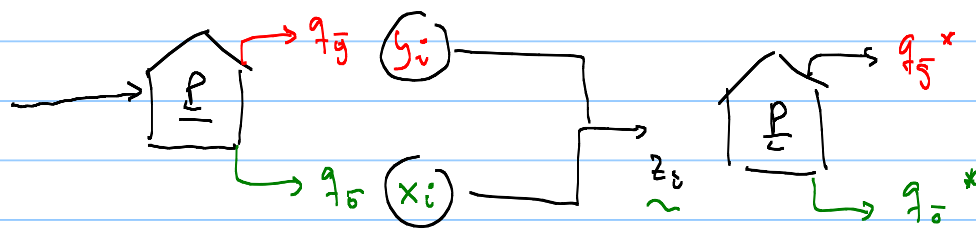
http://www.ipt.ntnu.no/~stanko/files/Courses/PG8405

Class 5

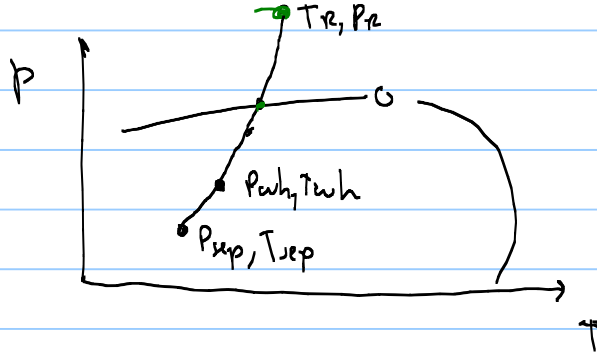
- **Class 1:** Generalities about modeling. Performance of production system: coupling between reservoir and well. Flow equilibrium for dry gas well. Excel VBA functions and routines.
- **Class 2:** Dry gas flowline equation. Choke and pumping design. Choke performance . Networks. Network solving in commercial software.
- **Class 3:** IPR. Feasible flow region of network. Pressure traverse in gas well. EOS and flash calculations. Introduction to Hysys.
- **Class 4:** tuning EOS. Calculating local volumes of oil and gas with compositional simulator. BO properties. BO properties generation. Recombination of separator fluids to match GOR.

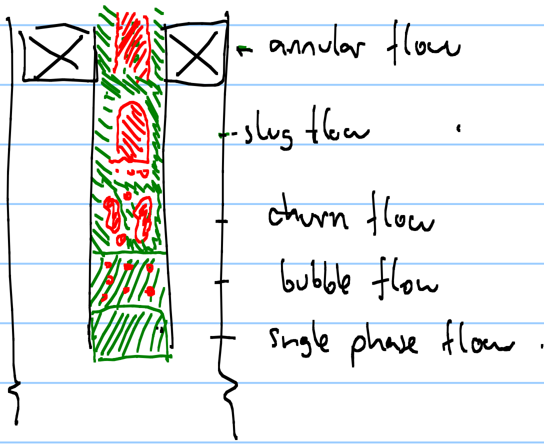


Class exercises:

- Compare the values of required flowing bottom-hole pressure calculated: 1) using a Ct with an average of reservoir and separator pressure versus 2) using a Ct with an average between the actual flowing-bottomhole pressure calculated and separator pressure (implicit).
- Create a vba macro to estimate the equilibrium point for several reservoir pressures.
- Read choke equation development for dry gas and liquid.
- Read IPR equation development for dry gas.
- **Optional:** generate choke performance curve with excel file.
- Solve flow equilibrium of 2-well network.
- Calculate feasible flow region for 2-well network varying choke DPs.
- Example of compositional calculations with Hysys.
- Calculate local rates of oil and gas at p,T using compositional simulator (Hysys or Flash-Pack)
- Generate BO properties for P, T with Flash-pack, Hysys.

multiphase flow in conduits (tubing, flowlines, pipelines)

