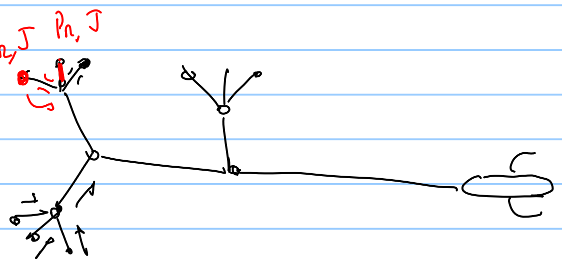
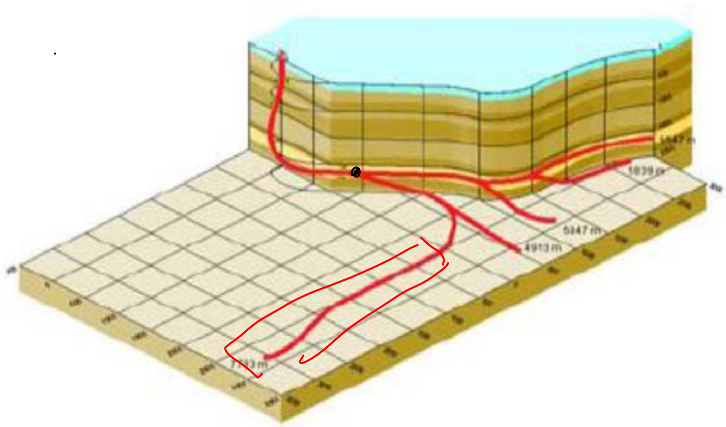
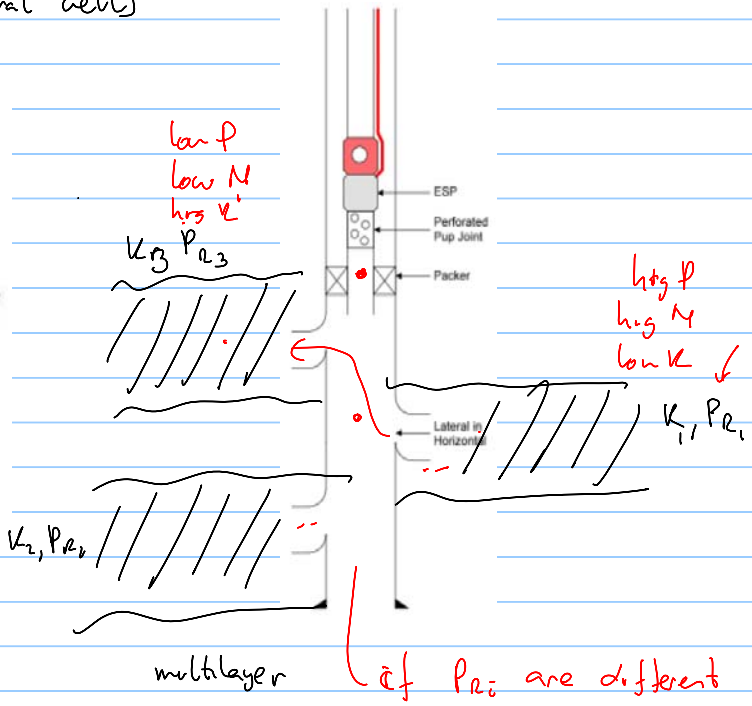
- Next class 09.03.2017 will be in P2. MBAL (mbal), PROSPER (flowing single well), GAP (→ networks)
  (PETEX (Petroleum experts)
  10 Academic licenses available.



- Pressure calculated counter-current and co-current is the same for a given point.
- mass balance → surface rates should be conserved

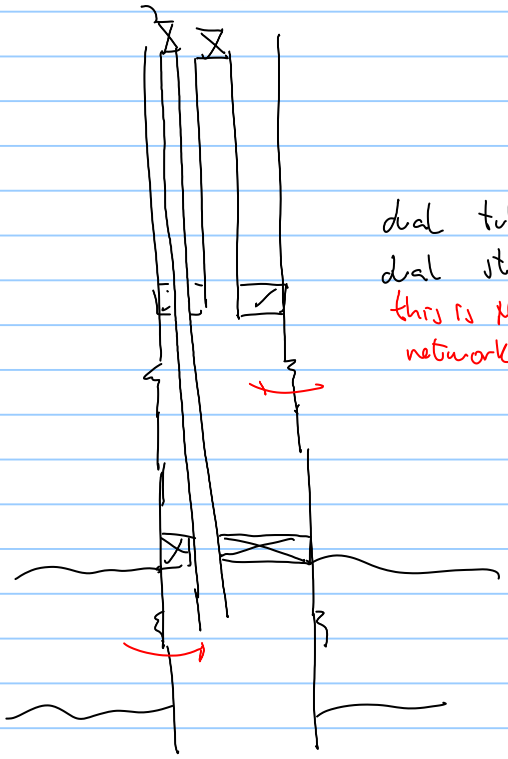
- We have downhole networks: multilateral wells



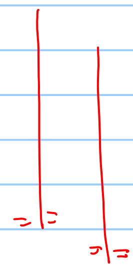


if P_{Ri} are different one might have cross flow between formations

↑ P_R formation "charge" other formations.

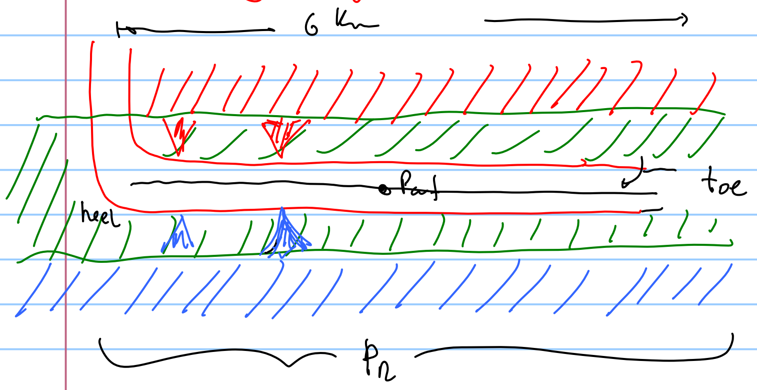


dual tubing completions
dual strings completion
this is NOT a downhole network!



