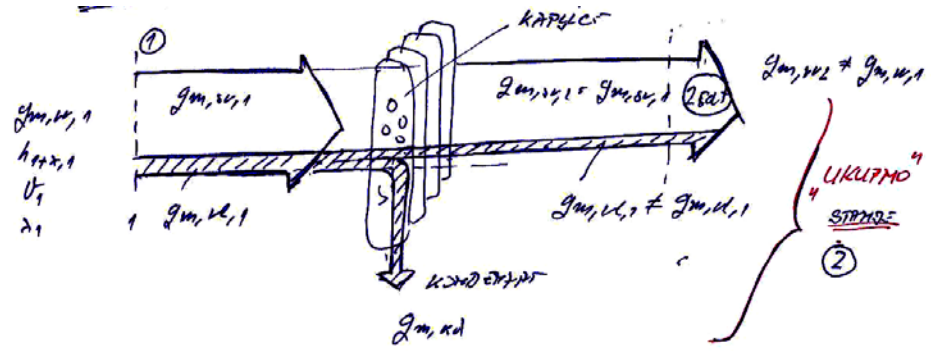
$$q_{\mathrm{m,sv}} \cdot h_{\mathrm{l}+x,1} + \cancel{P_{\mathrm{teh}}} = \Phi_{\mathrm{hl}} + q_{\mathrm{m,sv}} \cdot h_{\mathrm{l}+x,2} \quad \Rightarrow \quad \boxed{\Phi_{\mathrm{hl}} = q_{\mathrm{m,sv}}\,(h_{\mathrm{l}+x,2} - h_{\mathrm{l}+x,1})}$$

- Prikaz u Molijerovom dijagramu



- **Model 1 – „površinsko“ hlađenje**

  <u>2. slučaj</u> – sa izdvajanjem kondenzata



- Bilans mase

  – suv vazduh –

  $q_{m,\mathrm{sv},2} = q_{m,\mathrm{sv},1} = q_{m,\mathrm{sv}}$

  – vlaga –

  $q_{m,\mathrm{vl},1} = q_{m,\mathrm{vl},2} + q_{m,\mathrm{kd}}$

  – vlažan vazduh –

  $q_{m,\mathrm{vv},1} = q_{m,\mathrm{vv},2} + q_{m,\mathrm{kd}}$

  $q_{m,\mathrm{sv}}(1+x_1) = q_{m,\mathrm{sv}}(1+x_2) + q_{m,\mathrm{kd}}$

  $\Rightarrow$ maseni protok kondenzata $\boxed{q_{m,\mathrm{kd}} = q_{m,\mathrm{sv}}(x_2 - x_1)}$

  $q_{m,\mathrm{vv},2} \neq q_{m,\mathrm{vv},1}$

  $q_{m,\mathrm{sv}}(1+x_1) \neq q_{m,\mathrm{sv}}(1+x_{2,\mathrm{sat}}) \quad \Rightarrow \quad \boxed{x_1 \neq x_{2,\mathrm{sat}}}$

- Bilans energije ($p = \text{idem}$)

  $q_{m,\mathrm{sv}} \cdot h_{1+x,1} = \Phi_{\mathrm{hl}} + q_{m,\mathrm{sv}} \cdot h_{1+x,\mathrm{sat}} + q_{m,\mathrm{kd}} \cdot h_{\mathrm{kd}}$

  $q_{\mathrm{m,sv}} \cdot h_{1+x,1} = \Phi_{\mathrm{hl}} + q_{\mathrm{m,sv}} \cdot \left\{ \left[c_{p,\mathrm{sv}} \cdot \vartheta_2 + (r_{\mathrm{sat}} + c_{p,\mathrm{vp}} \cdot \vartheta_2) \cdot x_{2\mathrm{sat}} \right] + (x_1 - x_{2,\mathrm{sat}}) c_{p,\mathrm{t}}\, \vartheta_{\mathrm{kd}} \right\}$

