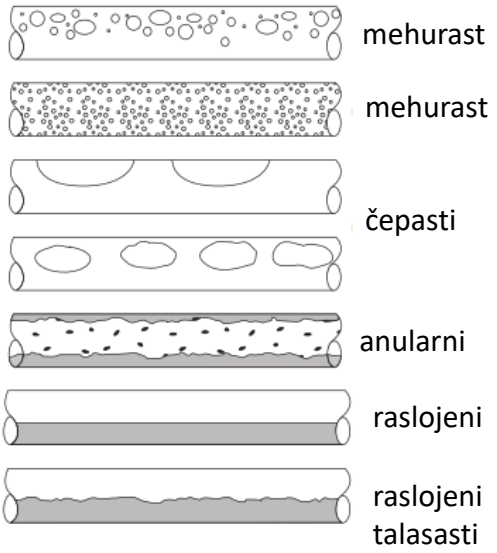
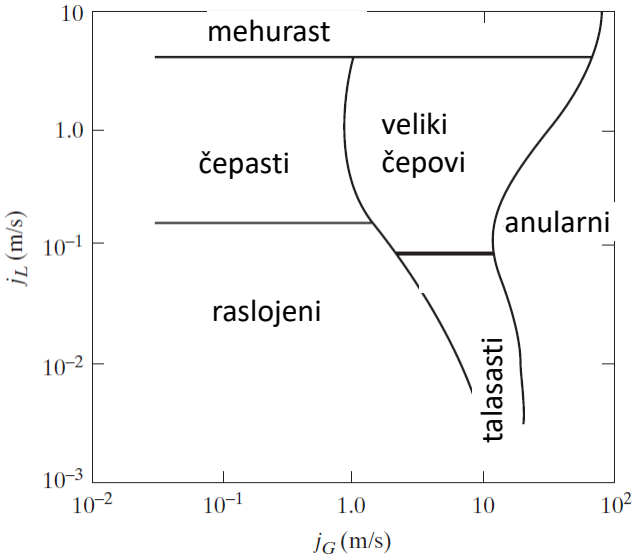
Oblici dvofaznog strujanja tečne i gasne faze

Oblici dvofaznih strujanja u horizontalnoj cevi (1/2)

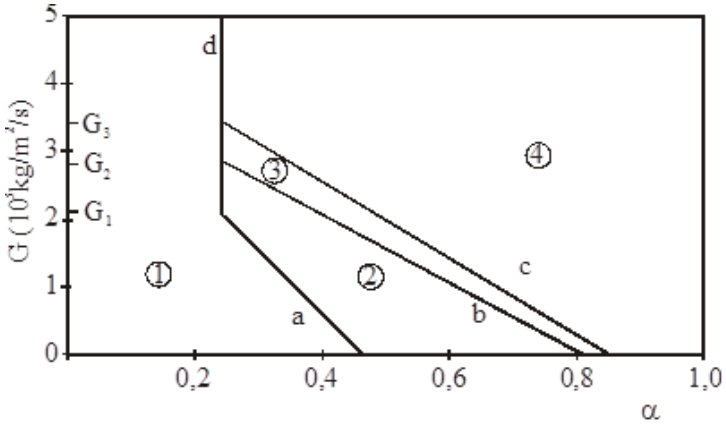




Mapa za istosmerno strujanje u horizontalnoj cevi (Mandhane i dr., 1974)

Na mapi je *j* prividna brzina, gde je $j = \dot{V}/A$, $\dot{V}$ je zapreminski protok, *A* je površina poprečnog preseka cevi, indeks G – gasna faza, L – tečna faza.
Na osnovu eksperimentalnih podataka za: prečnik cevi 12,7-165,1 mm, gustina tečnosti 705-1009 kg/m³, gustina gasa 0,8-50,5 kg/m³

Oblici dvofaznih strujanja u vertikalnoj isparivačkoj cevi (2/2)