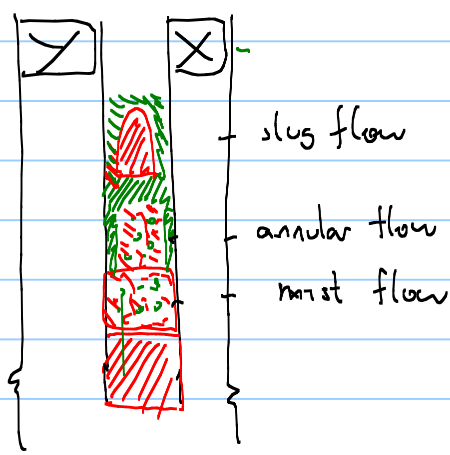




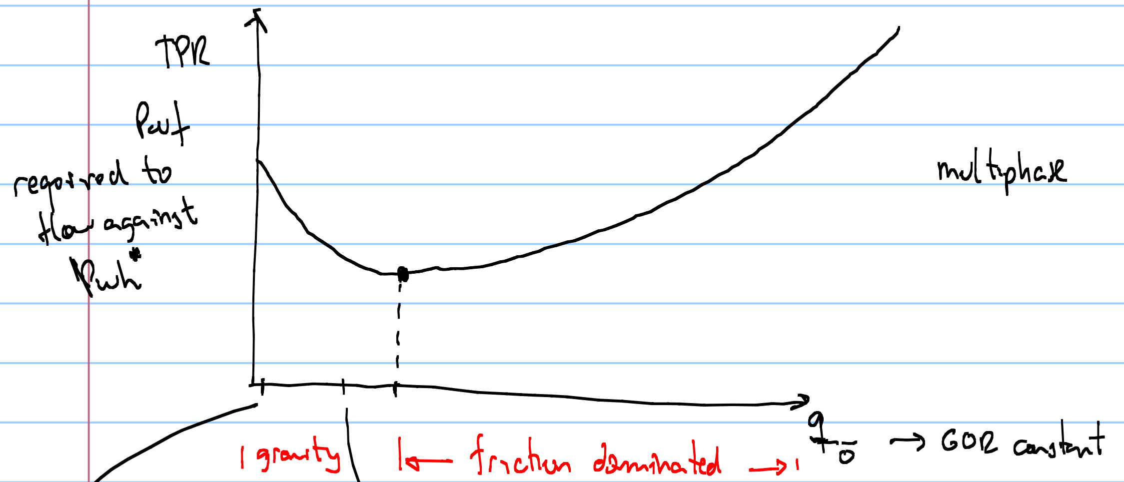
oil/gas configured in wellbore

↳ flow pattern (pressure drop)