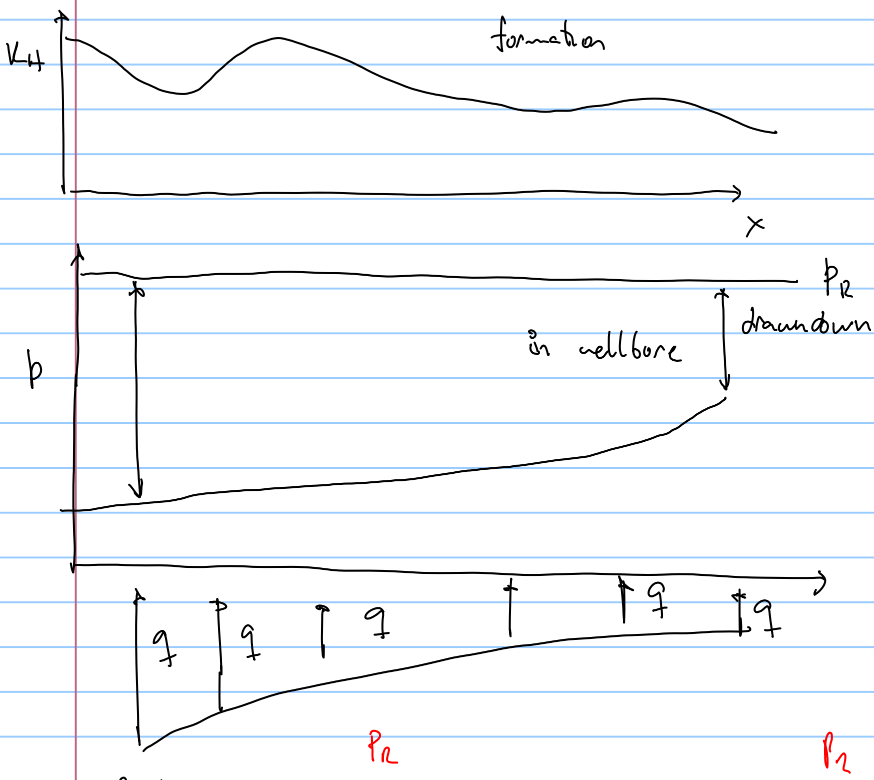
Inflow control devices (ICD) to control (passive or active) the rates coming out of a given formation, section)

in coning horizontal wells



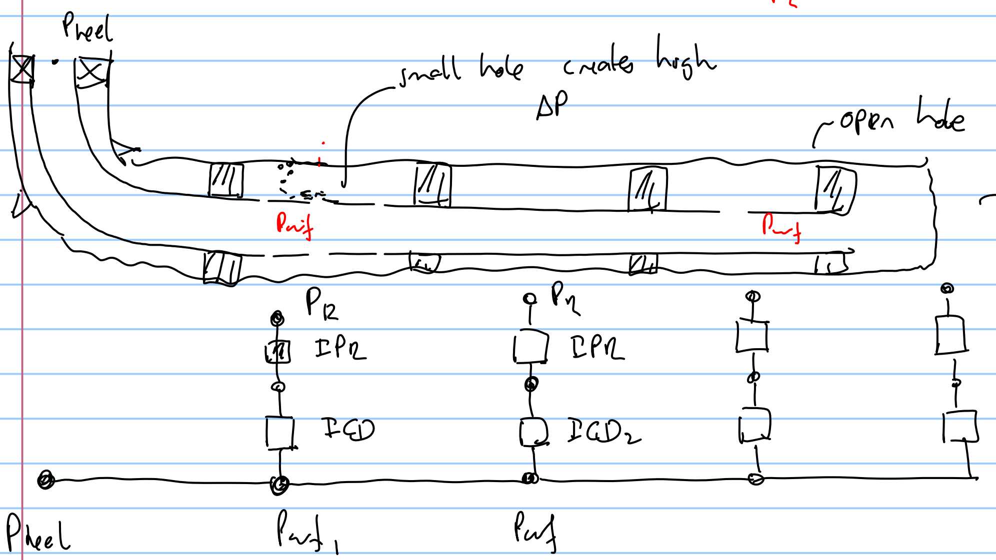
$\frac{\Delta p}{\Delta x} \propto \frac{1}{k}$ $q = \frac{k}{\mu} \frac{\partial p}{\partial}$

μ r



this causes an uneven distribution of inflow, of reservoir rates along the wellbore

which can cause coning, uneven depletion, etc

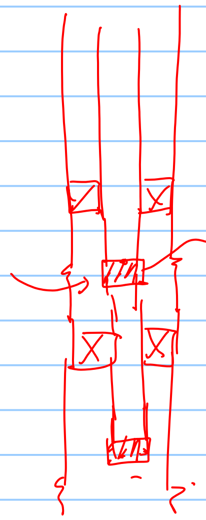


Completion design

Design of ICD

- define the number of sections
- define the orifice diameter and number of orifices

Netool ⤳ Weatherford ? commercial simulator to design completions.