  kako je

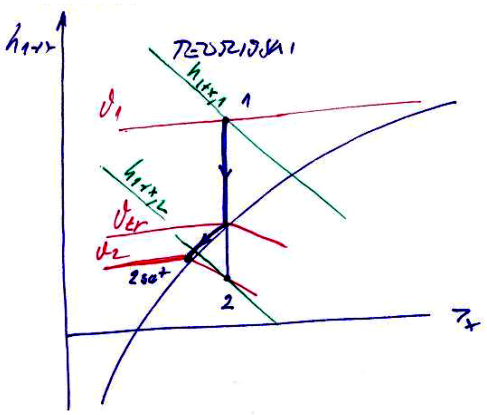
  $\boxed{\vartheta_2 = \vartheta_{\mathrm{kd}}}$

  $\Rightarrow \quad q_{m,\mathrm{sv}} \cdot h_{1+x,1} = \Phi_{\mathrm{hl}} + q_{m,\mathrm{sv}} \cdot h_{1+x,2}$

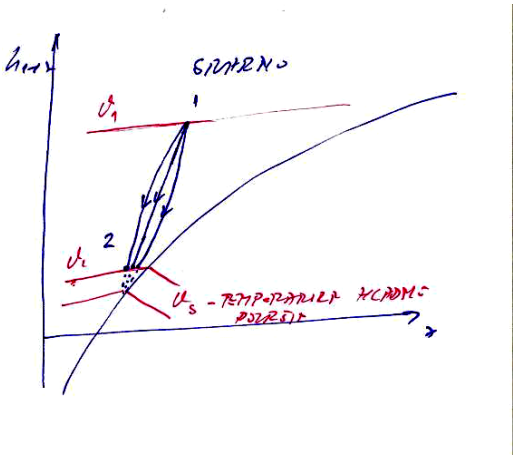
  $\Rightarrow \quad \boxed{\Phi_{\mathrm{hl}} = q_{m,\mathrm{sv}} \cdot (h_{1+x,1} - h_{1+x,2})}$