oil well

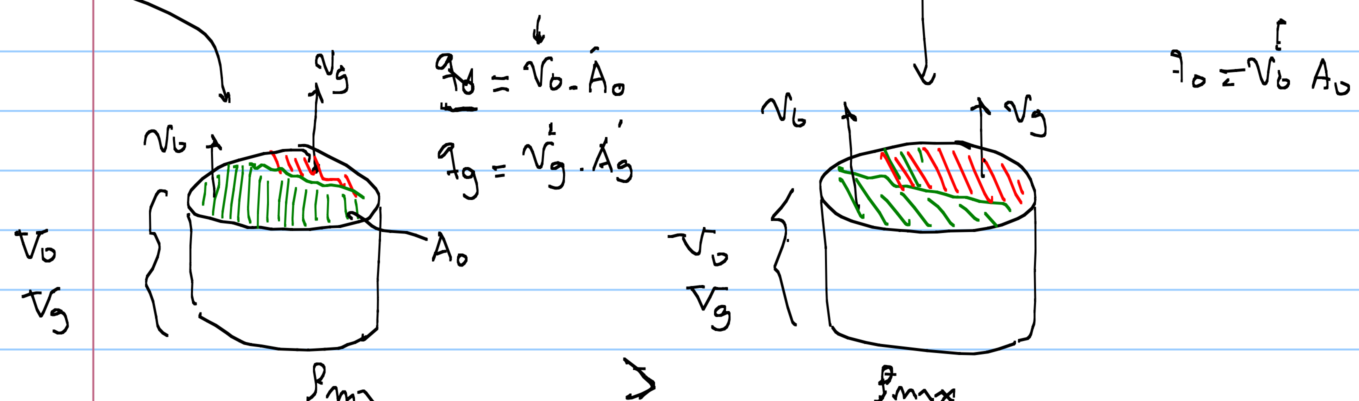


TPR tubing performance relationship



$$\Delta p = \Delta p_{hydrostatic} + \Delta p_{friction}$$

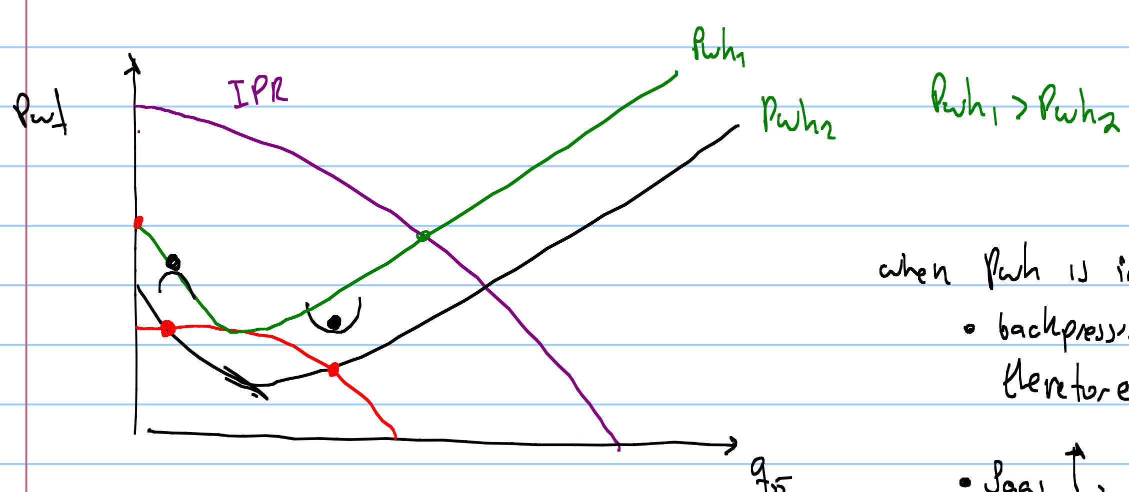
ρ_{mix} v^2



$$q_o = v_o \cdot A_o$$

$$q_g = v_g \cdot A_g$$

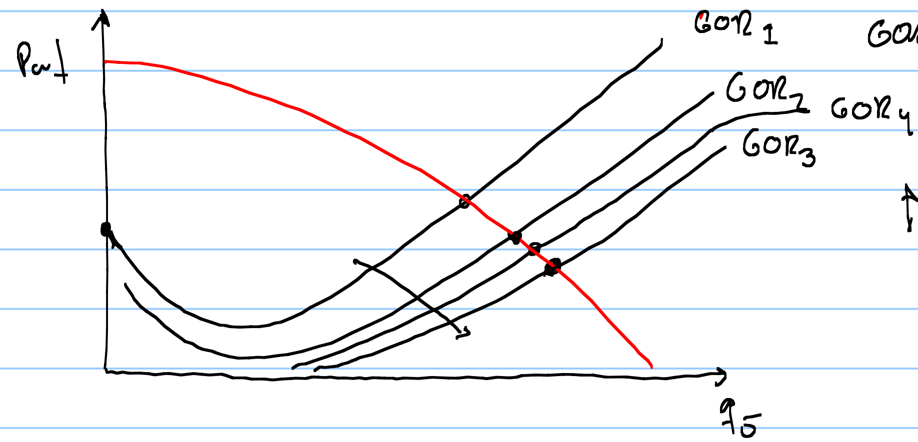
$$q_o = v_o\, A_o$$



when Pwh is increased

- backpressure is increased therefore $q_{o\,equ}$ ↓
- ρ_{gas} ↑, $\Delta p_{friction}$ ↓

