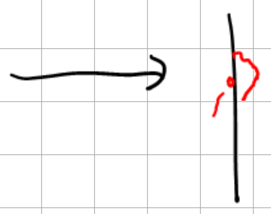
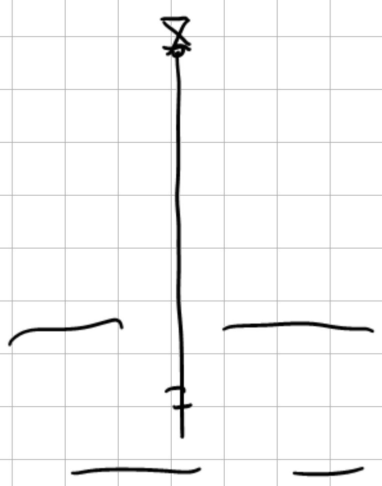
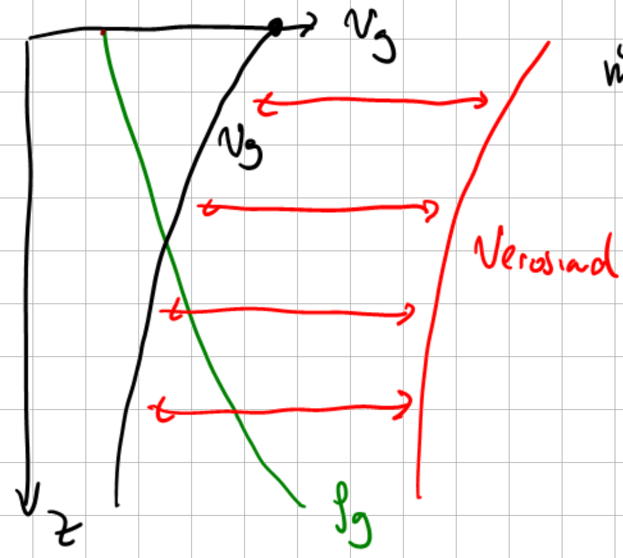
- erosional velocity



$$v_f < \underbrace{v_{erosional\ velocity}}$$

gas well $\quad v_f = v_g = \frac{q_g}{A}$





$$\dot m_g = \bar\rho_g \bar q_g = q_g \cdot \rho_g = v_g \cdot A \cdot \rho_g$$

$$v_g = \frac{\bar\rho_g \bar q_g}{A\,\rho_g}$$ — constant with depth

API 14E $\sim$ $v_{erosional} = \frac{C}{\sqrt{\rho_m}} \rightarrow (100 - 125)$ "severe" $[ft/s]$

conservative $\quad$ $\sim [lb/ft^3]$

$$\rho_m = f(\rho_L, \rho_g)$$

eg $\quad \rho_m = \frac{q_o \rho_o + q_g \rho_g + q_w \rho_g}{q_o + q_g + q_w}$

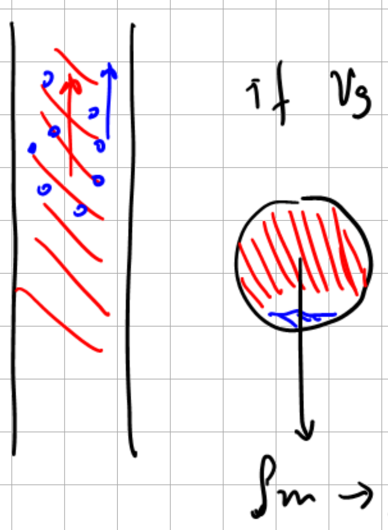
what happens if there is more than 1 fluid in the tubing?

o + g + w

$$v_m = \frac{(q_o + q_g + q_w)}{A} = \underbrace{\frac{q_o}{A}}_{u_{so}} + \underbrace{\frac{q_g}{A}}_{u_{sg}} + \underbrace{\frac{q_w}{A}}_{u_{sw}}$$