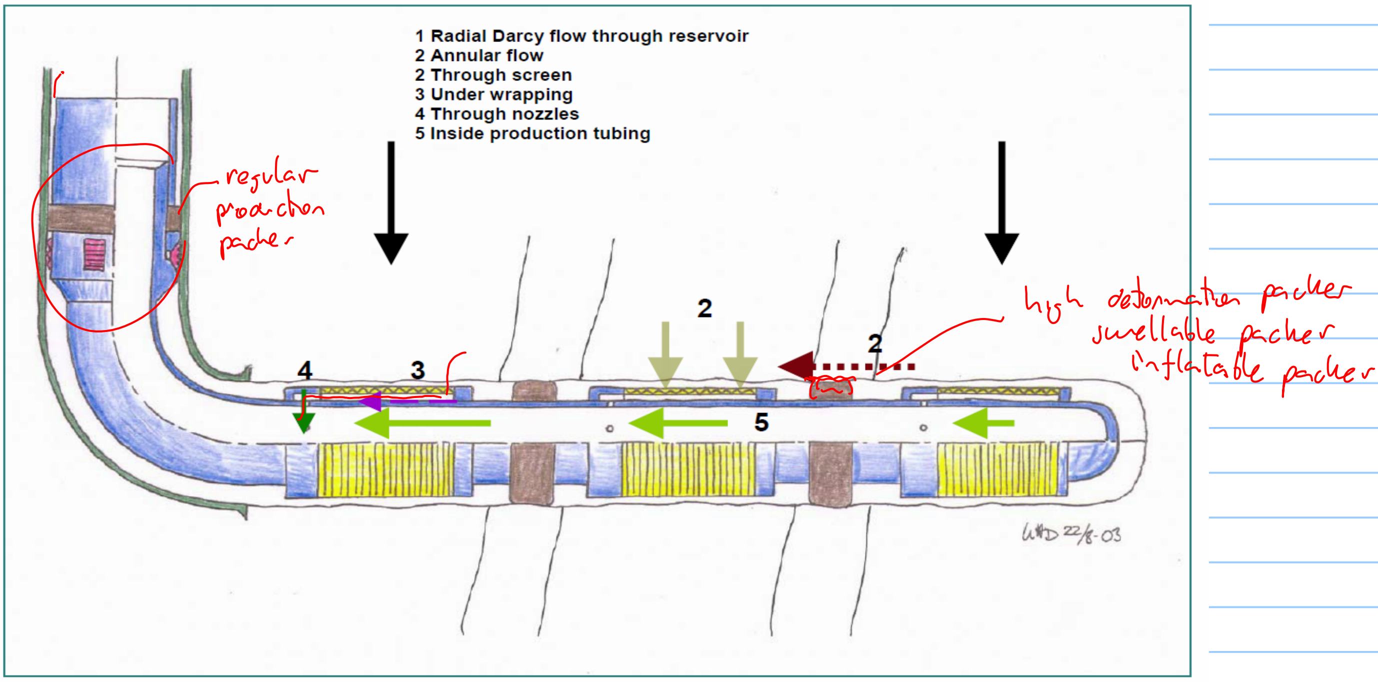
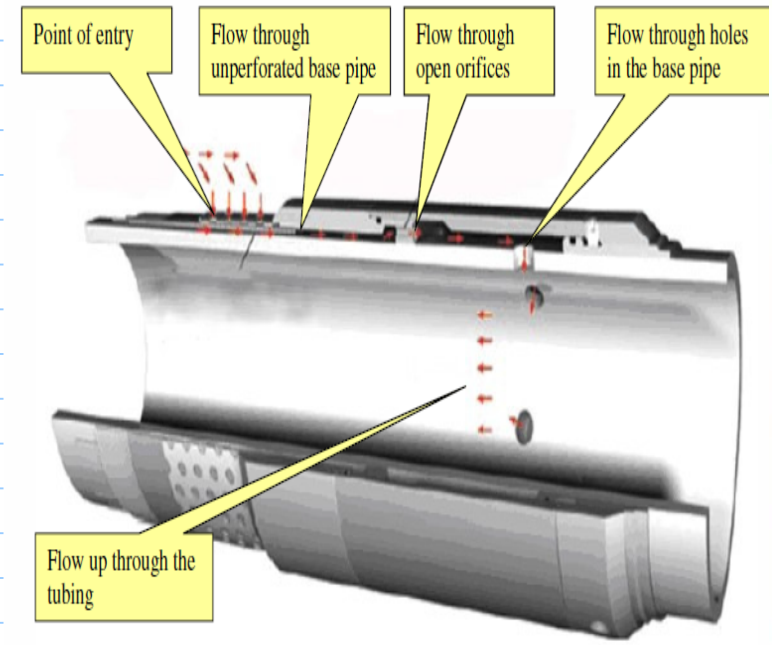


Figure-8 Functioning and interplay of an ICD completion architecture. Fluids enter the screen and flow between the axial wires and the un-perforated base pipe into the ICD housing, before passing throug… issues are properly analyzed and put in the right perspective to achieve…



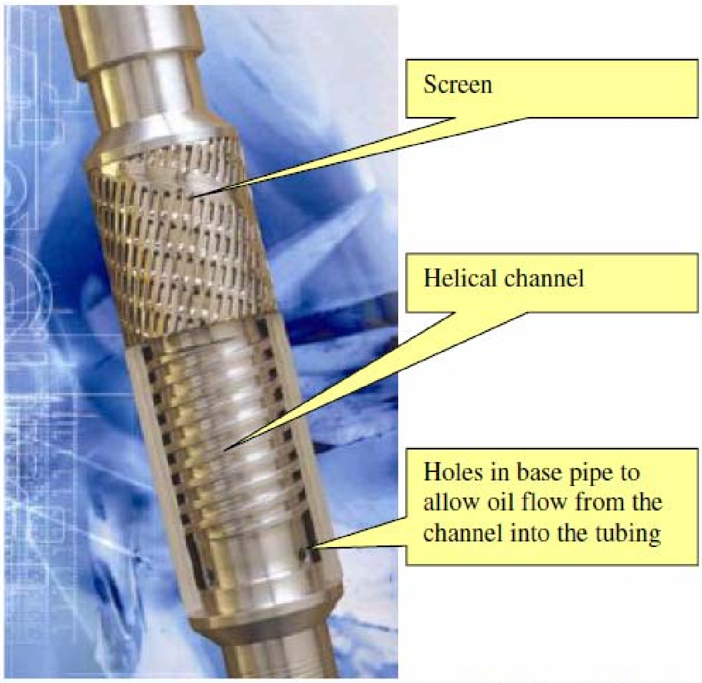
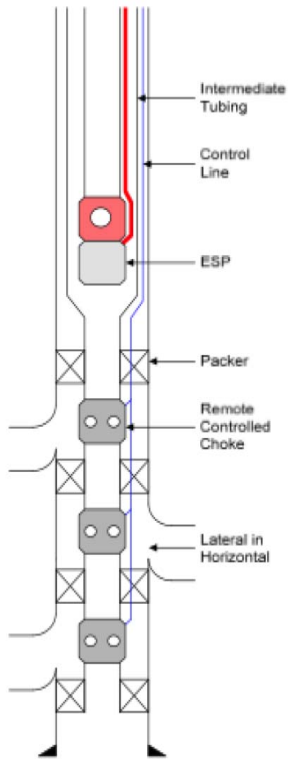