  $q_{o\,eq}$ ↑

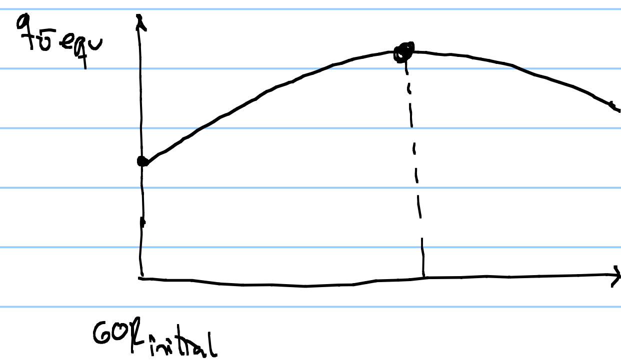


$GOR_2 > GOR_1$

↑ GOR, ↓ ρ_{mix}, $\rho_{mix} \approx \rho_{gas}$

↓ $\Delta p_{hydrostatic}$

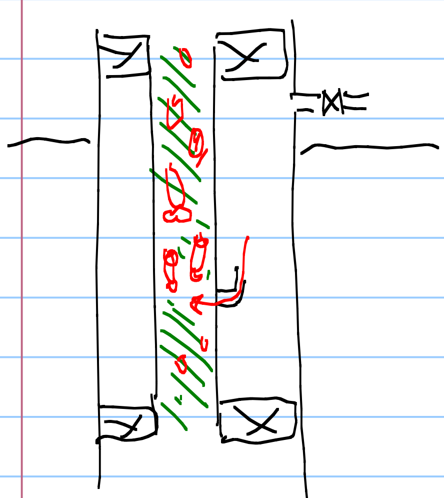
↑ $\Delta p_{frictional}$

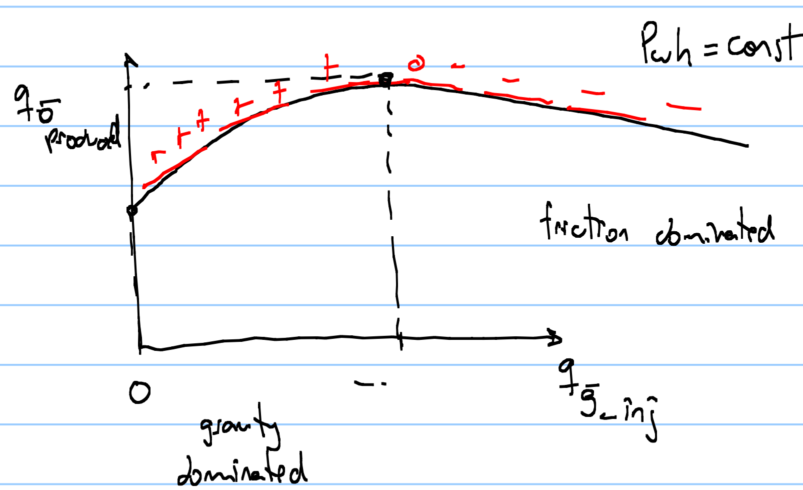


\ GOR changing due to → depletion

→ q_w — $GLR = \frac{q_g}{q_o + q_w}$

→ gas lift





$q_{\bar{o}} = f(q_{g\_inj})$ if funtion is concave

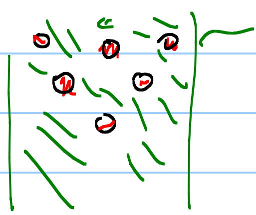
max $\frac{\partial f}{\partial q_{g\_inj}} = 0$

revenue function $Rev = q_{\bar{o}} \cdot P_o - q_{g\_inj} \cdot P_g$

max Rev. $\frac{\partial Rev}{\partial q_{g\_inj}} = \frac{\partial q_{\bar{o}}}{\partial q_{g\_inj}} \cdot P_o - P_g = 0$

