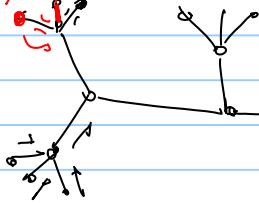


- Next class 09.03.2017 will be in P2. MBAL, PROSPER, GAP → networks
(PETEX (petroleum experts))

10 Academic licenses available.

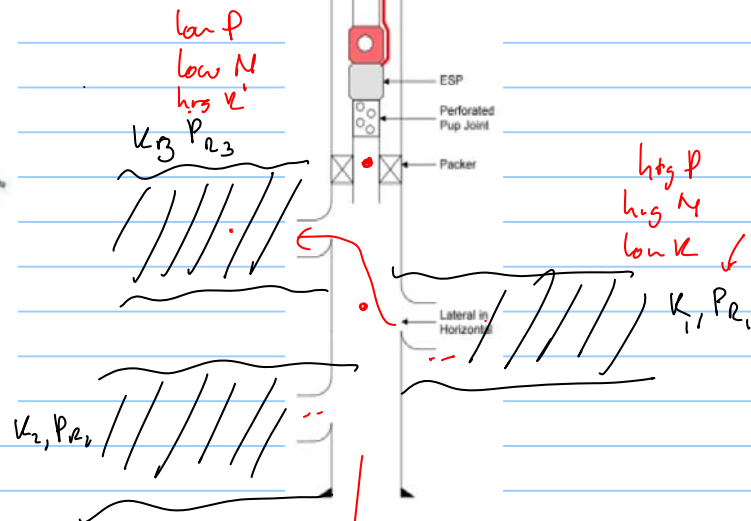
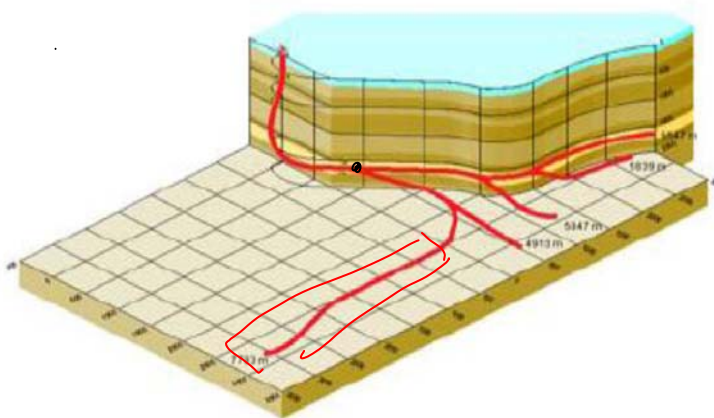
$P_{a,j}$ $P_{a,j}$



Pressure calculated counter-current and co-current is the same for a given point.

mass balance → surface rates should be conserved

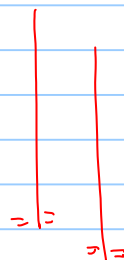
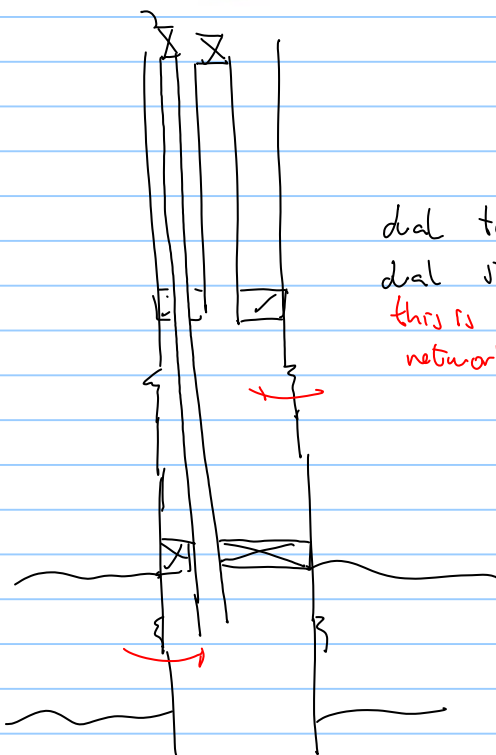
- We have downhole networks : multilateral wells



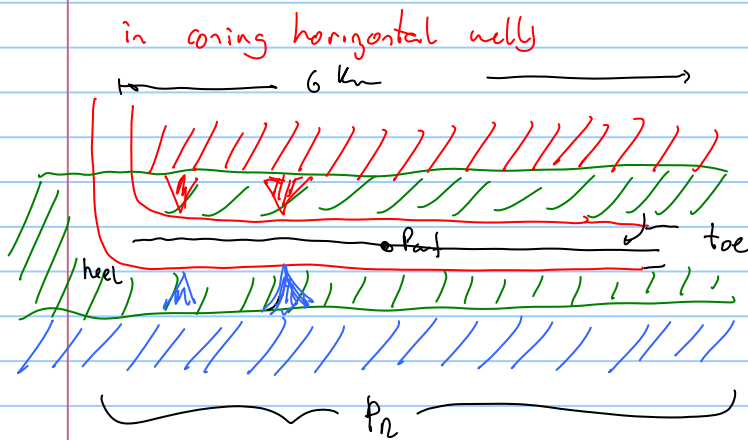
multilayer if P_{2i} are different are might have cross flow between formations

TPe formation "charge" other formations.