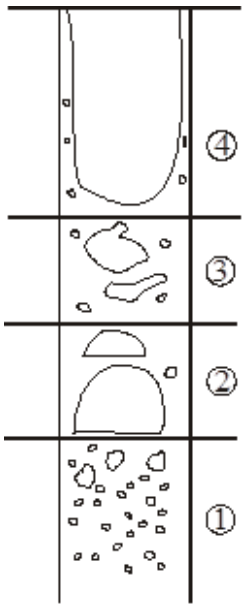
1 – mehurasti tok, 2 – čepasti tok
3 – penasti tok, 4 – anularni tok

$$G_1 = 2063 \frac{kg}{m^2 s} \quad a: -1{,}08 \cdot 10^{-4} G + 0{,}465 = \alpha$$

$$G_2 = 2789 \frac{kg}{m^2 s} \quad b: -2{,}06 \cdot 10^{-4} G + 0{,}817 = \alpha$$

$$G_3 = 3343 \frac{kg}{m^2 s} \quad c: -1{,}86 \cdot 10^{-4} G + 0{,}865 = \alpha$$

$$d: 0{,}243 = \alpha$$

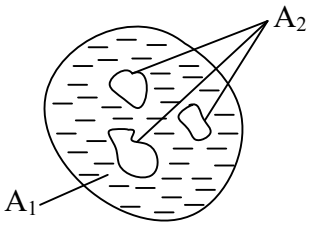


Strujanje u vertikalnoj cevi naviše

Osnovne relacije dvofaznog strujanja sa generacijom pare

- površina poprečnog preseka strujnog kanala (indeks 1 – tečnost, 2 – gasna faza (para ili nekondenzujući gas, na primer strujanje vode i vazduha na sobnoj temperaturi i atmosferskom pritisku))

$$A = A_1 + A_2 = \sum_{i=1}^{2} A_i \ (\mathrm{m}^2)$$



- zapreminski udeo pare (gasne faze)

$$\alpha_2 = \frac{V_2}{V} = \frac{V_2}{V_1 + V_2} = \frac{A_2 \cdot \Delta z}{\left(A_1 + A_2\right) \cdot \Delta z} = \frac{A_2}{A_1 + A_2} \ (-)$$

z – koordinata u pravcu strujanja

- zapreminski udeo tečne faze

$$\alpha_1 = \frac{V_1}{V} = \frac{V_1}{V_1 + V_2} = \frac{A_1 \cdot \Delta z}{\left(A_1 + A_2\right) \cdot \Delta z} = \frac{A_1}{A_1 + A_2} = \frac{A_1}{A} \ (-) \ , \ \alpha_1 + \alpha_2 = 1$$

- maseni fluks (masena brzina) dvofazne mešavine

$$G = G_1 + G_2 = \alpha_1 \rho_1 u_1 + \alpha_2 \rho_2 u_2 = \sum_{i=1}^{2} \alpha_i \rho_i u_i \ (\mathrm{kg/(m^2 s)})$$

- maseni protok dvofazne mešavine

$$\dot{m} = \dot{m}_1 + \dot{m}_2 = \rho_1 u_1 A_1 + \rho_2 u_2 A_2 = \left(\alpha_1 \rho_1 u_1 + \alpha_2 \rho_2 u_2\right) \cdot A = \left(G_1 + G_2\right) \cdot A \ (\mathrm{kg/s})$$

- relativna brzina faza

$$u_r = u_2 - u_1 \ (\mathrm{m/s})$$

- faktor klizanja

$$S = \frac{u_2}{u_1}$$

- prividna brzina

$$j = \frac{\dot{V}_1 + \dot{V}_2}{A} = \frac{\dot{V}_1}{A} + \frac{\dot{V}_2}{A} = \frac{u_1 A_1}{A} + \frac{u_2 A_2}{A} = \alpha_1 u_1 + \alpha_2 u_2 = j_1 + j_2 = \sum_{i=1}^{2} \alpha_i u_i \ (\mathrm{m/s})$$