$$\frac{\partial q_{\bar{o}}}{\partial q_{g\_inj}} = \frac{P_g}{P_o}$$

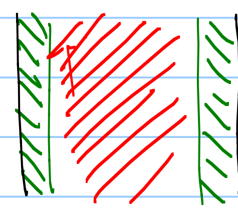
theory about multiphase flow



ρ_{mix}

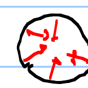
V_{mix}

homogeneous model



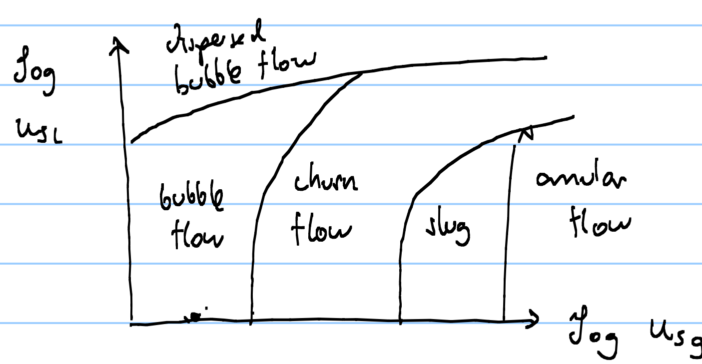
1 equ for each phase

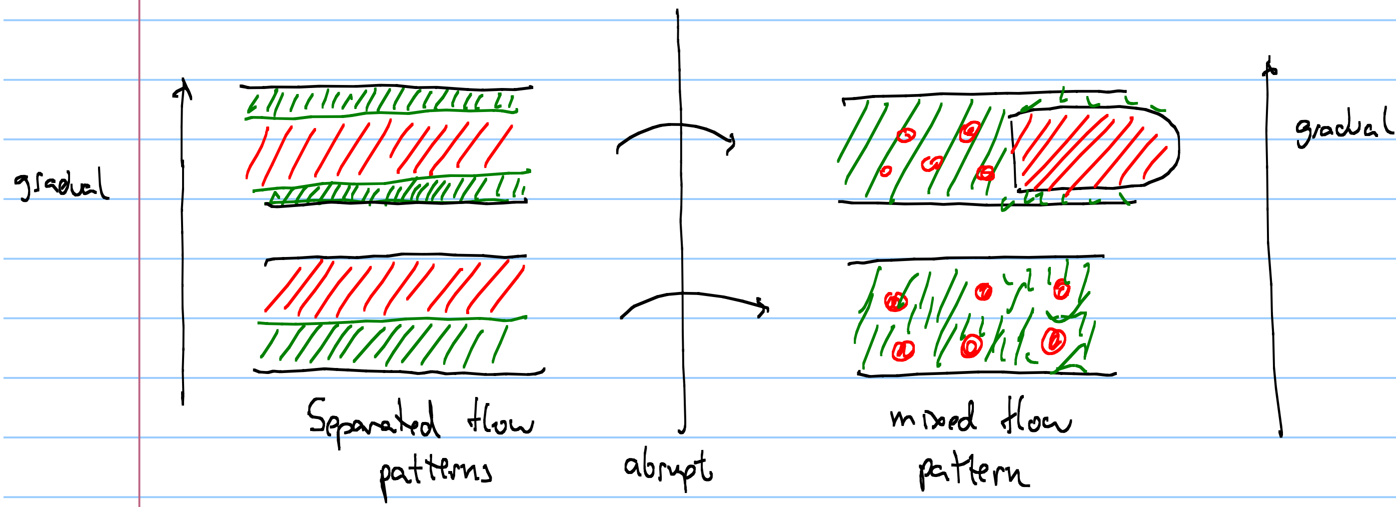
$V_g, V_L, \theta, ID, \varepsilon, \rho_L, \rho_g, \mu_L, \mu_g, \sigma_{Lg}$



$U_{sL} = \frac{q_L}{A}$

$U_{sg} = \frac{q_g}{A}$

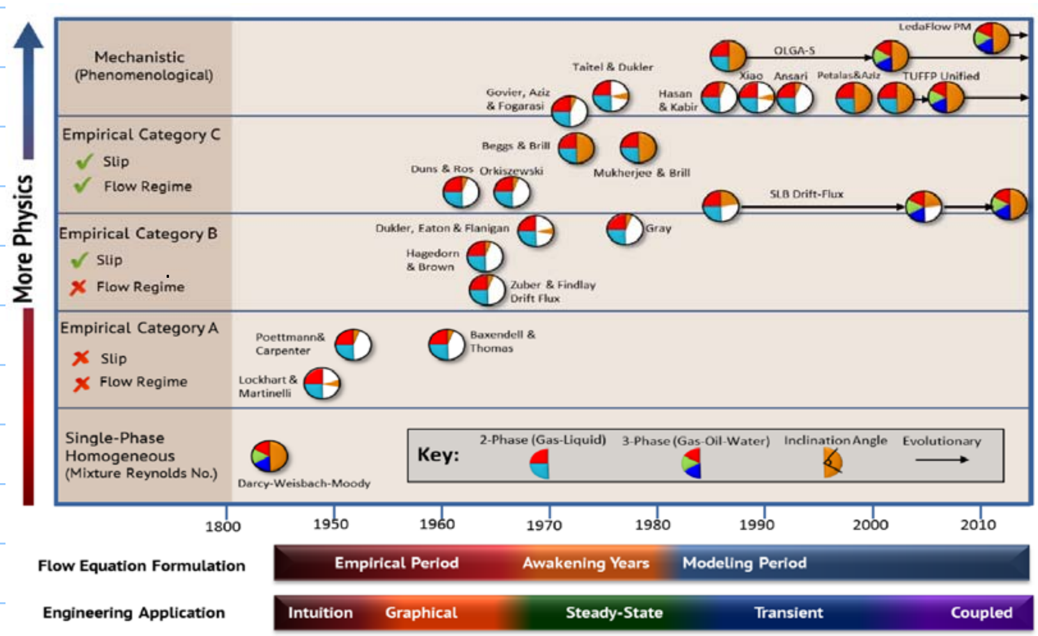




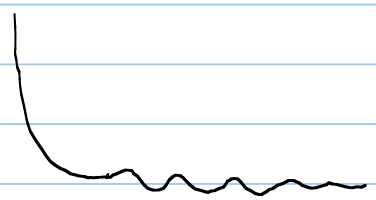
models:
- mechanistic:
  making momentum balance on phase to calculate
  - $\frac{dP}{dx}$
  - flow pattern transition
  - needs correlation → closure model
- mix → drift flux model