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

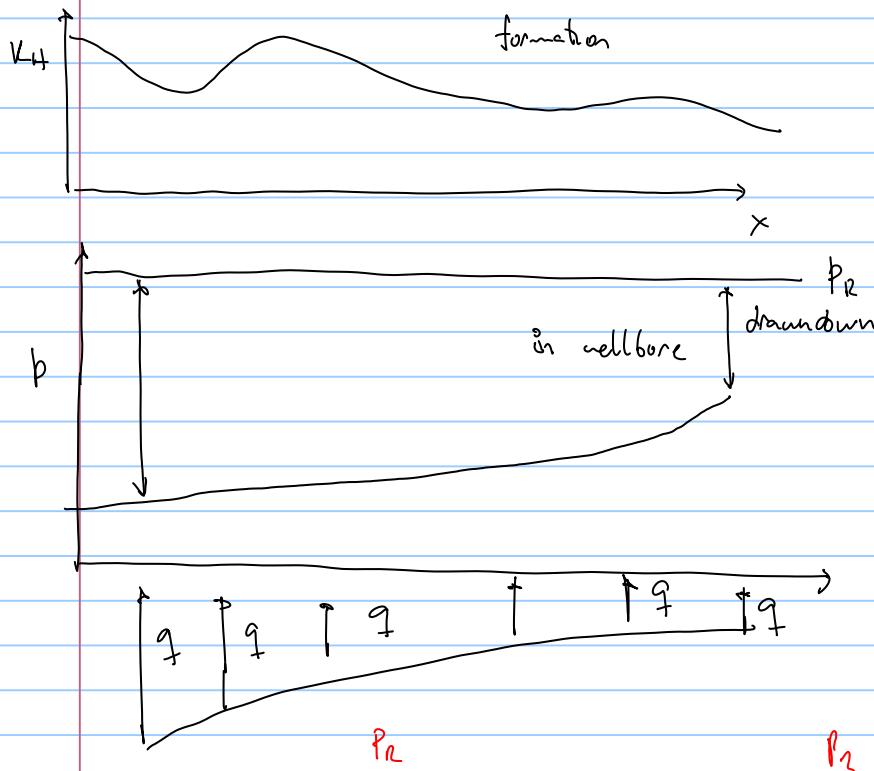


Inflow control devices (ICD) to control (passive or active) the rates coming out of a given formation, section)

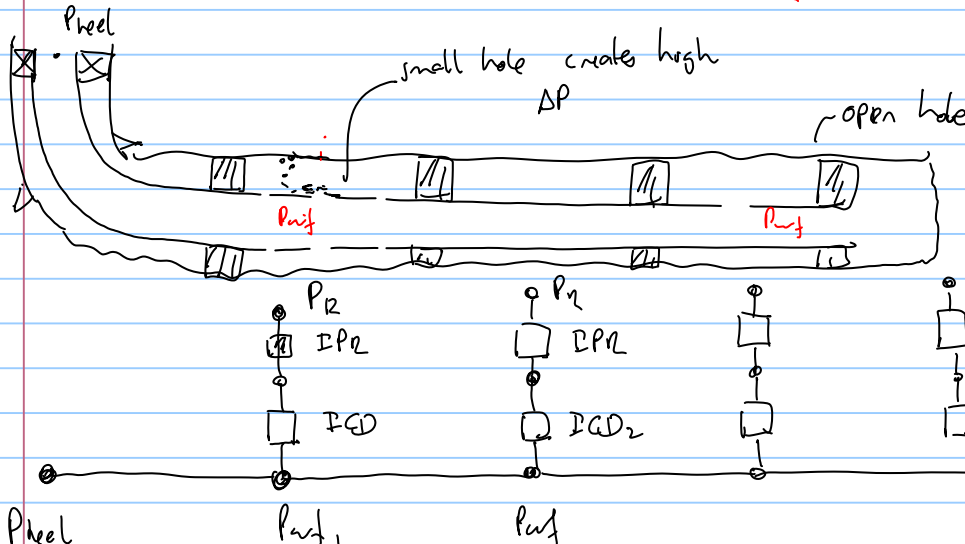


$$\frac{\Delta p}{\Delta x} \propto \frac{1}{k} \quad q = \frac{k}{\mu} \frac{\partial p}{\partial x}$$

M r



this causes an uneven distribution of inflow, of reservoir rates along the wellbore which can cause coning, uneven depletion, etc



→ slotted liner wire mesh

Completion design

Design of ICD
o determine the number of sections

• define the orifice diameter and number of orifices

Netool ~ Weatherford? commercial simulator to design completions.