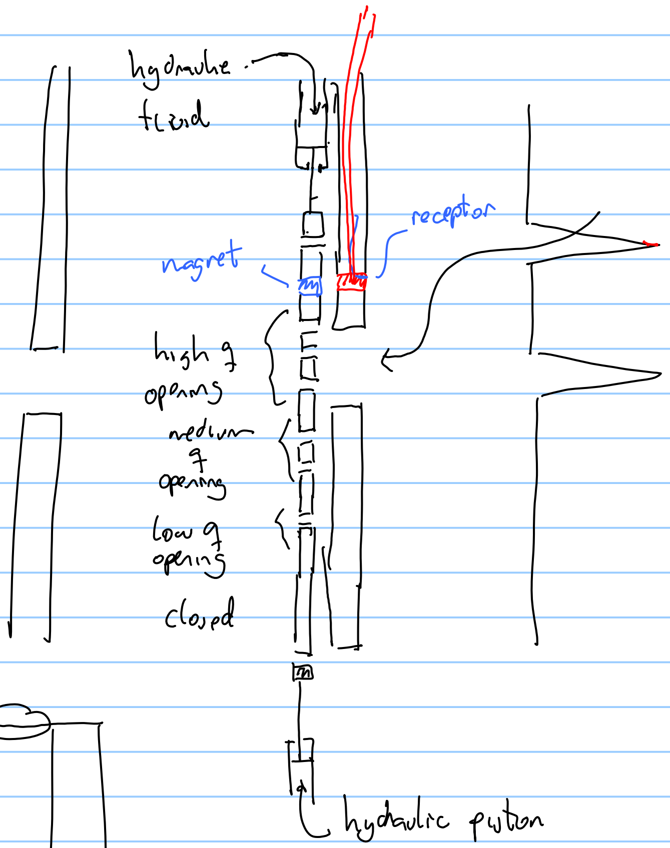
Figure 14 Helical channel type, EqualizerTM, Baker Oil Tools [22]

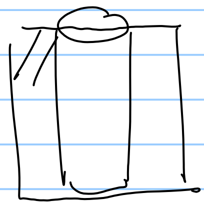
So far we have discussed passive inflow control devices

but we also have active inflow control devices (ICV) — inflow control valve

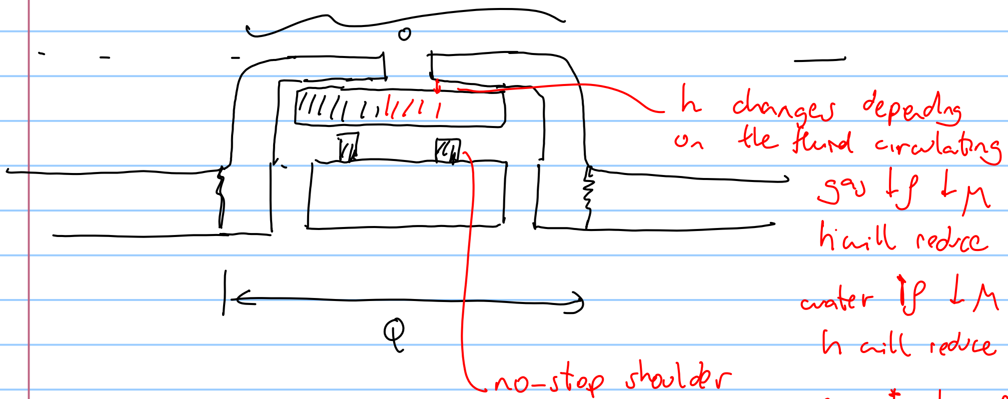
- manually activated
- {downhole adjustable choke}
- autonomous





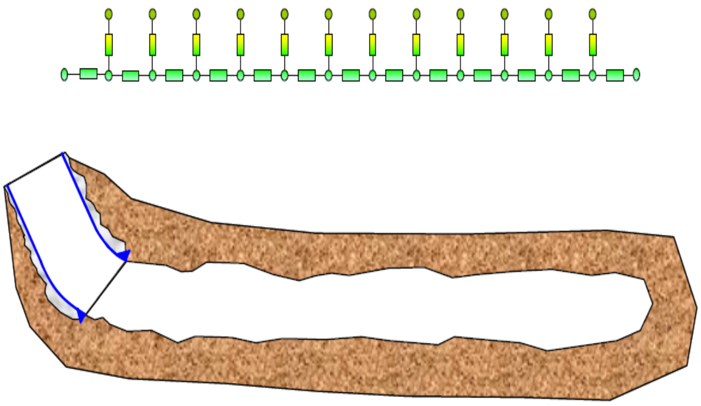


• Autonomous, AICD, AICV

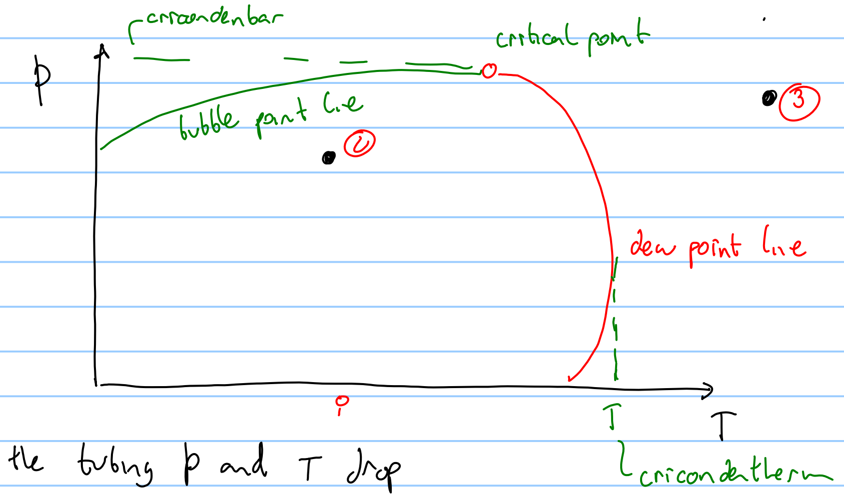


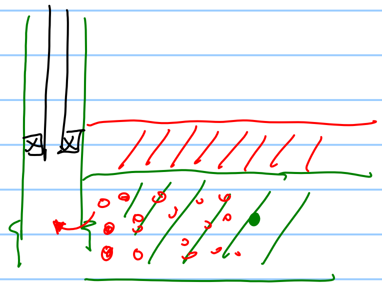
if there is a big variation of reservoir properties along the wellbore it is also necessary to use network solving.