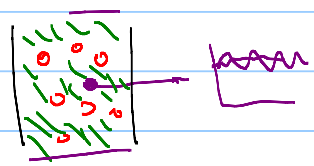
separating forces	mixing forces
gravity	inertia
interfacial tension	turbulence
diffusion	
centrifugal	

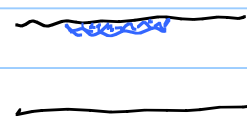
- correlation / empirical
  - lab / field measurements
    fure to a correlation.



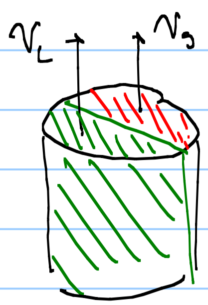
- multiphase models for different purpose → $\frac{dP}{dx}$ $\quad \frac{\partial}{\partial t} = 0$ steady-state
  - → transient → slugging
    - severe slugging
    - liquid accumulation
    - start up
    - shut down
  - → phase distribution, velocity distribution, etc.
    - separator design
    - tol corrosion
    - emulsion oil + w







multiphase flow definitions



homogeneous model $\quad v_g = v_L = v_{mix}$ no slip

$$v_{mix} = \frac{q_L + q_g}{A} = u_{sL} + u_{sg}$$

$\frac{A_g}{A}$ $\quad \frac{A_L}{A}$ $\quad$ if homogeneous flow

$$\lambda_g = \frac{A_g}{A} \quad \lambda_L = \frac{A_L}{A} \quad \lambda_g + \lambda_L = 1$$

$$q_L = v_L \cdot A_L$$

$$q_g = v_g \cdot A_g$$

for homogeneous flow:

$$q_g = A_g \cdot v_m \qquad q_g = A_g \frac{(q_g + q_L)}{A} \Rightarrow \lambda_g = \frac{q_g}{q_g + q_L} \qquad \lambda_L = \frac{q_L}{q_L + q_g} \qquad \lambda_g = \frac{q_g}{q_L + q_g}$$

for most cases $\quad v_g \neq v_L \quad$ slip

Liquid holdup $\quad H_L = \frac{A_L}{A} \qquad \varepsilon = \frac{A_g}{A}$ void fraction

$$H_L = f(u_{sL}, u_{sg}, \theta, ID, \rho_L, \rho_g, \mu_L, \mu_g, \dots)$$

$$\varepsilon = \frac{U_{SG}}{U_{SG}\left(1+\left(\frac{U_{SL}}{U_{SG}}\right)^{\left(\frac{\rho_G}{\rho_L}\right)^{0.1}}\right)+2.9\left[\frac{gD\sigma(1+\cos\theta)(\rho_L-\rho_G)}{\rho_L^2}\right]^{0.25}(1.22+1.22\sin\theta)^{\frac{p_{atm}}{p_{system}}}}$$

Comparison of void fraction correlations for different flow patterns in horizontal and upward inclined pipes