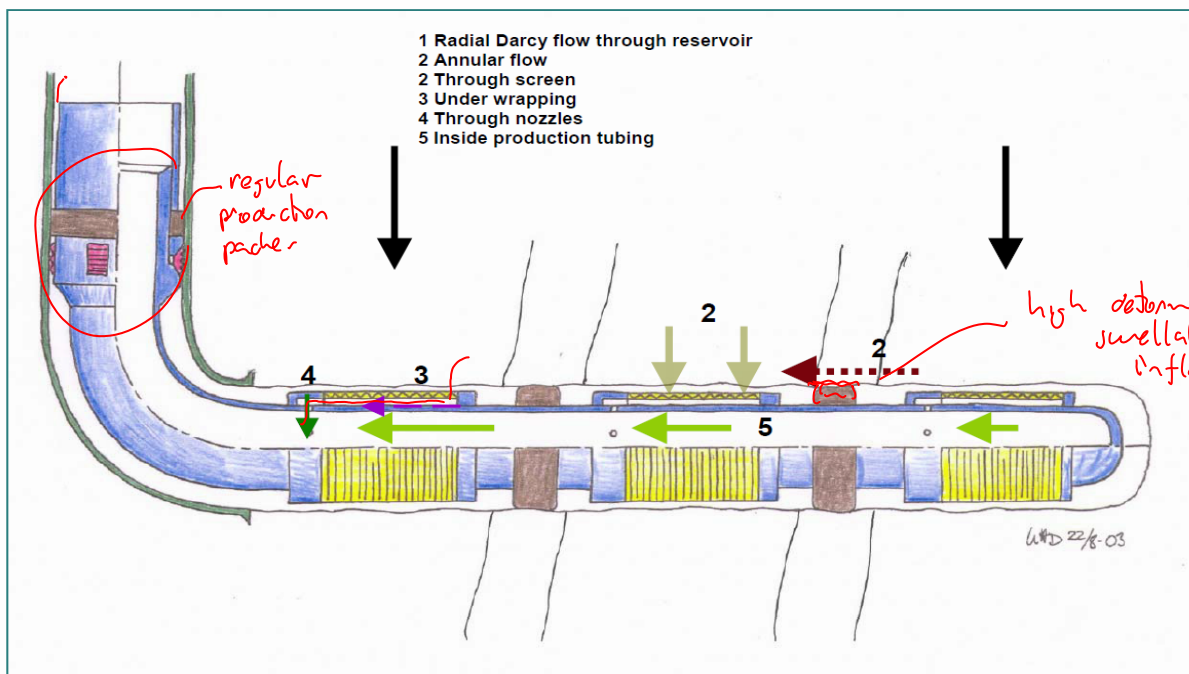
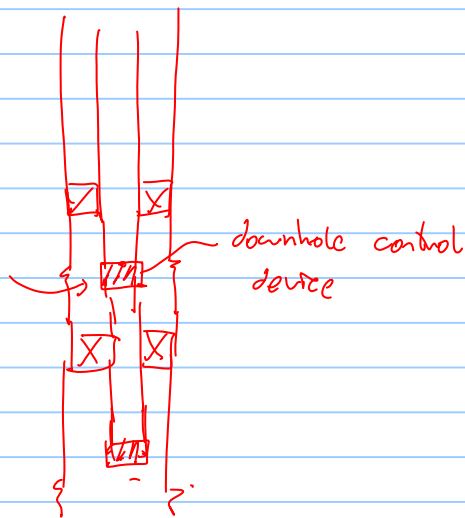


Figure-8 Functioning and interplay of an ICD completion architecture. Fluids enter the screen and flow between the axial wires and the un-perforated base pipe into the ICD housing, before passing through. Issues are properly analyzed and put in the right perspective to achieve

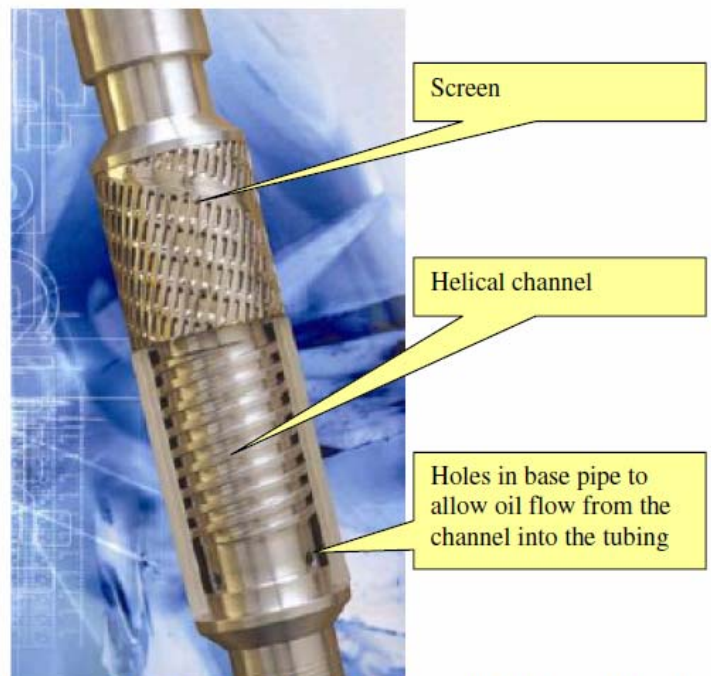
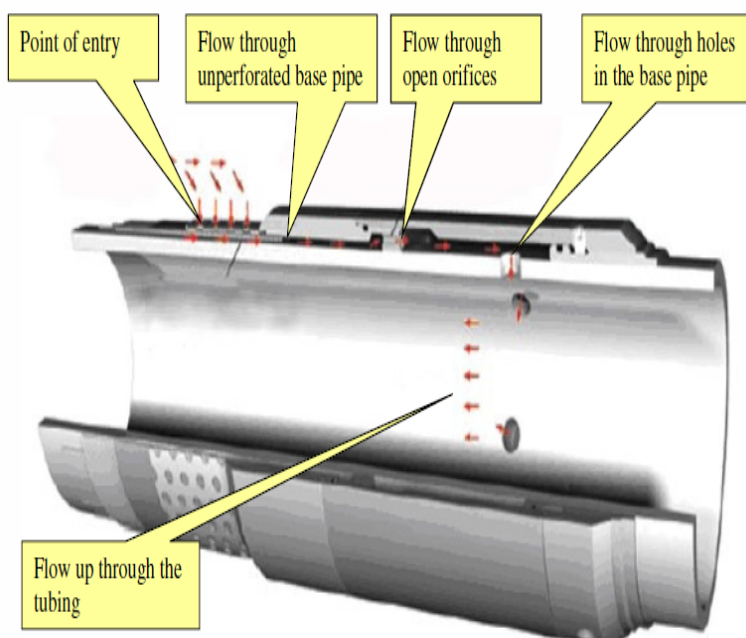
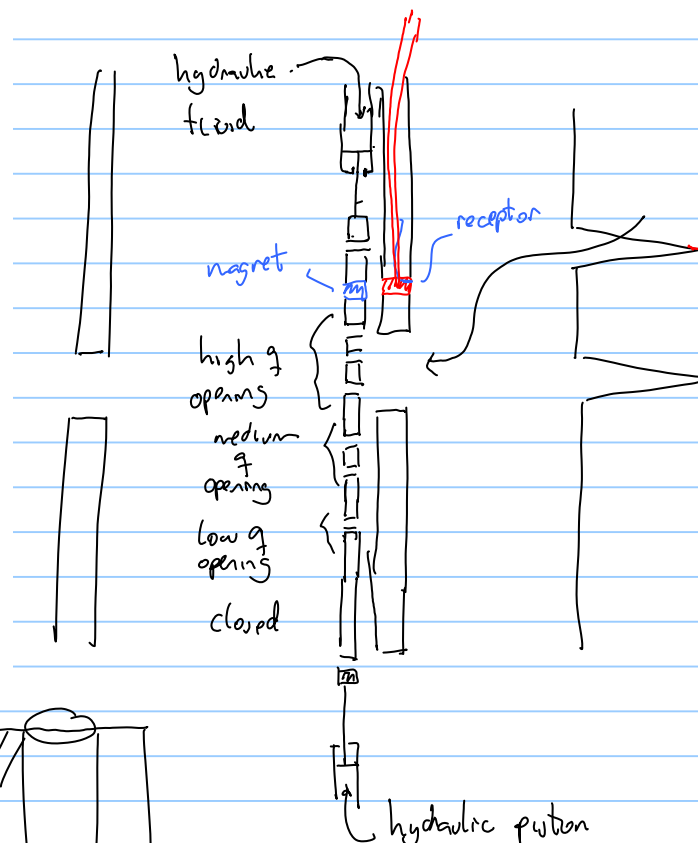
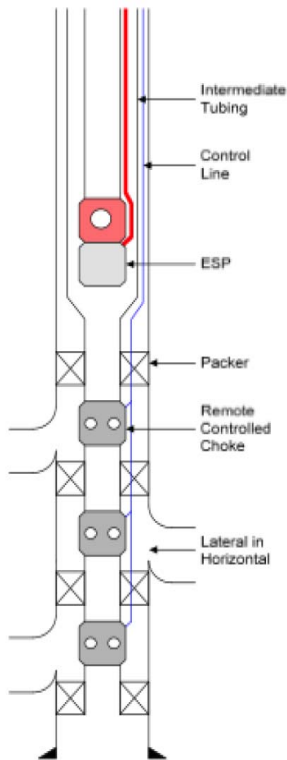
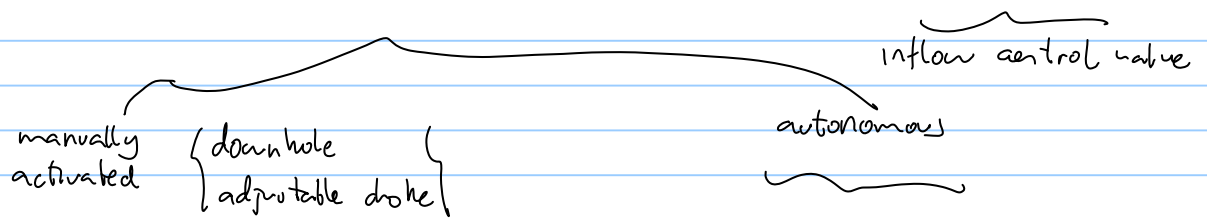