- Prikaz u Molijerovom dijagramu

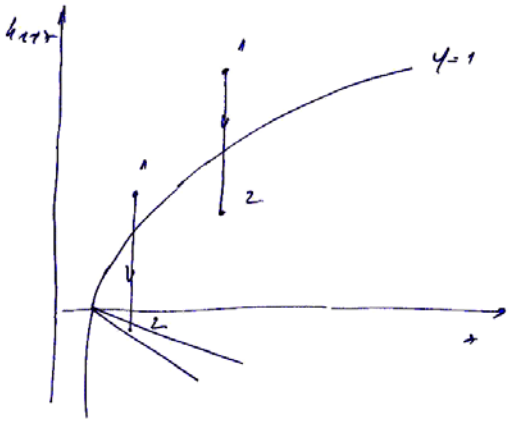
Teorijski

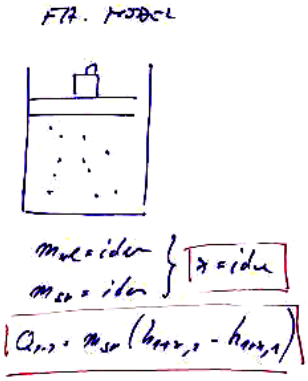


Stvarno

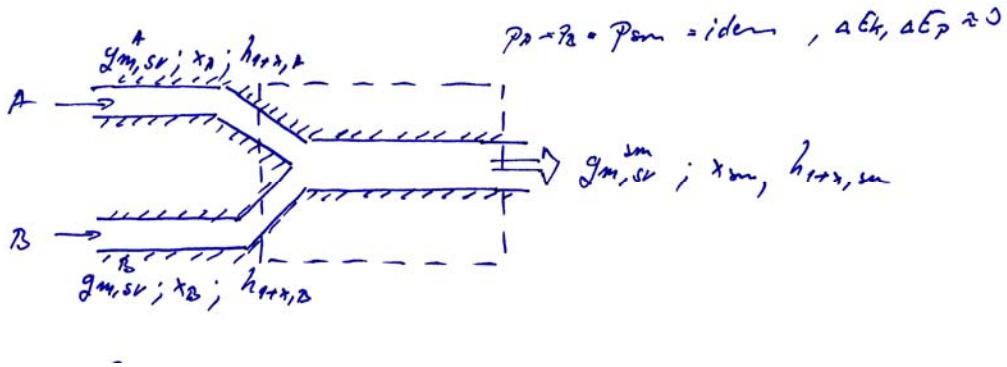


Model 2 – „zapreminsko“ hlađenje – u prirodi





8.3.3.3 Izobarsko i adijatermno (adijabatsko) mešanje dve struje vlažnog vazduha



- Bilans mase

  – vlage –

  $$q^{\mathrm{A}}_{m,\mathrm{vl}} + q^{\mathrm{B}}_{m,\mathrm{vl}} = q^{\mathrm{sm}}_{m,\mathrm{vl}}$$

  – suvog vazduha –

  $$q^{\mathrm{A}}_{m,\mathrm{sv}} + q^{\mathrm{B}}_{m,\mathrm{sv}} = q^{\mathrm{sm}}_{m,\mathrm{sv}}$$

  – vlažnog vazduha –

  $$q^{\mathrm{A}}_{m,\mathrm{vv}} + q^{\mathrm{B}}_{m,\mathrm{vv}} = q^{\mathrm{sm}}_{m,\mathrm{vv}}$$

  $$q^{\mathrm{A}}_{m,\mathrm{sv}}(1+x_{\mathrm{A}}) + q^{\mathrm{B}}_{m,\mathrm{sv}}(1+x_{\mathrm{B}}) = q^{\mathrm{sm}}_{m,\mathrm{sv}}(1+x_{\mathrm{sm}}) = (q^{\mathrm{A}}_{m,\mathrm{sv}} + q^{\mathrm{B}}_{m,\mathrm{sv}})\cdot(1+x_{\mathrm{sm}})$$

$$\boxed{x_{\mathrm{sm}} = \frac{q^{\mathrm{A}}_{\mathrm{m,sv}}\, x_{\mathrm{A}} + q^{\mathrm{B}}_{\mathrm{m,sv}}\, x_{\mathrm{B}}}{q^{\mathrm{A}}_{\mathrm{m,sv}} + q^{\mathrm{B}}_{\mathrm{m,sv}}}} \qquad (1)$$

- Bilans energije

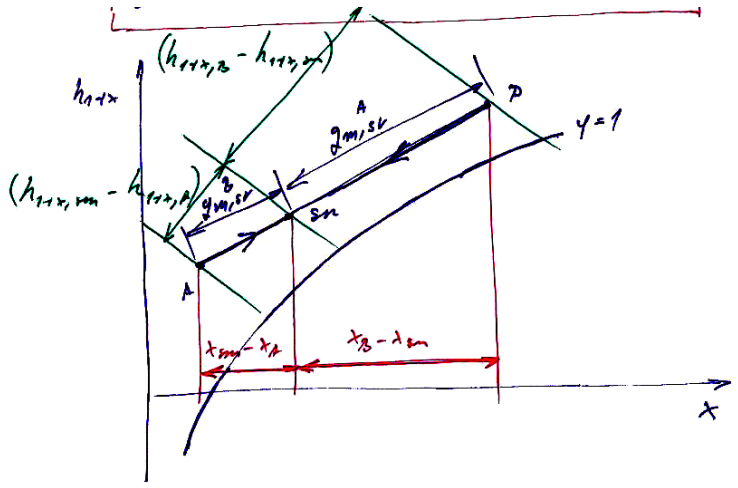
  $$q^{\mathrm{A}}_{m,\mathrm{sv}}\, h_{1+x,\mathrm{A}} + q^{\mathrm{B}}_{m,\mathrm{sv}}\, h_{1+x,\mathrm{B}} = (q^{\mathrm{A}}_{m,\mathrm{sv}} + q^{\mathrm{B}}_{m,\mathrm{sv}})\cdot h_{1+x,\mathrm{sm}}$$

$$\boxed{h_{1+x,\mathrm{sm}} = \frac{q^{\mathrm{A}}_{m,\mathrm{sv}}\, h_{1+x,\mathrm{A}} + q^{\mathrm{B}}_{m,\mathrm{sv}}\, h_{1+x,\mathrm{B}}}{q^{\mathrm{A}}_{m,\mathrm{sv}} + q^{\mathrm{B}}_{m,\mathrm{sv}}}} \qquad (2)$$