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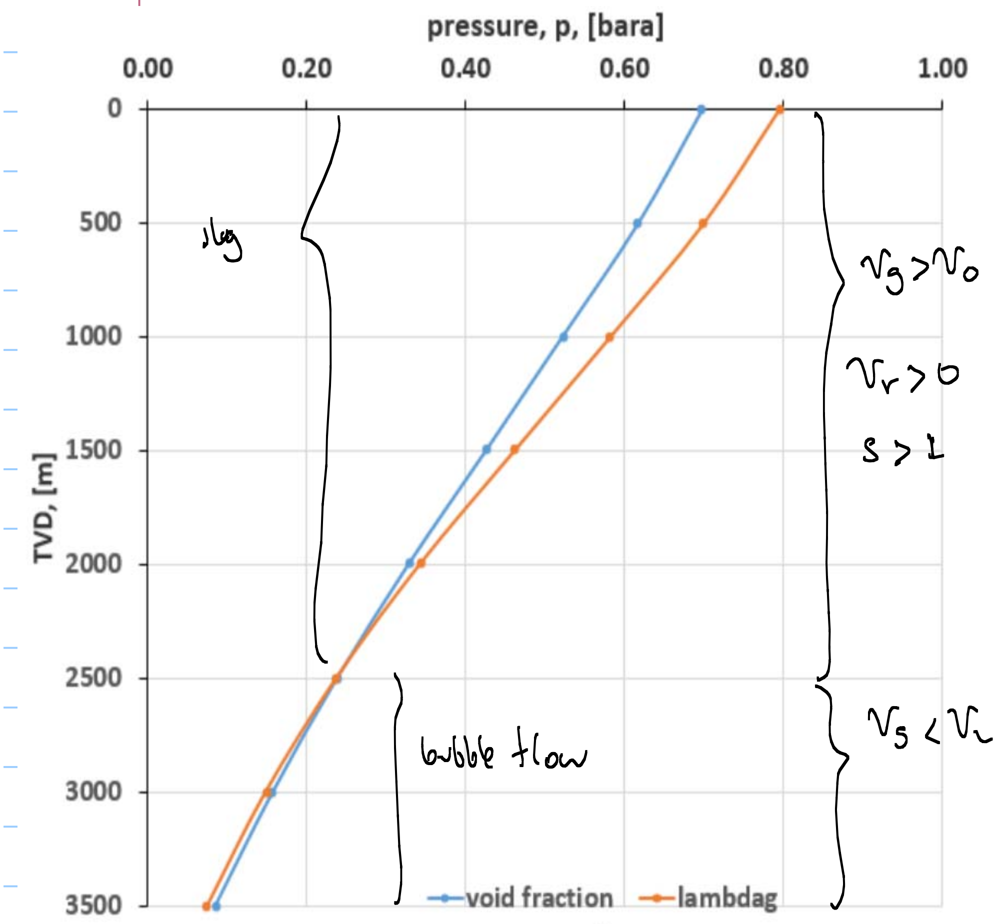
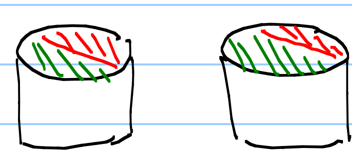


$\lambda_g > \varepsilon$??



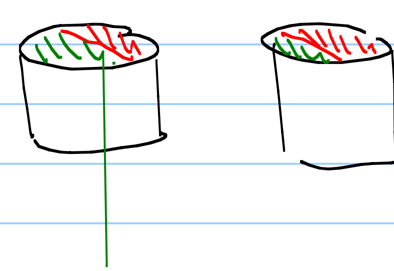
$q_o = A_o \cdot v_o$ q_o

$q_g = A_g \cdot v_g$ q_g

$v_r = v_g - v_L$

$S = \text{slip} = \frac{v_g}{v_L}$

$\lambda_g < \varepsilon$



$$\rho_{mix} = H_L \rho_L + (1 - H_L)\rho_g$$

$$\rho_{mix} = \varepsilon \rho_g + (1-\varepsilon)\rho_L$$

drift flux model ~> mixture equation to represent liquid + gas

$$\left.\frac{dp}{dx}\right|_{@P,T} = -\rho_{mix} \cdot g \cdot \sin\theta - \rho_{mix} \cdot f \frac{v_m^{?2}}{\phi \cdot 2}$$

neglecting acceleration

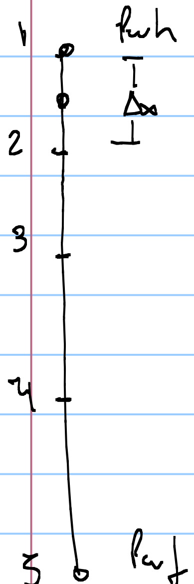
ε ~ $\rho_g(p,T)$
~ $\rho_o(p,T)$
$q_o(p,T)$
$q_g(p,T)$

f ... single phase flow but with Re_m

$$Re_m = \frac{\rho_{mix}\, \phi\, v_m}{\mu_m}$$

$$\mu_m = \mu_L(1-\varepsilon) + \varepsilon \mu_g$$

Integration procedure.