Figure 14 Helical channel type, Equalizer™, Baker Oil Tools [22]

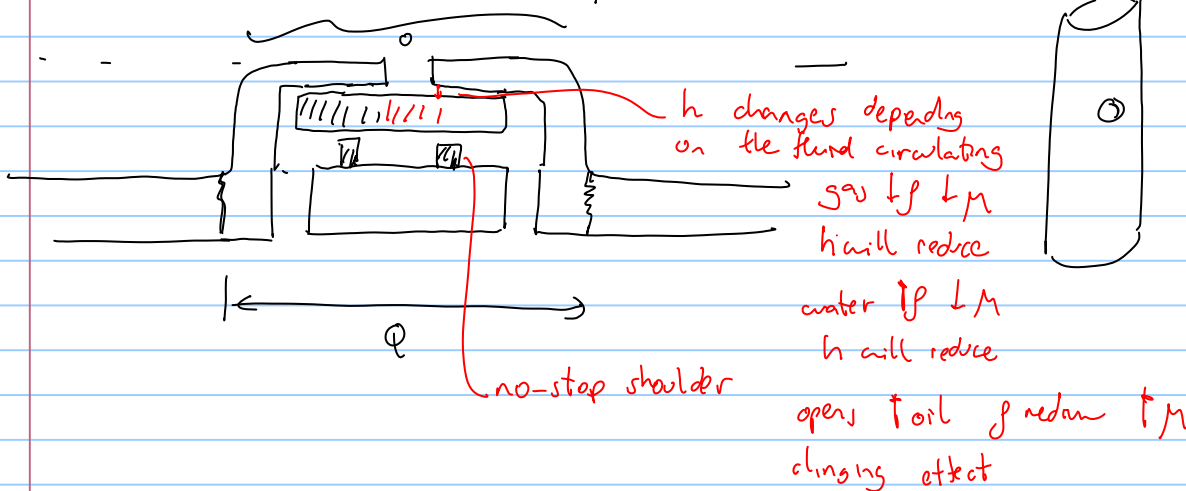
So far we have discussed passive inflow control devices

but we also have active inflow control devices (ICV)



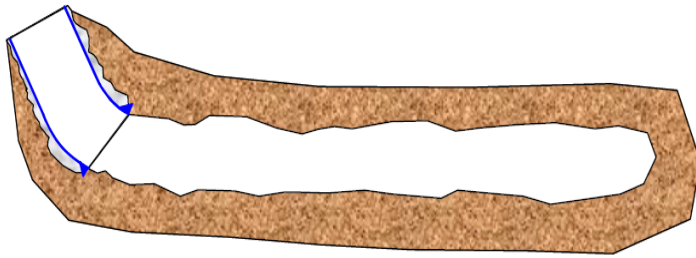
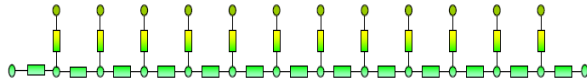
• Autonomous,