- gustina mešavine

$$\rho = \frac{m}{V} = \frac{m_1 + m_2}{V} = \frac{\rho_1 V_1 + \rho_2 V_2}{V} = \rho_1 \alpha_1 + \rho_2 \alpha_2 = (1 - \alpha_2)\rho_1 + \alpha_2 \rho_2 \ (\mathrm{kg/m^3})$$

- specifična zapremina dvofazne mešavine

$$v = \frac{V}{m} = \frac{v_1 m_1 + v_2 m_2}{m} = (1 - x) v_1 + x v_2$$

- maseni udeo pare (gasne faze) – stepen suvoće ("static quality - statički kvalitet")

$$x=\frac{m_2}{m}=\frac{m_2}{m_1+m_2}=\frac{V_2\rho_2}{V_1\rho_1+V_2\rho_2}=\frac{\alpha_2 V\rho_2}{\alpha_1 V\rho_1+\alpha_2 V\rho_2}=\frac{1}{1+\frac{\alpha_1}{\alpha_2}\frac{\rho_1}{\rho_2}}=\frac{1}{1+\frac{1-\alpha_2}{\alpha_2}\frac{\rho_1}{\rho_2}}=\frac{1}{1+\frac{1-\alpha_2}{\alpha_2}\frac{v_2}{v_1}}$$

$$\alpha_2=\frac{1}{1+\frac{1-x}{x}\frac{\rho_2}{\rho_1}}$$

- protočni maseni udeo pare (gasne faze) ("flow quality- protočni kvalitet")

$$\chi=\frac{\dot m_2}{\dot m}=\frac{\dot m_2}{\dot m_1+\dot m_2}=\frac{\alpha_2\rho_2u_2A}{\left(\alpha_1\rho_1u_1+\alpha_2\rho_2u_2\right)\cdot A}=\frac{1}{1+\frac{1-\alpha_2}{\alpha_2}\frac{u_1}{u_2}\frac{\rho_1}{\rho_2}}=\frac{1}{1+\frac{1-\alpha_2}{\alpha_2}\frac{1}{S}\frac{v_2}{v_1}}$$

$$\alpha_2=\frac{1}{1+\frac{1-\chi}{\chi}S\frac{\rho_2}{\rho_1}}$$

- energetski udeo pare ("thermodynamic quality - termodinamički kvalitet")

$$x_T=\frac{h-h'}{h''-h'}$$

-strujna ravnoteža

$u_1=u_2\Rightarrow x=\chi$

- termička ravnoteža tečne i parne faze

$T_1=T_2=T_{sat}$

$x=x_T$ - stepen suvoće

$$h=\frac{H}{m}=\frac{h'm_1+h''m_2}{m}=\left(1-x\right)h'+xh''=h'+x\left(h''-h'\right)$$

$$x=\frac{h-h'}{r}=x_T$$

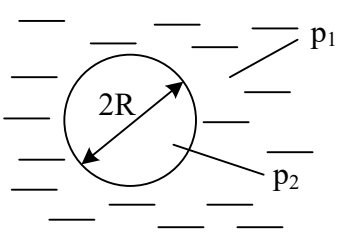
- mehanička ravnoteža

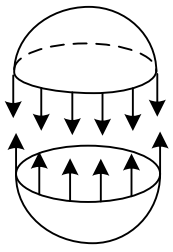
$p_1=p_2$

$\Delta p=p_2-p_1=\frac{2\sigma}{R}$, σ (N/m) – površinski napon

$\pi 2R\sigma=\pi R^2\Delta p$

$\Delta p=\frac{2\sigma}{R}$, $R\to\infty\Rightarrow\Delta p=0$ mehanička ravnoteža