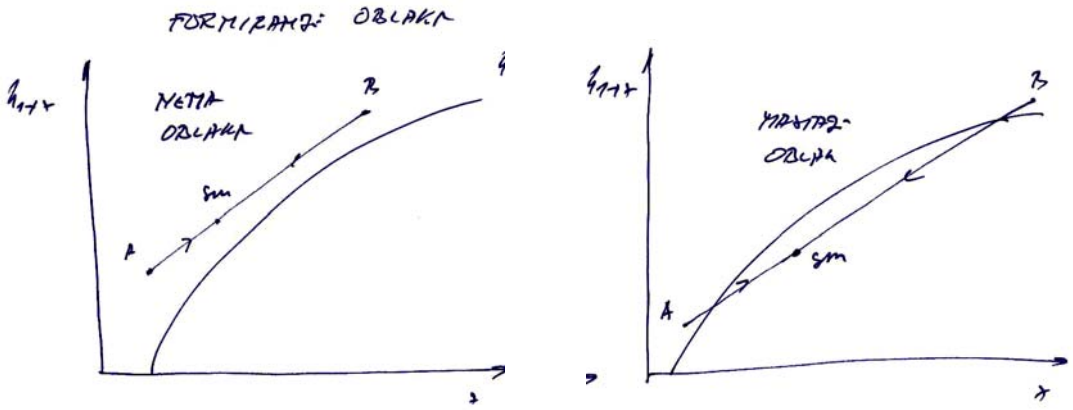
$$(1) \quad \rightarrow \quad q^{\mathrm{A}}_{m,\mathrm{sv}}(x_{\mathrm{sm}} \cdot x_{\mathrm{A}}) = q^{\mathrm{B}}_{m,\mathrm{sv}}(x_{\mathrm{B}} - x_{\mathrm{sm}})$$

$$(2) \quad \rightarrow \quad q^{\mathrm{A}}_{m,\mathrm{sv}}(h_{1+x,\mathrm{sm}} - h_{1+x,\mathrm{A}}) = q^{\mathrm{B}}_{m,\mathrm{sv}}(h_{1+x,\mathrm{B}} - h_{1+x,\mathrm{sm}})$$

$$\frac{(2)}{(1)} \quad \rightarrow \quad \frac{q^{\mathrm{B}}_{m,\mathrm{sv}}}{q^{\mathrm{A}}_{m,\mathrm{sv}}} = \frac{x_{\mathrm{sm}} - x_{\mathrm{A}}}{x_{\mathrm{B}} - x_{\mathrm{sm}}} = \frac{h_{1+x,\mathrm{sm}} - h_{1+x,\mathrm{A}}}{h_{1+x,\mathrm{B}} - h_{1+x,\mathrm{sm}}} \quad \rightarrow \quad \text{jednačina stanja}$$