AICD, AICV

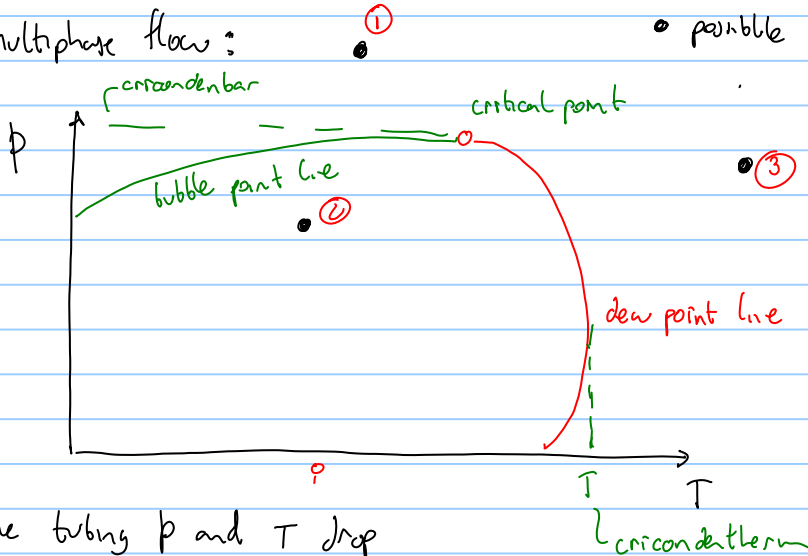


if there is a big variation of reservoir properties along the wellbore
 it is also necessary to use network solving.

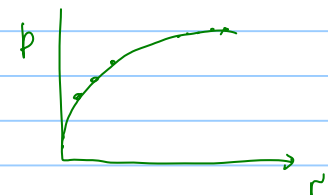
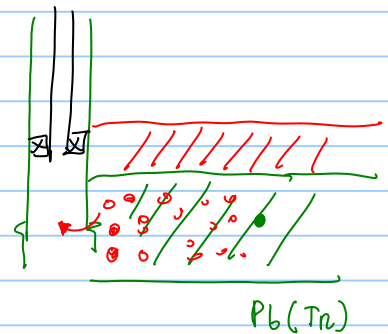
Horizontal well with Open Hole completion
 - Including damage zone



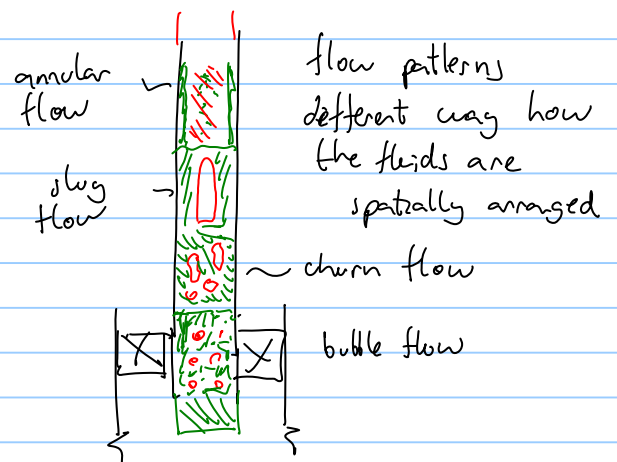
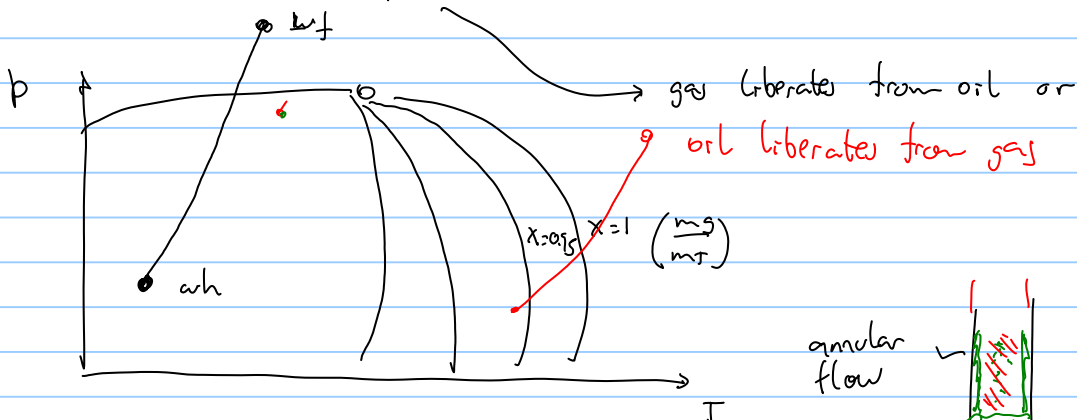
Multiphase flow:



possible entry points to wellbore

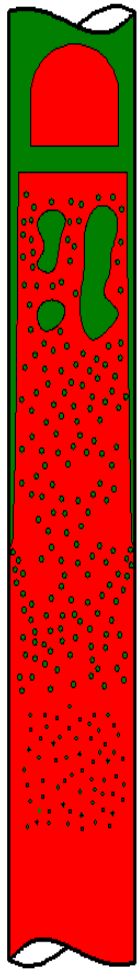


in the tubing p and T drop



course on multiphase flow,

TEP4250 Ole jørgen Nydal {



slug flow

- be able to estimate Δp , ΔT with length

churn flow

- 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

annular flow

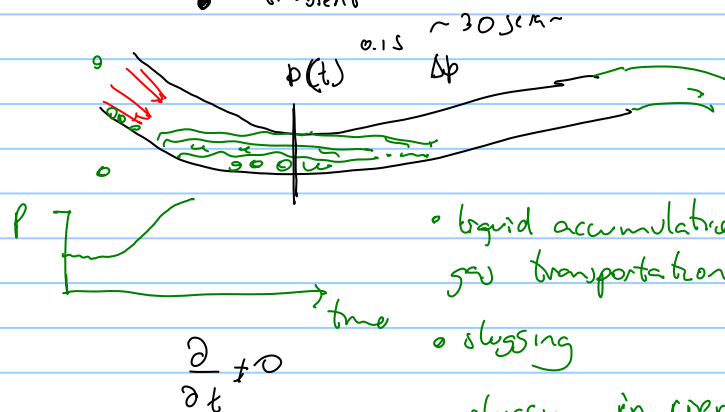
- steady state $\left\{ \frac{\partial}{\partial t} = 0 \right.$

↳ pipes, pipeflow, PEO, prosper, gap

dew mist

- transient

mist flow



• liquid accumulation in gas transportation pipelines

• slugging

• slugging in rivers

commercial tools : OLGA, HetaFlow.

transient multiphase flow simulator

- there are two approaches to analyze multiphase flow

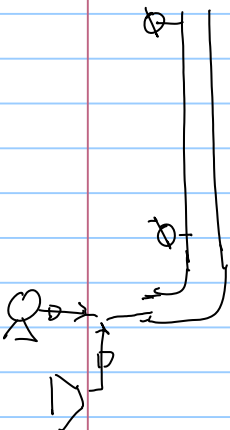
- correlation-based, Beggs and Brill, Orkiszewski, Ans and Roy, Hagedorn and Brown

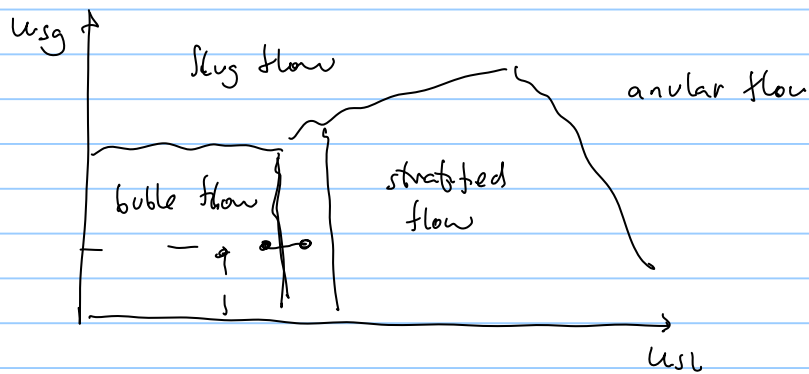
correlations develop based on experimental data, some physics and limited range of applicability

Superficial velocity $v_{sl} = \frac{q_L}{A_p} \rightarrow m^3/s$

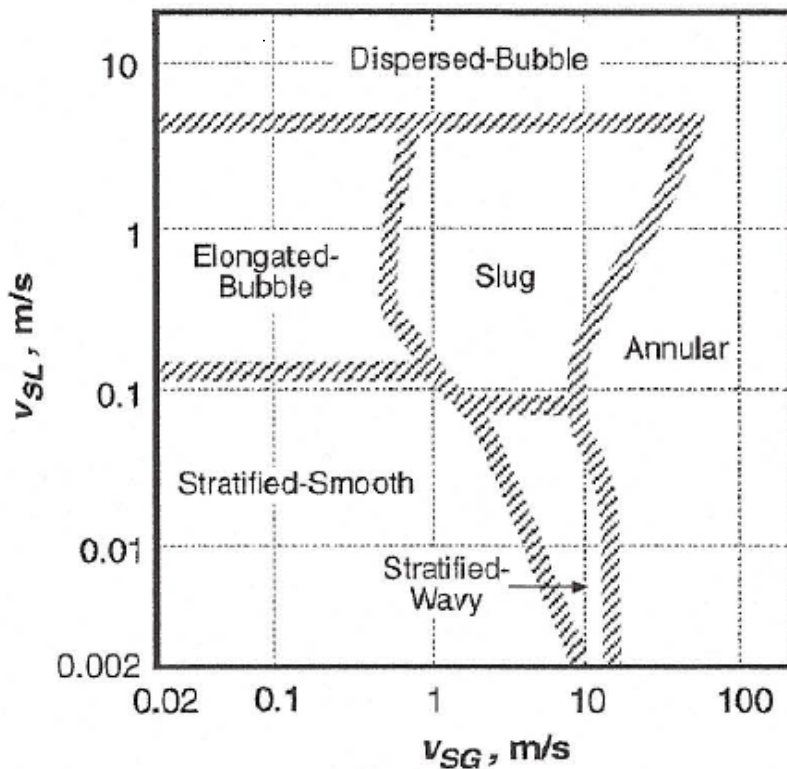
A_p ~ cross section area of pipe (πr^2)

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





this plot depends on fluid properties $\left\{ \begin{array}{l} \rho_o, \rho_g \\ \mu_o, \mu_g \\ \sigma_{og} \end{array} \right.$
inclination, pipe diameter