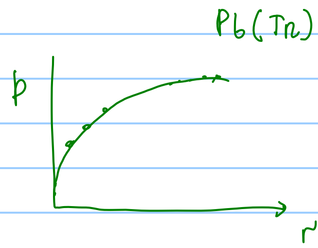
- Horizontal well with Open Hole completion
  - Including damage zone



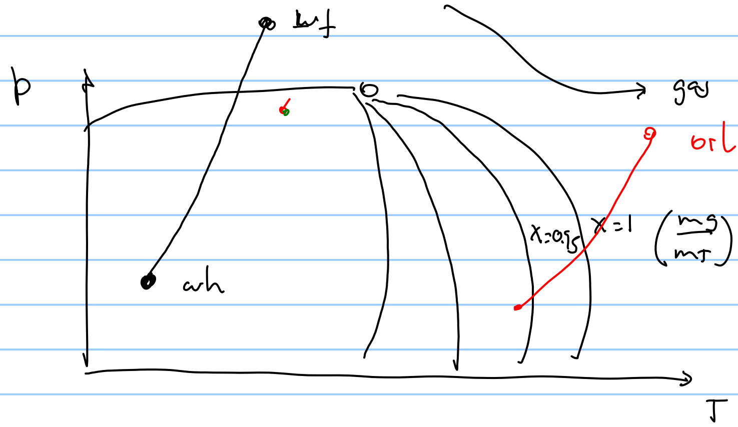
multiphase flow: • possible entry points to wellbore



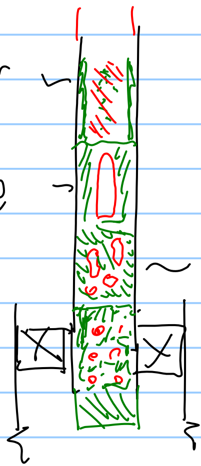




in the tubing p and T drop

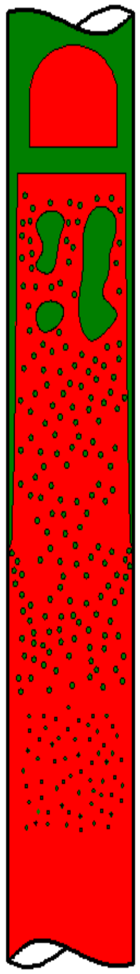


gas liberates from oil or oil liberates from gas

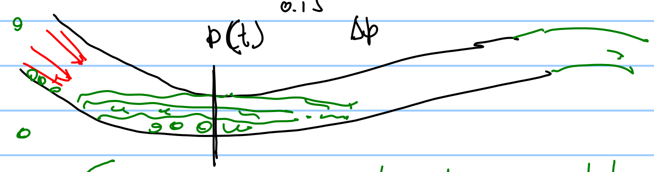


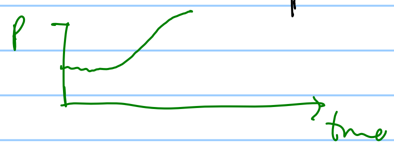
flow patterns different way how the fluids are spatially arranged

course on multiphase flow,
TEP4250 Ole jørge Hydal {



- be able to estimate Δp, ΔT with length
- due to variation in p, T, and the variation in flow patterns, the Δp calculation have to be made in a stepwise manner.
  → subdivide the tubing in segments!
- there are two ways to study multiphase flow
  - steady state, $\{ \frac{\partial}{\partial t} = 0$
    (pipesim, pipephase, ReO, prosper, gap
  - transient



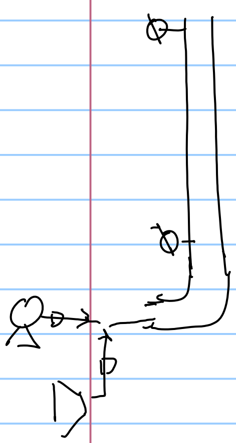


$\frac{\partial}{\partial t} \neq 0$

- liquid accumulation in gas transportation pipelines
- slugging
- sluggin in risers

commercial tools : OLGA, LedaFlow.
transient multiphase flow simulator

- there are two approaches to analyze multiphase flow

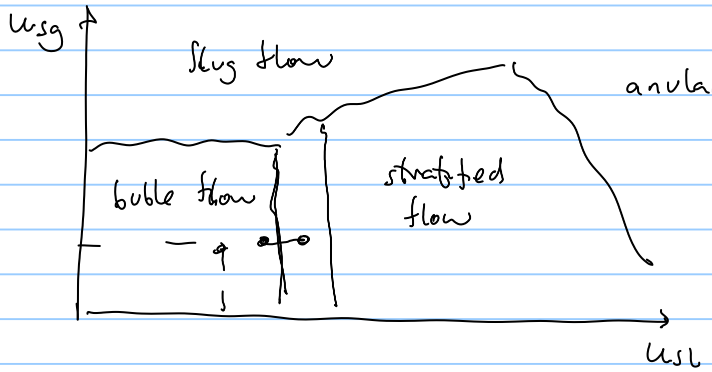


- correlation-based, Beggs and Brill, Orkiejwski, Ons and Ros, Hagedorn and Brown

correlations develop based on experimental data, some physics and limited range of applicability