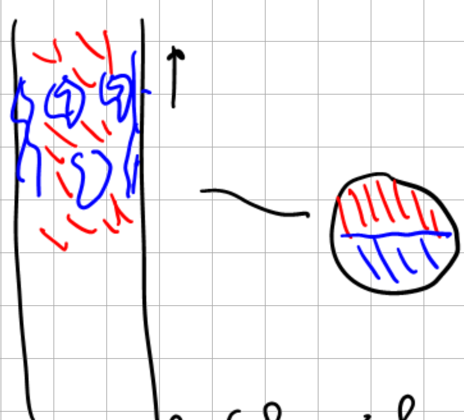
↳ superficial velocity

- only in gas wells → avoid liquid loading



if $v_g \downarrow$

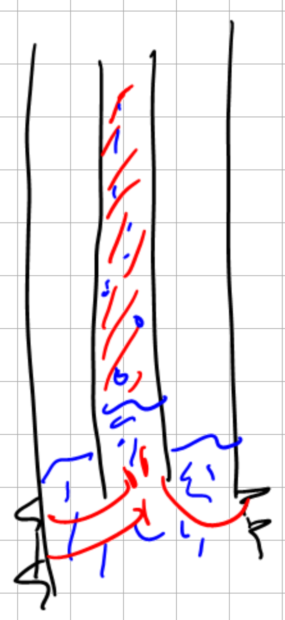
$\rho_m \rightarrow \rho_g$



→ $\uparrow \Delta p$

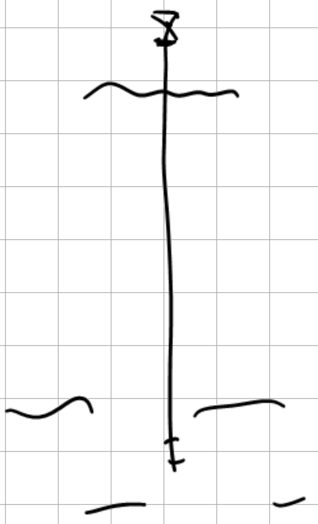
$\rho_g < \rho_m < \rho_L$

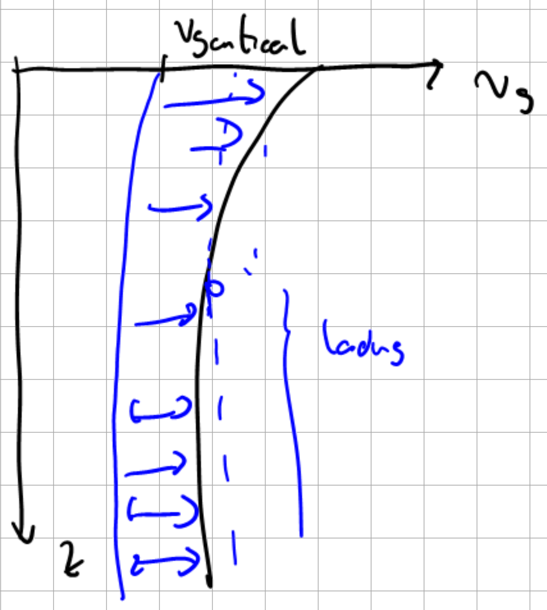
$H_L = \frac{A_L}{A} \quad \rho_m = (H_L)\rho_L + (1-H_L)\rho_g$



in general $H_L \neq \dfrac{q_L}{q_L + q_g}$

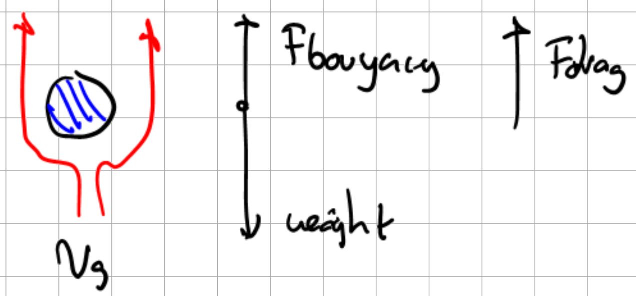
$v_g > v_{critical}$ for all tubing depths





How to calculate $v_{critical}$?

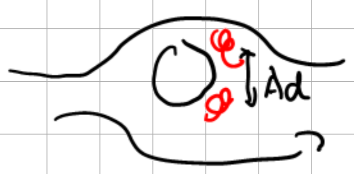
Turner criteria

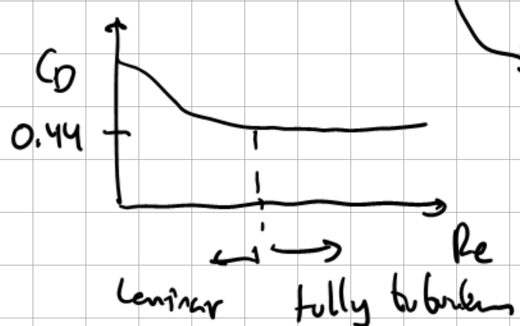


$F_{drag} + F_{bouyancy} = F_{weight}$

$\frac{1}{2} \rho_g C_D v_g^2 A_d + V_d \rho_g g = V_d \cdot \rho_L \cdot g$

$C_D \to 0.44$





$V_d = \dfrac{\pi \phi^3}{6}$ $\quad A_d = \dfrac{\pi \phi^2}{4}$

$\frac{1}{2} \rho_g \, 0.44 \, v_g^2 \dfrac{\cancel{\pi} \phi^2}{4} = (\rho_L - \rho_g) g \dfrac{\cancel{\pi} \phi^3}{6}$