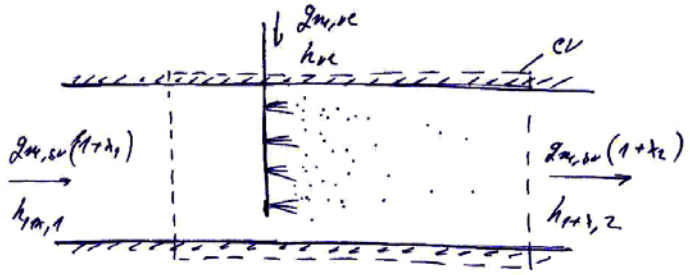


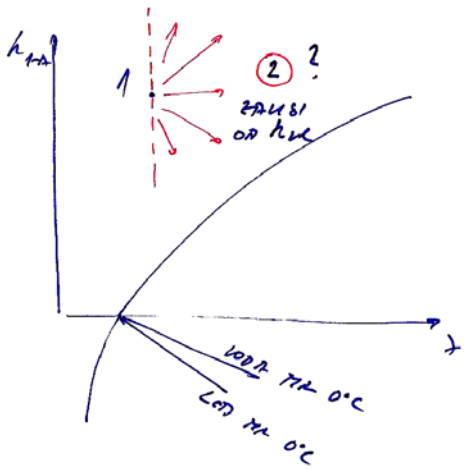
- Formiranje oblaka



8.3.3.4 Izobarno i adijatermno vlaženje vlažnog vazduha

- Vlaženje se obavlja u "maglenoj" komori – vodenom parom ili vodom (sitno raspršene kapljice)





- Bilans mase za kontrolnu zapreminu – maglenu komoru (ustaljen proces)

$$\underbrace{q_{m,sv}(1+x_1)+q_{m,vl}}_{\text{ulaz u CV}}=\underbrace{q_{m,sv}(1+x_2)}_{\text{izlaz iz CV}} \qquad \Rightarrow \quad x_2=x_1+\frac{q_{m,vl}}{q_{m,sv}} \qquad (1)$$

- Bilans energije za kontrolnu zapreminu – maglenu komoru (ustaljen proces)

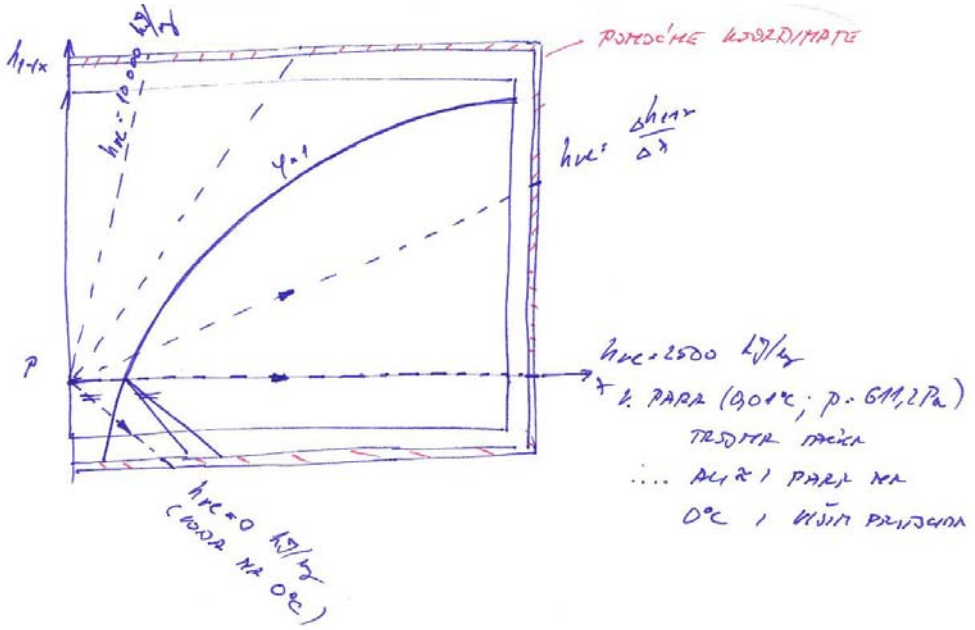
$$\underbrace{q_{\mathrm{m,sv}}\, h_{\mathrm{l}+x,1} + q_{\mathrm{m,vl}} \cdot h_{\mathrm{vl}}}_{\text{ulaz u CV}} = \underbrace{q_{\mathrm{m,sv}}\, h_{\mathrm{l}+x,2}}_{\text{izlaz iz CV}} \qquad h_{\mathrm{l}+x,2} = h_{\mathrm{l}+x,1} + \frac{q_{\mathrm{m,vl}}}{q_{\mathrm{m,sv}}} \cdot h_{\mathrm{vl}} \qquad (2)$$

$$\text{iz} \quad (1) \quad \Rightarrow \quad x_2 - x_1 = \frac{q_{\mathrm{m,vl}}}{q_{\mathrm{m,sv}}} \qquad (1')$$

$$\text{iz} \quad (2) \quad \Rightarrow \quad h_{\mathrm{l}+x,2} - h_{\mathrm{l}+x,1} = \frac{q_{\mathrm{m,vl}}}{q_{\mathrm{m,sv}}} \cdot h_{\mathrm{vl}} \qquad (2')$$