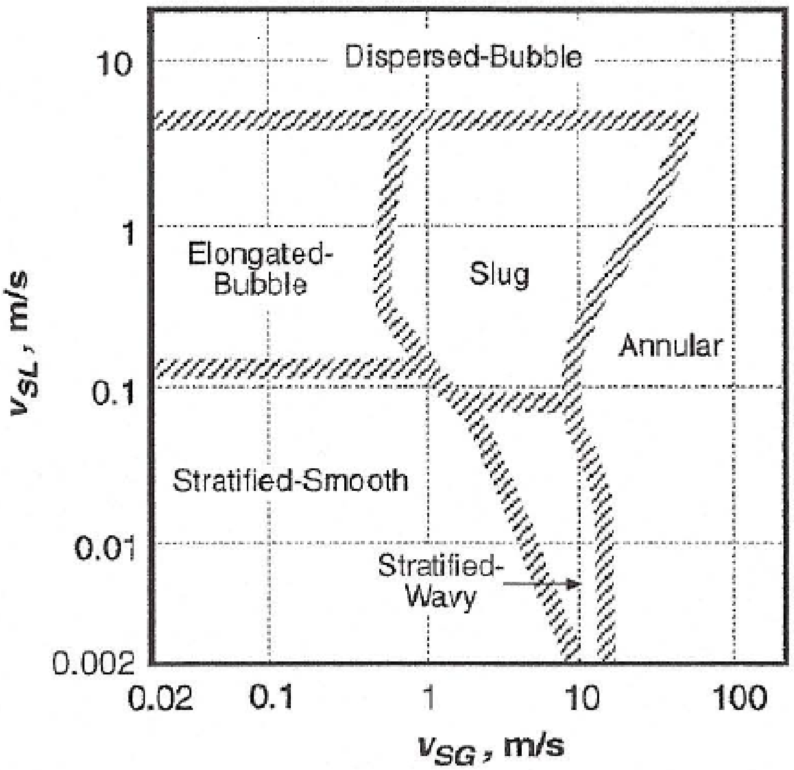
Superficial velocity $v_{sL} = \frac{q_L}{A_p}$ → m^3/s
A_p ~ cross section area of pipe (πr^2)

$v_{sg} = \frac{q_g}{A_p}$



this plots depends on fluid properties { ρ_o, ρ_g ; μ_o, μ_g ; σ_{og} }

inclination, pipe diameter



Mandhane

- mechanistic modeling → applying { mass conservation for each phase ; momentum conservation { to each phase ; to the mixture }

→ closure laws derived empirically (by exp)

$$-\frac{dp}{dL} = -\left.\frac{dp}{dL}\right)_F - \left.\frac{dp}{dL}\right)_G - \left.\frac{dp}{dL}\right)_A$$

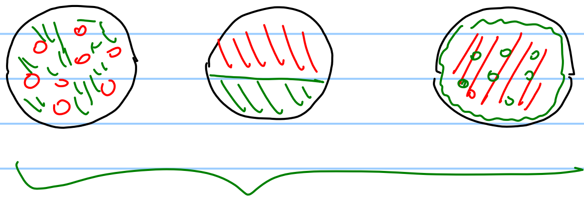
momentum equation mixture

(friction, gravity, acceleration)

$$-\frac{dp}{dL} = \frac{2}{d} f_{TP(F)}\,\rho_{TP}\,v_{TP}^2 + \rho_{TP})g\sin\theta + \rho_{TP}\,v_{TP}\frac{dv_{TP}}{dL},$$

} momentum eq. for the mixture

ρ_{TP} ↳ density of the mixture



$A_L + A_g = A_p$

if we assume $v_g = v_L$
- homogeneous model
- no slip model { bubble flow, mist flow

$\dot{m}_g$ [kg/s] $\dot{m}_L$ [kg/s]

ρ_g ρ_L @ P, T

local flow rate $q_g = \frac{\dot{m}_g}{\rho_g}$ $q_L = \frac{\dot{m}_L}{\rho_L}$

$v_g = \frac{q_g}{A_g}$ $v_L = \frac{q_L}{A_L}$

if homogeneous model

$v_L = v_g \Rightarrow \frac{q_g}{A_g} = \frac{q_L}{A_L}$ $A_L = A_p - A_g$

$A_p - A_g = \frac{q_L}{q_g} A_g$

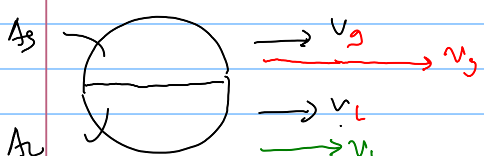
$A_p = \left(\frac{q_L}{q_g} A_g + A_g \right)$

$\frac{A_p}{A_g} = \left(\frac{q_L}{q_g} + 1 \right)$

$\frac{A_g}{A_p} = \frac{1}{\frac{q_L}{q_g} + 1} = \left(\frac{q_g}{q_L + q_g} \right)$ ~ gas volume fraction (λ_g)

$\rho_m = \lambda_g \rho_g + (1-\lambda_g) \rho_L$, where $(1-\lambda_g) = \lambda_L$

usually $u_L \neq u_g$

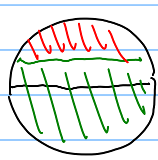


$q_g = v_g \cdot A_g$

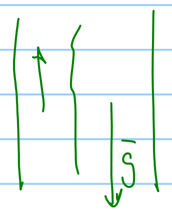
$q_L = v_L \cdot A_L$

if the gas travels faster than liquid

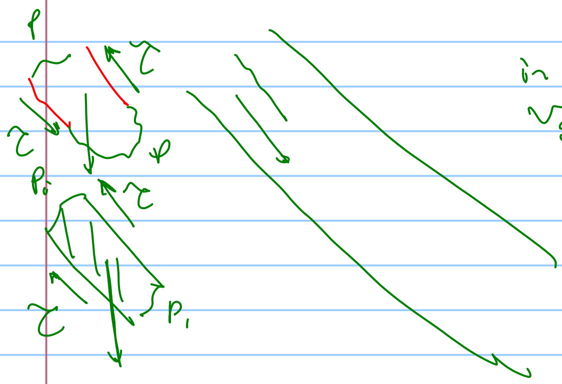
liquid holdup $= H_L = \frac{A_L}{A_p}$ with slip



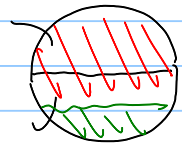
$H_L \neq \lambda_L$ $\quad\quad$ $\rho_m = H_L \rho_L + (1 - H_L)\rho_g$



in upwards flow gravity pulls liquid down, thus $v_g > v_L$



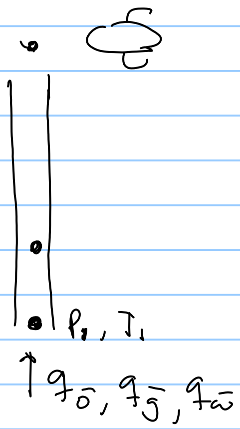
in downwards flow gravity helps liquid down thus $v_g < v_L$