$x \cdot 2 \qquad x \cdot 3$

$v_{crit} = \sqrt{\dfrac{4}{3} \dfrac{(\rho_L - \rho_g)}{\rho_g} \dfrac{\phi \cdot g}{0.44}}$

Analysis and Prediction of Minimum Flow Rate for the Continuous Removal of Liquids from Gas Wells

R. G. Turner, SPE-AIME, Baker Oil Tools, Inc.
M. G. Hubbard, SPE-AIME, U. of Houston
A. E. Dukler, U. of Houston

1969

$N_{we} = \dfrac{\rho_g u_g^2 d}{\sigma_{gL}}$ — Drag

σ_{gL} — interfacial tension

Weber

Fundamentals of the Hydrodynamic Mechanism of Splitting in Dispersion Processes

J. O. Hinze, Royal Dutch Shell-Laboratory, Delft, Holland

1955

$N_{we} = 30 \to \phi_{max}$

$30 = \dfrac{\rho_g u_g^2 \phi}{\sigma_{Lg}}$

$\phi = \dfrac{\sigma_{Lg} \, 30}{\rho_g u_g^2}$

for every depth in tubing

$v_g \geq v_{crit}$

$v_{crit} = 5.46 \left[\dfrac{\sigma_{Lg}^{0.25} (\rho_L - \rho_g)^{0.25}}{\rho_g^{0.5}} \right]$ $\quad [m/s]$

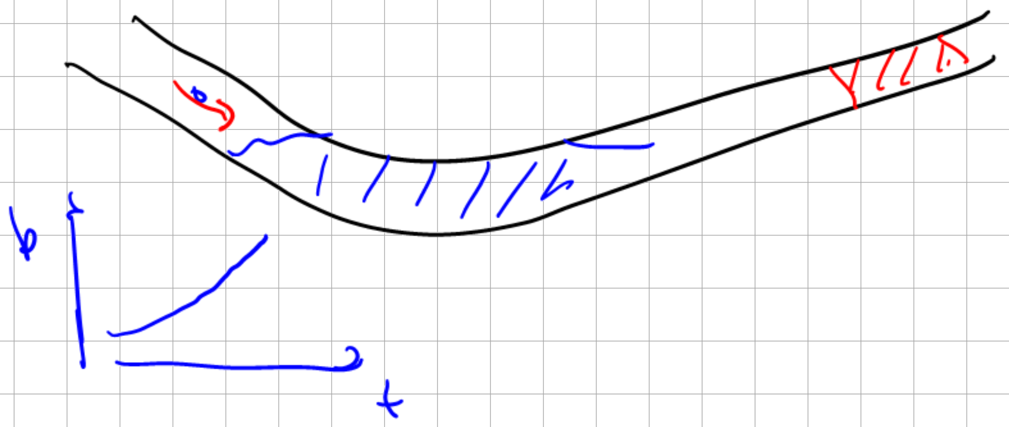
σ in $\left(\frac{N}{m}\right)$

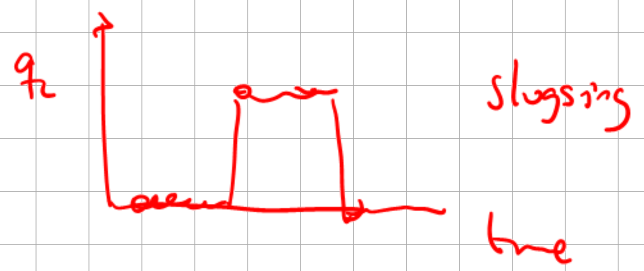
ρ in $\left(kg/m^3\right)$

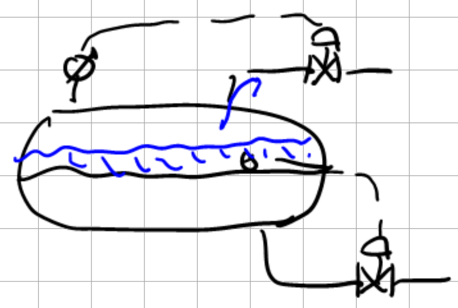
- pipeline sizing considerations

$$\uparrow q_g, \ \uparrow q_o \qquad \downarrow \text{cost}$$

- v_g high enough to avoid accumulation of liquid (gas condensate pipeline)







- heat transfer

$$\dot{q} = A \cdot U (T_f - T_{amb})$$

$$\pi D \cdot L \, U (T_f - T_{amb})$$

$$D \uparrow \quad \dot{q} \uparrow \quad T_f \rightarrow \downarrow$$

can also cause hydrate formation