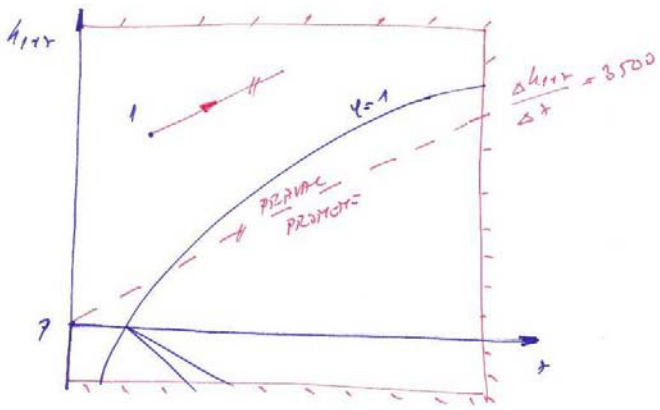
$$\frac{(1')}{(2')} \quad \Rightarrow \quad h_{\mathrm{vl}} = \frac{h_{\mathrm{l}+x,2} - h_{\mathrm{l}+x,1}}{x_2 - x_1} = \frac{\Delta h_{\mathrm{l}+x}}{\Delta x} = \frac{\mathrm{d}\, h_{\mathrm{l}+x}}{\mathrm{d}x}$$

- $\mathrm{d}\, h_{\mathrm{l}+x} / \mathrm{d}x$ – koeficijent pravca promene koja opisuje proces vlaženja u $h_{\mathrm{l}+x} - x$ koordinatnom sistemu

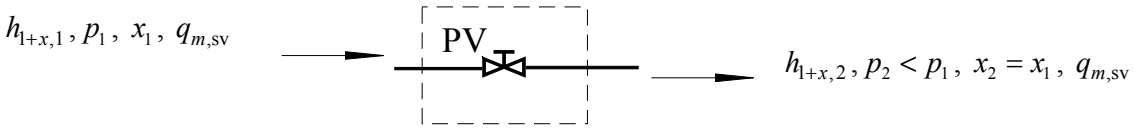


  - npr. $h_{\mathrm{vl}} = 3500$ kJ/kg

$h_{\mathrm{vl}} = f(p_{\mathrm{vl}}, v_{\mathrm{vl}})$



8.3.3.5 Proces adijatermnog prigušivanja vlažnog vazduha ($p \neq$ idem)



- Bilans mase za kontrolnu zapreminu (ustaljen proces)

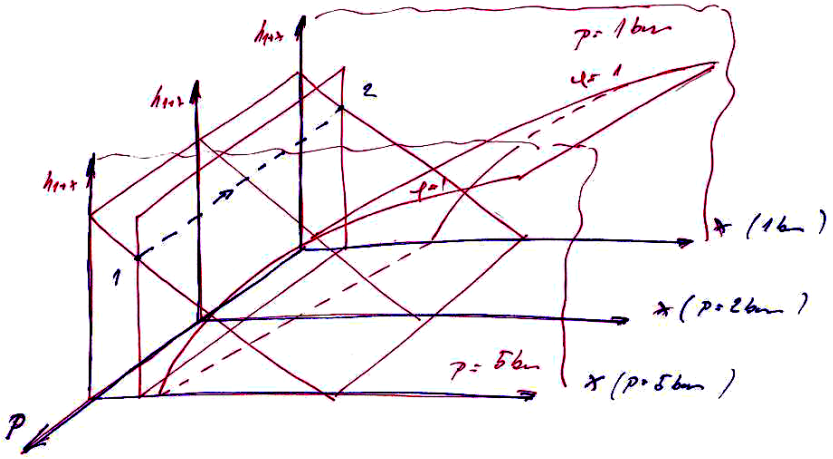
$$\underbrace{q_{m,sv}(1+x_1)}_{\text{ulaz u CV}} = \underbrace{q_{m,sv}(1+x_2)}_{\text{izlaz iz CV}}$$