Calculating the real fluid velocities: $v_L = \frac{q_L}{A_L} = \frac{q_L}{H_L A_p} = \left(\frac{u_{SL}}{H_L}\right)$

$$v_g = \frac{q_g}{(1-H_L)A_p} =$$

- How to perform multiphase calculation in conduits

① Depart from a point with know p, T. assume rate. calculate the rest with GOR, WC.
(depth)

② Covert from sc to local conditions

Black oil

compute black oil properties from table, correlation

$$\begin{bmatrix} q_g \\ q_o \\ q_w \end{bmatrix} = \begin{bmatrix} \frac{B_g}{1-R_s \cdot r_s} & \frac{-B_g \cdot R_s}{1-R_s \cdot r_s} & 0 \\ \frac{-B_o \cdot r_s}{1-R_s \cdot r_s} & \frac{B_o}{1-R_s \cdot r_s} & 0 \\ 0 & 0 & B_w \end{bmatrix}_{(p,T)} \cdot \begin{bmatrix} q_{\bar{g}} \\ q_{\bar{o}} \\ q_{\bar{w}} \end{bmatrix}$$

obtain q_g, q_o q_w

compositional model (EOS) Peng Robinson, SRK
composition is available

z_i $\begin{cases} C_1 & z_{c_1} \\ C_2 & z_{c_2} \\ C_3 & c_{c_3} \end{cases}$

calculate the mass fraction of oil and gas $x_g = \frac{m_g}{m_T}$ @ p, T

Calculate $\frac{\dot{m}_g}{\dot{m}_L}$ @ p, T

with $\dot{m}_T$

- calculate q_g, q_o using properties ρ_g, ρ_o

(v_{SL}, v_{Sg})

- with input v_{SL}, v_{Sg}, ϕ, inclination, ε (roughness), $\rho_g, \rho_L, \mu_g, \mu_L, \sigma_{og}, \sigma_{ow}, \sigma_{gw}$

multiphase expert

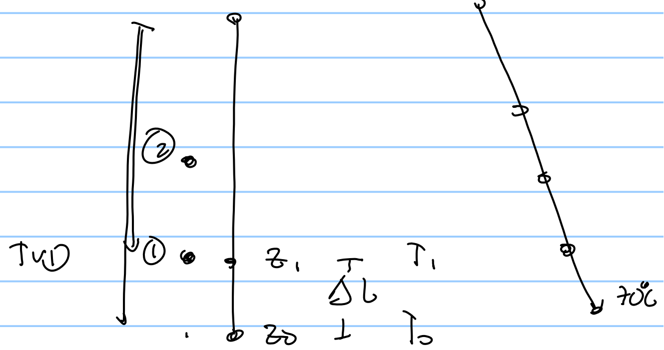
→ give me $\frac{dp}{dz}$

- ODE
numerical integration of ODE { explicit / implicit } { Euler's method / Corrector predictor / Runge-Kutta etc }

$\frac{dp}{dz}$ { with starting point $P = P_0$ @ $z = z_0$ }

Euler's method

$$P_1 = P_0 + \Delta L \cdot \left.\frac{dp}{dL}\right|_{z_0}$$



for the next point one needs to have T_1 beforehand

or if a Temperature drop model is available $T = f(z)$

AND Repeat !

CLASS EXERCISE

fluid calculator to calculate $x_0 = \frac{m_o}{m_T}$, ρ_s, ρ_g i need a fluid model, calculator

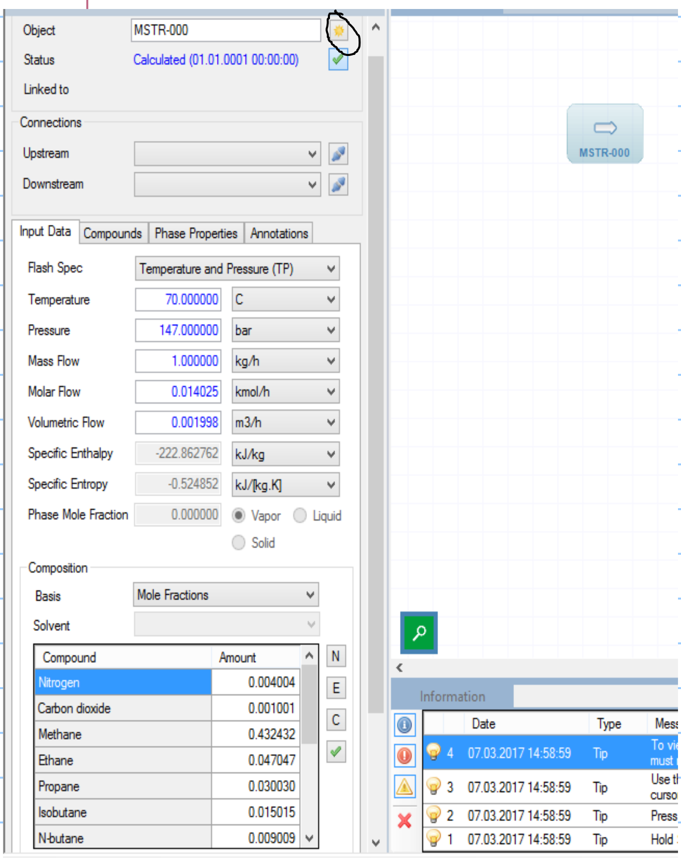
Compositional { HYSYS process simulator / DWSIM }

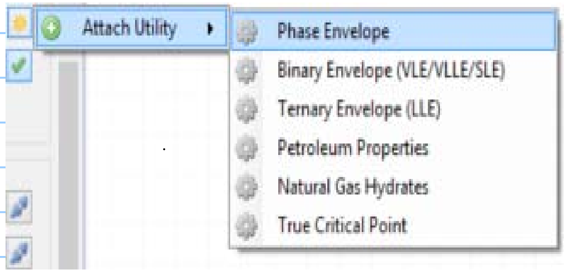
http://dwsim.inforside.com.br/wiki/index.php?title=Main_Page