- subdivide the conduit (tubing, flowline) in segments
- start from boundary with know p, T (Pwh)
- calculate local q_o, q_g properties (ρ_o, ρ_g, μ_o, μ_g, σ_{og})
- calculate $\left.\frac{dp}{dx}\right|_{P,T}$ → correlation → drift flux → olga, leda
- integration

$P_2 = ?$

Euler's method explicit

$$\left.\frac{dp}{dx}\right|_{P_1,T_1} = \frac{P_2 - P_1}{\Delta x}$$

$$P_2 = P_1 - \Delta x \frac{dP}{dx}$$

implicit

$$\left.\frac{dP}{dx}\right|_{\frac{P_1+P_2}{2},\ \frac{T_1+T_2}{2}} = \frac{P_2 - P_1}{\Delta x}$$

- Assume P_2
- Calculate P_{av}.
- calculate $\left.\frac{dP}{dx}\right|_{P_{av}}$
- calculate $P_{2\,cal} = P_1 - \left.\frac{dP}{dx}\right|_{av} \cdot \Delta x$

Is P_2 assumed $= P_2$ calc ? yes → proceed to P_3; not → (back to Assume P_2)

ODE

$\frac{dP}{dx}$ = constant

$P_1 =$

$T_1 =$

x_2

x_3

x_4

$\frac{dP}{dx} = 0.02 \frac{bar}{m}$

hydrostatic colum of water

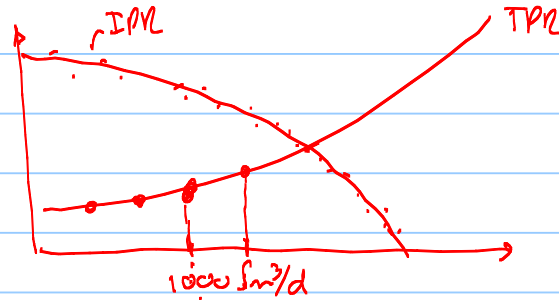
$\frac{dP}{dx} \simeq 0.1 \frac{bar}{m}$

hydrostatic colum of air

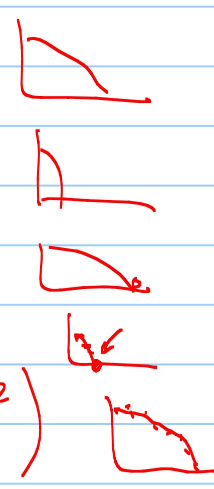
$\frac{dP}{dx} \simeq 0.001 \frac{bar}{m}$

		BO table colum	3	4	5	6	8	10	7	9	11								
TVD [m]	T [C]	p[bara]	Rs [Sm^3/Sm^3]	rs [Sm^3/Sm^3]	Bo [m^3/Sm^3]	Bg [m^3/Sm^3]	deng [kg/m^3]	viscg [cp]	deno [kg/m^3]	viso [cp]	sigma_o_g [N/m	qo [m^3/d]	qg[m^3/d]	uso [m/s]	usg [m/s]	Flow pattern	lambdag[-]	e[-]	dp/dx [bara/m]
0	50.0	28	22.6	1.28E-05	1.2	3.44E-02	37.8	0.0	728.8	1.8	1.15E-02	1174.3	4.566E+03	0.769	2.991		0.80	0.70	0.0260
500	63.0	41.0	33.7	1.25E-05	1.2	2.36E-02	56.4	0.0	711.0	1.1	9.23E-03	1224.4	2.862E+03	0.802	1.874		0.70	0.62	0.0312
1000	76.0	56.6	46.8	1.25E-05	1.3	1.65E-02	78.8	0.0	691.8	0.8	7.09E-03	1283.1	1.791E+03	0.840	1.173		0.58	0.52	0.0373
1500	89.0	75.2	62.2	1.31E-05	1.4	1.25E-02	105.5	0.0	671.3	0.6	5.17E-03	1352.5	1.161E+03	0.886	0.761		0.46	0.43	0.0428
2000	102.0	96.7	79.3	1.45E-05	1.4	9.82E-03	133.4	0.0	650.4	0.5	3.60E-03	1430.1	7.452E+02	0.937	0.488		0.34	0.33	0.0476
2500	115.0	120.5	97.4	1.68E-05	1.5	8.17E-03	159.9	0.0	629.9	0.4	2.47E-03	1514.4	4.721E+02	0.992	0.309		0.24	0.24	0.0512
3000	128.0	146.1	115.9	2.02E-05	1.6	7.12E-03	182.9	0.0	610.4	0.3	1.68E-03	1602.1	2.803E+02	1.049	0.184		0.15	0.16	0.0537
3500	141.0	172.9	133.8	2.46E-05	1.7	6.46E-03	201.6	0.0	592.5	0.3	1.18E-03	1690.3	1.380E+02	1.107	0.090		0.08	0.09	0.0552

Homework: flow equilibrium saturated oil well



P_{wh}



Vogel $q_o = q_{o\,max}\left(1 - 0.2\frac{P_{wf}}{P_R} - 0.8\left(\frac{P_{wf}}{P_R}\right)^2\right)$