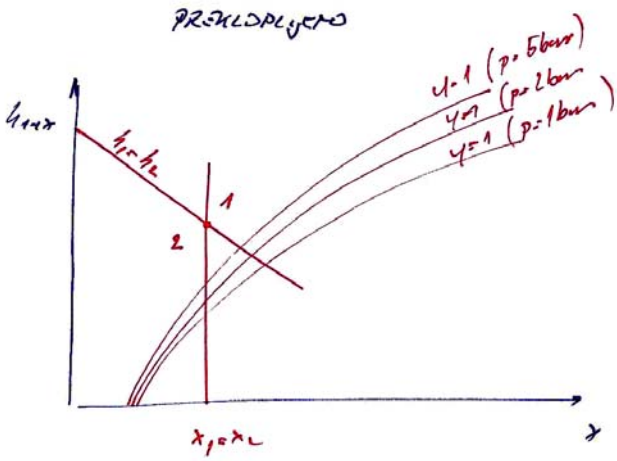
$$\Rightarrow \boxed{x_2 = x_1}$$

- Bilans energije za kontrolnu zapreminu – maglenu komoru (ustaljen proces)

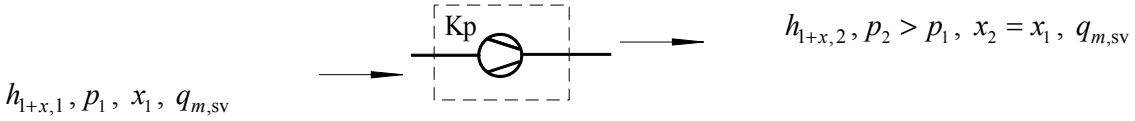
$$\underbrace{q_{m,sv}\, h_{1+x,1} + \cancel{\Phi} + \cancel{P_{teh}}}_{\text{ulaz u CV}} = \underbrace{q_{m,sv}\, h_{1+x,2}}_{\text{izlaz iz CV}}$$

$$\boxed{h_{1+x,2} = h_{1+x,1}}$$





8.3.3.6 Adijatermno sabijanje vlažnog vazduha ($p \neq$ idem)



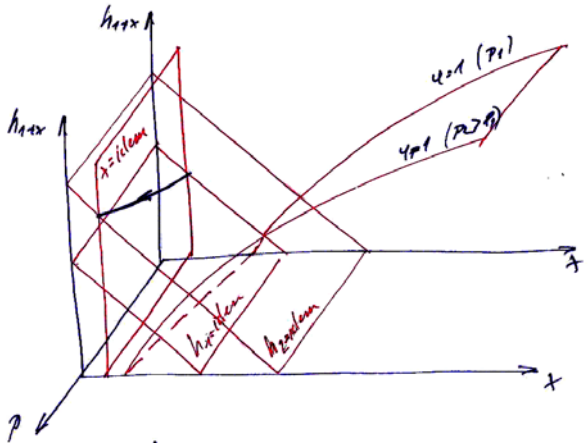
- Bilans mase za kontrolnu zapreminu (ustaljen proces)

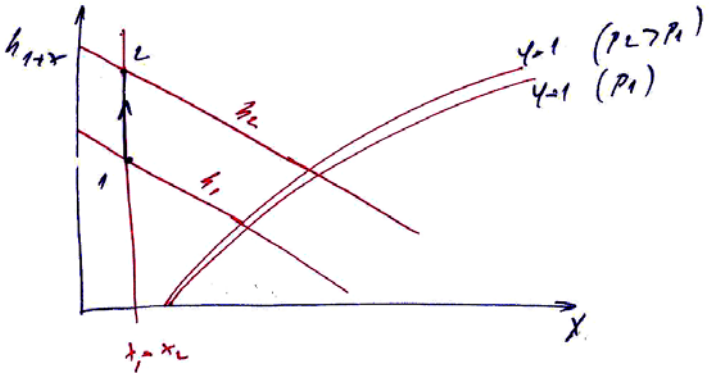
$$\underbrace{q_{m,\mathrm{sv}}\,(1+x_1)}_{\text{ulaz u CV}} = \underbrace{q_{m,\mathrm{sv}}\,(1+x_2)}_{\text{izlaz iz CV}}$$