Korisne relacije:

$$1=\frac{1-\alpha}{\alpha}\frac{x}{1-x}\frac{v_2}{v_1} \qquad \dot{m}=\rho A u$$

$$S=\frac{\chi}{1-\chi}\frac{1-\alpha}{\alpha}\frac{v_2}{v_1} \qquad \chi=\frac{\dot{m}_2}{\dot{m}_1+\dot{m}_2}$$ protočna koncentracija

$$S=\frac{\chi}{1-\chi}\frac{1-x}{x}$$ 1 – tečnost

$$\alpha=\frac{1}{1+\frac{1-x}{x}\frac{\rho_2}{\rho_1}}$$ 2 – gas/para

$$\chi=\frac{1}{1+\frac{1}{S}\frac{1-\alpha}{\alpha}\frac{\rho_1}{\rho_2}}$$

$$\alpha=\frac{1}{1+\frac{1-\chi}{\chi}S\frac{\rho_2}{\rho_1}}$$

Zadatak: Na dijagramu predstaviti zavisnost zapreminskog udela pare i gustine dvofazne mešavine vode i vodene pare, od masenog udela pare u opsegu od 0 do 1 na pritisku od 1 bar i 100 bar u uslovima termodinamičke ravnoteže.

$$\alpha=\frac{V_2}{V_1+V_2}=\frac{M_2 v''}{M_1 v'+M_2 v''}=\frac{x v''}{(1-x)v'+x v''}$$

$$\alpha=\frac{1}{1+\frac{1-x}{x}\frac{v'}{v''}}$$

$$\rho_m=\frac{1}{v_m}=\frac{1}{v'+x(v''-v')};\ \rho_m=(1-\alpha)\rho'+\alpha\rho''$$

<u>p = 1 bar</u>

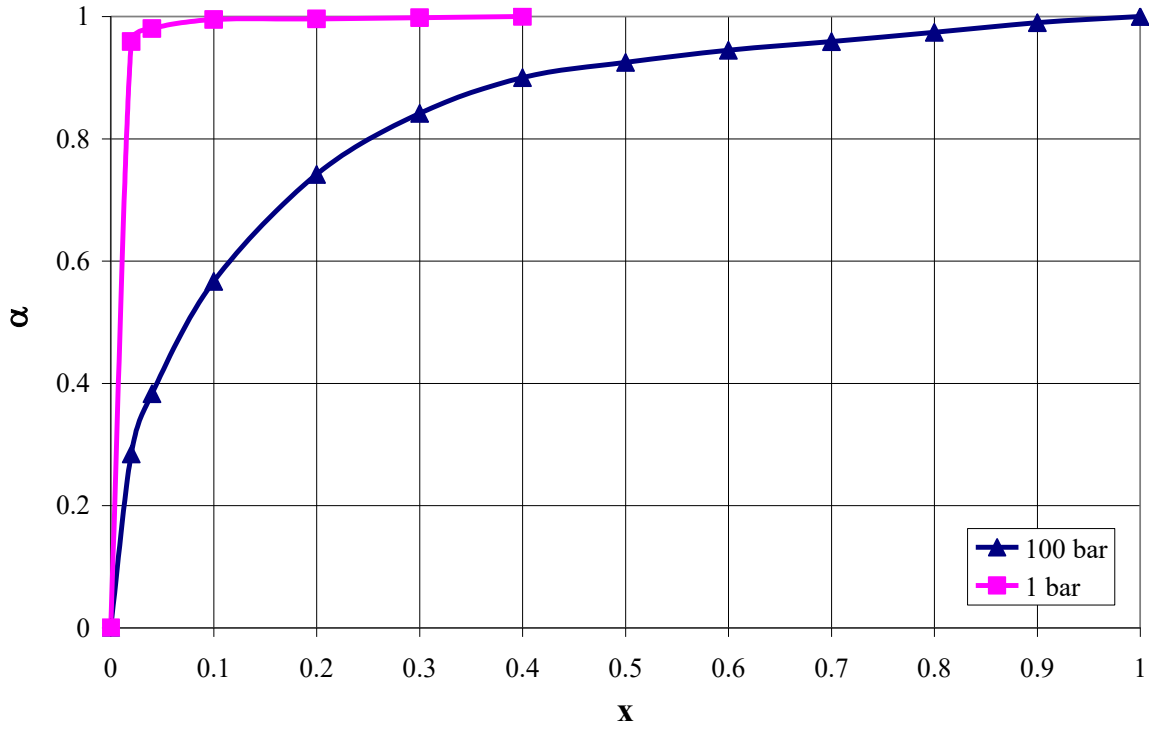
$$v'(1\text{ bar})=0{,}0010434\ \frac{\text{m}^3}{\text{kg}};\ \rho'=958\ \frac{\text{kg}}{\text{m}^3}$$