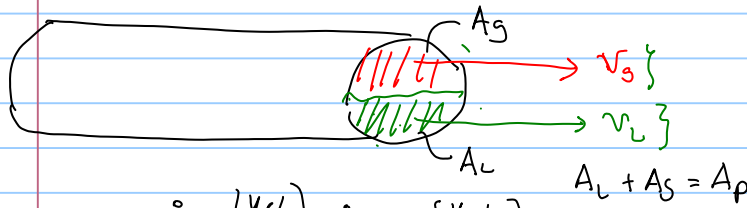
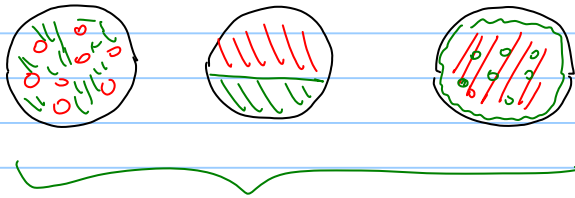


Fr and We

- mechanistic modeling $\rightarrow$ applying $\left\{ \begin{array}{l} \text{mass conservation for each phase} \\ \text{momentum conservation } \left\{ \begin{array}{l} \text{to each phase} \\ \text{to the mixture} \end{array} \right. \end{array} \right.$
 $\rightarrow$ closure laws derived empirically (by exp)

$$-\frac{dp}{dL} = \underbrace{-\frac{dp}{dL}}_{\text{friction}} \underbrace{-\frac{dp}{dL}}_{\text{gravity}} \underbrace{-\frac{dp}{dL}}_{\text{acceleration}} \quad \text{momentum equation mixture}$$

$$-\frac{dp}{dL} = \frac{2}{d} f_{TP(F)} \rho_{TP} v_{TP}^2 + \underbrace{\rho_{TP}}_{\text{density of the mixture}} g \sin \theta + \rho_{TP} v_{TP} \frac{dv_{TP}}{dL}, \quad \left. \begin{array}{l} \text{momentum eq. for the mixture} \end{array} \right\}$$



if we assume $v_g = v_L$

• homogeneous model

• no slip model

} bubble flow
must know

$$\dot{m}_g \left[\frac{kg}{s} \right] \quad \dot{m}_L \left[\frac{kg}{s} \right]$$

$$\rho_g \quad \rho_L \quad @ P, T$$

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

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

if homogeneous model

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

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

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

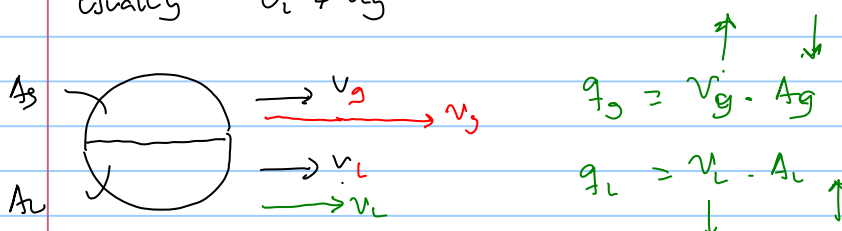
$$\frac{A_p}{A_g} = \left(\frac{q_L}{q_g} + 1 \right)$$

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

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

λ_L

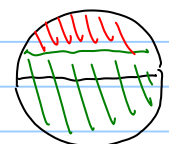
usually $v_L \neq v_g$



$$q_g = v_g \cdot A_g$$

$$q_L = v_L \cdot A_L$$

if the gas travels faster than liquid
liquid holdup $= v_L = \frac{A_L}{A_p}$ with slip



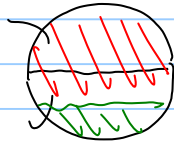
$$H_L \neq \lambda_L$$

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



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

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

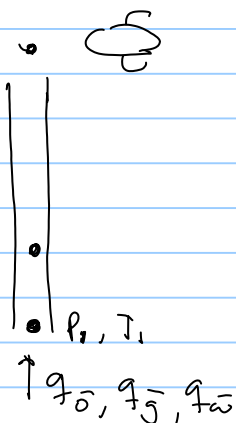


Calculating the real fluid velocities: $v_L = \frac{q_L}{A_L} = \frac{q_L}{H_L A_p} = \left(\frac{u_{SL}}{H_L} \right)$

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

• How to perform multiphase calculation in conduits

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



② Convert 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)

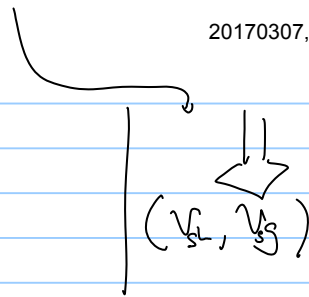
compositional model
(EoS) Peng Robinson, SRK
composition is available
 $z_i \begin{cases} C_1 & z_{C1} \\ C_2 & z_{C2} \\ C_3 & z_{C3} \end{cases}$

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

Calculate $\frac{m_g}{m_t} @ P, T$

with m_t

• calculate q_g, q_o using properties ρ_g, ρ_o



- with input V_{SL}, V_{SG}, Φ , inclination, ε , $\rho_g, \rho_L, \mu_g, \mu_L, T_{og}, T_{ow}$
roughness
 T_{gw}

multiphase experts

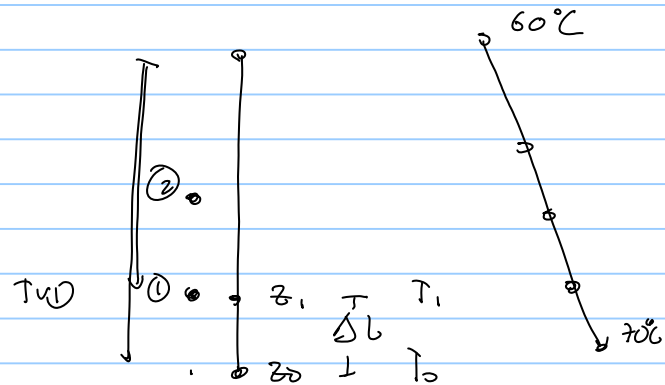
→ give me $\left[\frac{dP}{dz} \right]$

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

$$\frac{dP}{dz} \left\{ \begin{array}{l} \text{with starting point } P=P_0 \\ \text{at } z=z_0 \end{array} \right\}$$