$$\Rightarrow \quad \boxed{x_2 = x_1}$$

- Bilans energije za kontrolnu zapreminu – maglenu komoru (ustaljen proces)

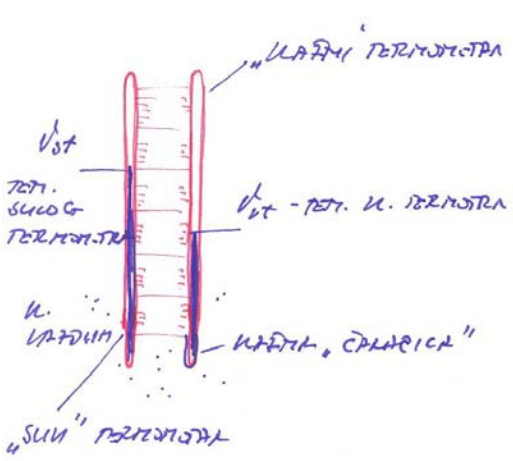
$$\underbrace{q_{m,\mathrm{sv}}\,h_{1+x,1} + \cancel{\Phi} + P_{\mathrm{teh}}}_{\text{ulaz u CV}} = \underbrace{q_{m,\mathrm{sv}}\,h_{1+x,2}}_{\text{izlaz iz CV}} \quad \Rightarrow \quad P_{\mathrm{teh}} = q_{m,\mathrm{sv}}\,(h_{1+x,2} - h_{1+x,1})$$

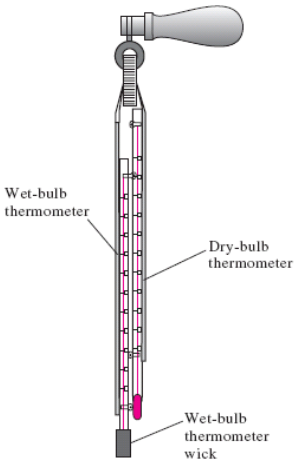




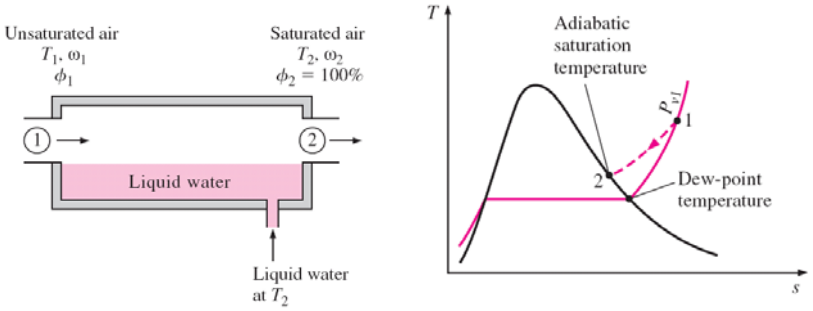
8.3.3.7 Određivanje stanja vlažnog vazduha Asmanovim (Assmann) psihometrom

- Psihrometar (grč. *psyhro*, hladan, *metron*, mera, merilo)
- Assmanov psihrometar – instrument koji se sastoji od dva termometra na istom postolju, od kojih jedan pokazuje temperaturu vazduha, a drugi navlažen vodom, usled isparavanja tečnosti, pokazuje nižu temperaturu i to u toliko nužu ukoliko je vazduh suvlji (jer tada je isparavanje intenzivnije).





- Energetska analiza (prevazilazi okvir ovog kursa termodinamike)



- Ako imamo Molijerov $h_{1+x,1} - x$ dijagram za vlažen vazduh pritiska p