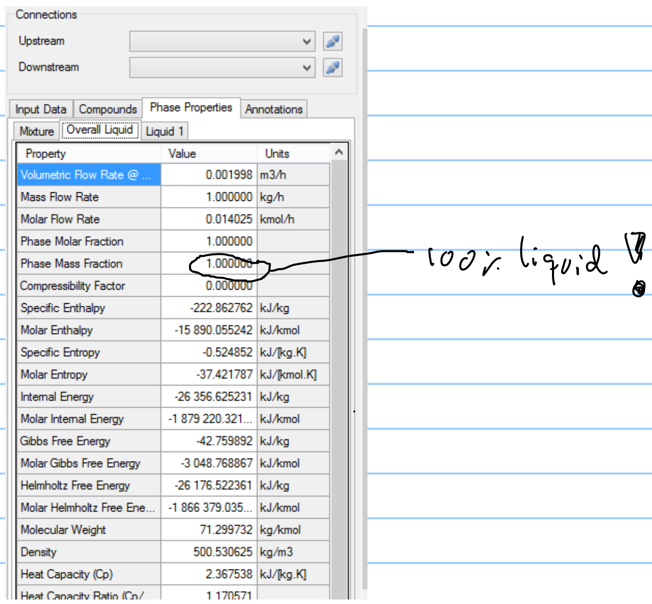
SUM | =G4*1000*G11/(24*3600)

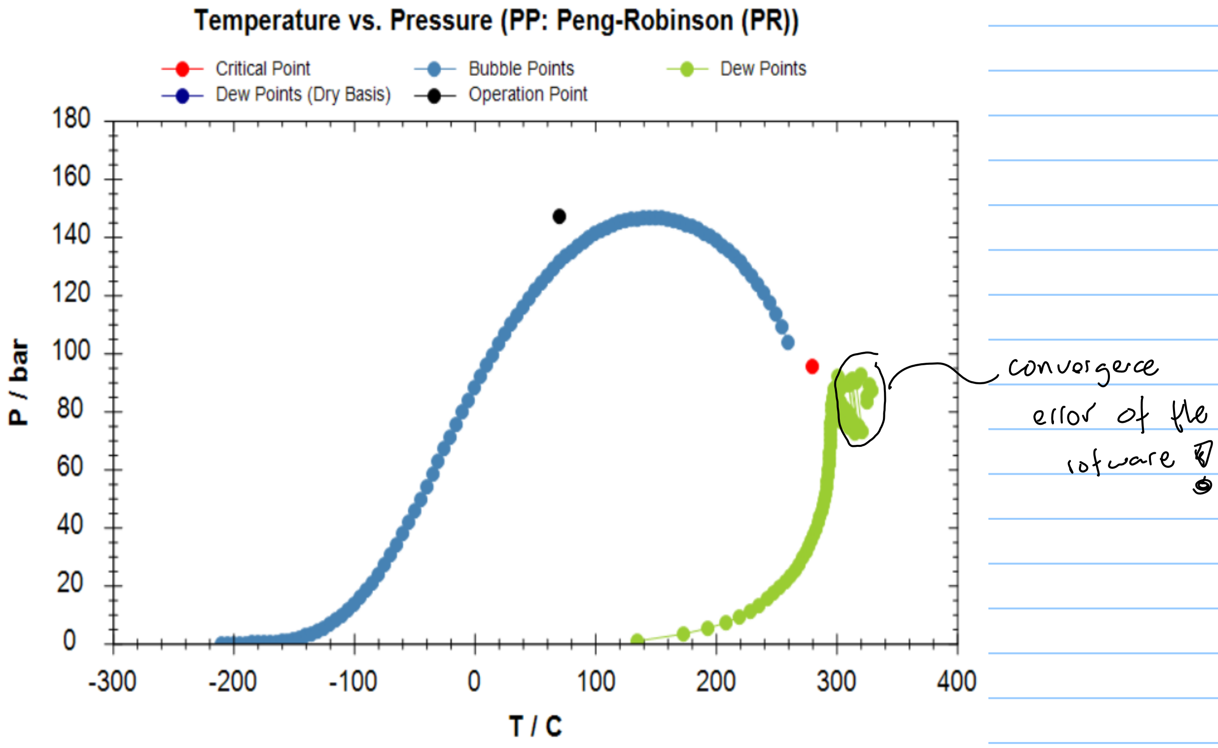
	A	B	C	D	E	F	G
1	TPG4230, Prof. Milan Stanko, 20170307						
2			Mole %	Mole frac			
3		Nitrogen	0.4	0.004		qo [Sm^3/d]	1000
4		CO2	0.1	0.001		qg [E03 Sm^3/d]	200
5		Methane	43.2	0.432		pwf [bara]	147
6		Ethane	4.7	0.047		TR [C]	70
7		Propane	3.0	0.03		ID [m]	0.12
8		i-butane	1.5	0.015		Well TVD Depth [m]	2500
9		n-butane	0.9	0.009		Twh [C]	60
10		neo-pentane	0.0	0		Sc oil density [Kg/m^3]	850
11		i-pentane	0.8	0.008		Sc gas density [Kg/m^3]	0.91
12		n-pentane	0.5	0.005			
13		Hexanes	1.8	0.018			
14		Heptanes	4.1	0.041		mosc [kg/s]	9.8
15		Octanes	5.0	0.05		mgsc [kg/s]	=G4*1000*G
16		Nonanes	3.8	0.038		mt [kg/s]	11.9
17		Decanes	30.1	0.301			

	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
24		TVD	p	T	Liquid Mass fraction	mo	mg	deno	deng	qo	qg	vso	vsg	dp/dx
25		[m]	[bara]	[C]	[-]	[kg/s]	[kg/s]	[kg/m^3]	[kg/m^3]	[m^3/s]	[m^3/s]	[m/s]	[m/s]	[bara/m]
26	1	2500	147	70										
27	2	1000												
28	3	500												
29	4	0												









	TVD	p	T	Liquid Mass fraction	mo	mg	deno	deng	qo	qg	vso	vsg	dp/dx
	[m]	[bara]	[C]	[-]	[kg/s]	[kg/s]	[kg/m^3]	[kg/m^3]	[m^3/s]	[m^3/s]	[m/s]	[m/s]	[bara/m]
1	2500	**147**	**70**	1	11.9	0.0							
2	1000												
3	500												
4	0												