Euler's method

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



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 $X_o = \frac{m_o}{m_T}$, ρ_s, ρ_g need a fluid model, calculator

Compositional $\left\{ \begin{array}{l} \text{HYSYS process simulator} \\ \text{DWSIM} \end{array} \right\}$

SUM	=G4*1000*G11/(24*3600)																	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
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														
18																		
19																		
20																		
21																		
22																		
23																		
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												

Object: MSTR-000

Status: Calculated (01.01.0001 00:00:00)

Linked to:

Connections:

Upstream:

Downstream:

Input Data: Compounds Phase Properties Annotations

Flash Spec: Temperature and Pressure (TP)

Temperature: 70.000000 C

Pressure: 147.000000 bar

Mass Flow: 1.000000 kg/h

Molar Flow: 0.014025 kmol/h

Volumetric Flow: 0.001998 m³/h

Specific Enthalpy: -222.862762 kJ/kg

Specific Entropy: -0.524852 kJ/[kg.K]

Phase Mole Fraction: 0.000000 ☒ Vapor ☐ Liquid ☐ Solid

Composition:

Basis: Mole Fractions

Solvent:

Compound	Amount
Nitrogen	0.004004
Carbon dioxide	0.001001
Methane	0.432432
Ethane	0.047047
Propane	0.030030
Isobutane	0.015015
N-butane	0.009009

Information

Date	Type	Message
07.03.2017 14:58:59	Tip	To view must
07.03.2017 14:58:59	Tip	Use the cursor
07.03.2017 14:58:59	Tip	Press
07.03.2017 14:58:59	Tip	Hold

Attach Utility

- Phase Envelope
- Binary Envelope (VLE/VLLE/SLE)
- Ternary Envelope (LLE)
- Petroleum Properties
- Natural Gas Hydrates
- True Critical Point

Connections:

Upstream:

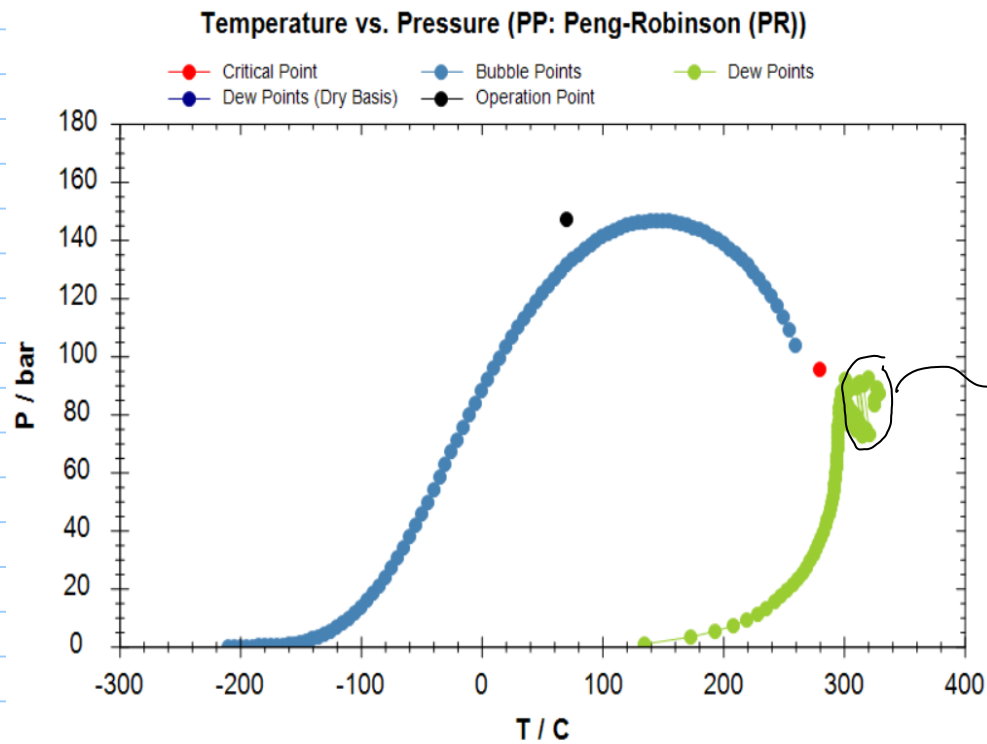
Downstream:

Input Data: Compounds Phase Properties Annotations

Mixture: Overall Liquid Liquid 1

Property	Value	Units
Volumetric Flow Rate @ ...	0.001998	m ³ /h
Mass Flow Rate	1.000000	kg/h
Molar Flow Rate	0.014025	kmol/h
Phase Molar Fraction	1.000000	
Phase Mass Fraction	1.000000	
Compressibility Factor	0.000000	
Specific Enthalpy	-222.862762	kJ/kg
Molar Enthalpy	-15.890.055242	kJ/kmol
Specific Entropy	-0.524852	kJ/[kg.K]
Molar Entropy	-37.421787	kJ/[kmol.K]
Internal Energy	-26.356.625231	kJ/kg
Molar Internal Energy	-1.879.220.321...	kJ/kmol
Gibbs Free Energy	-42.759892	kJ/kg
Molar Gibbs Free Energy	-3.048.768867	kJ/kmol
Helmholtz Free Energy	-26.176.522361	kJ/kg
Molar Helmholtz Free Energy	-1.866.379.035...	kJ/kmol
Molecular Weight	71.299732	kg/kmol
Density	500.530625	kg/m ³
Heat Capacity (Cp)	2.367538	kJ/[kg.K]
Heat Capacity Ratio (Cp/Cv)	1.170571	

100% liquid!



convergence
error of the
software

[illegible]