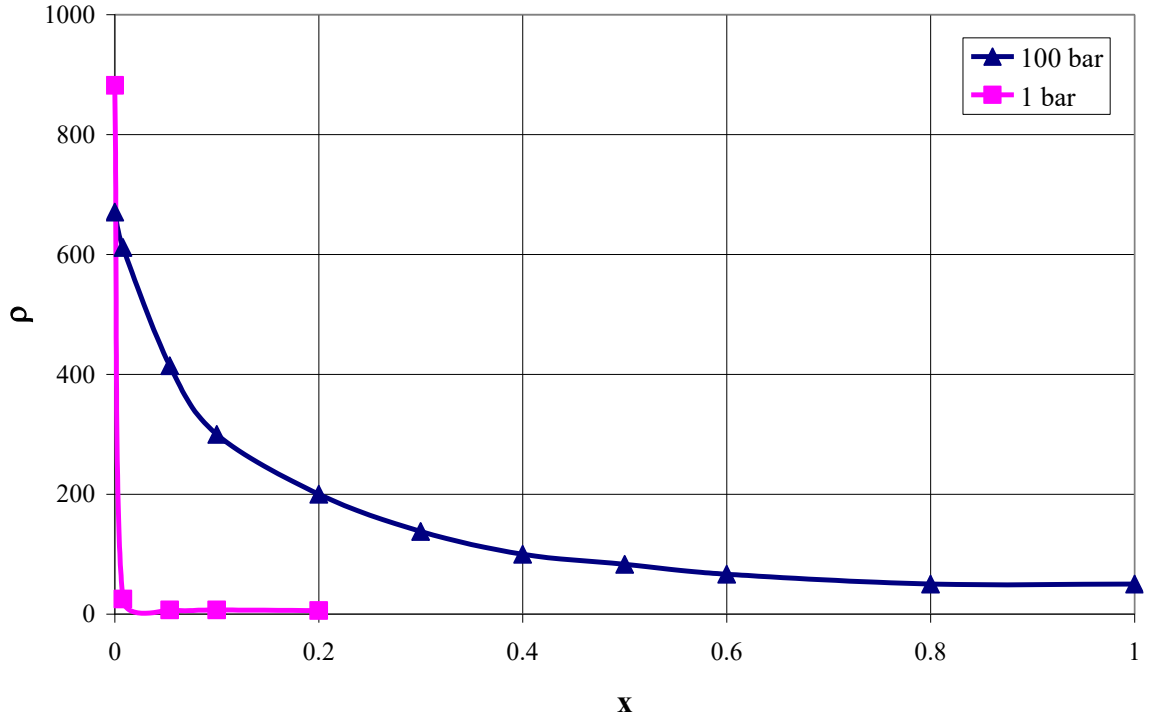
$$v''(1\text{ bar})=1{,}694\ \frac{\text{m}^3}{\text{kg}};\ \rho''=0{,}59\ \frac{\text{kg}}{\text{m}^3}$$

<u>p = 100 bar</u>

$$v'(100\text{ bar})=0{,}0014526\ \frac{\text{m}^3}{\text{kg}};\ \rho'=688\ \frac{\text{kg}}{\text{m}^3}$$

$$v''(100\text{ bar})=0{,}01804\ \frac{\text{m}^3}{\text{kg}};\ \rho''=55\ \frac{\text{kg}}{\text{m}^3}$$


1
0.8
0.6
0.4
0.2
0
α
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x
100 bar
1 bar


1000
800
600
400
200
0
ρ
0
0.2
0.4
0.6
0.8
1
x
100 bar
1 bar