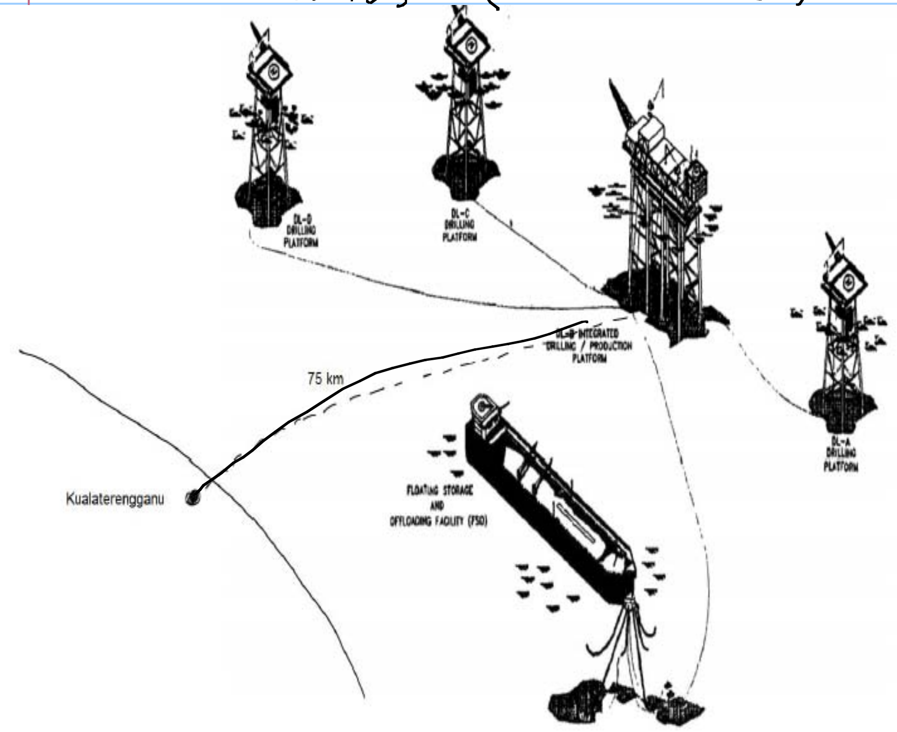
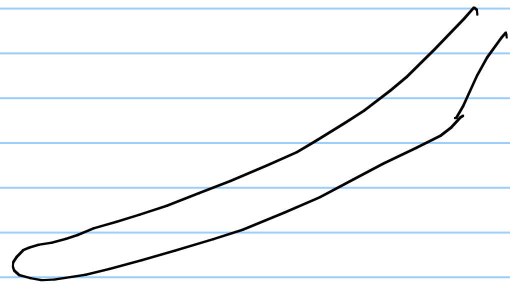
Day 7:

- exercise P and T drop in pipeline (75 km) → oil with low GOR (Sm^3/Sm^3)
- Introduction to multiphase flow in wells (tubing)

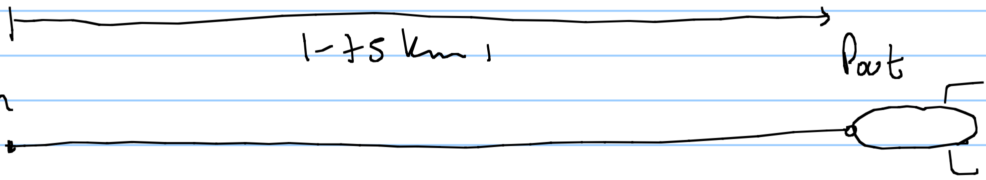
Class exercise (home exercise)



Dulang Malaysia



Kualaterengganu



1-75 km

P_{in} P_{out} P_{sep} = 50 bara

→ 100 000 stb/d

16" ID

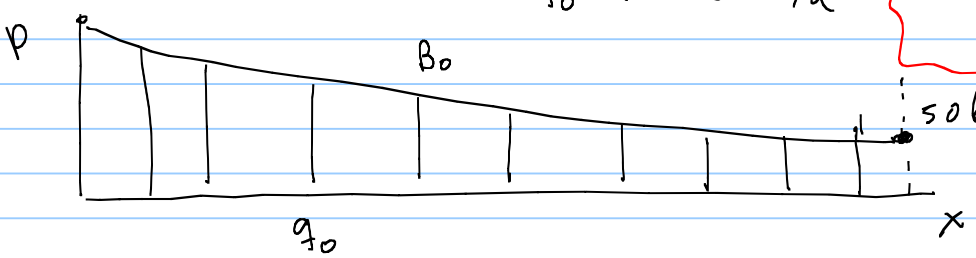
GOR = 0.5 Sm^3/Sm^3

60°C

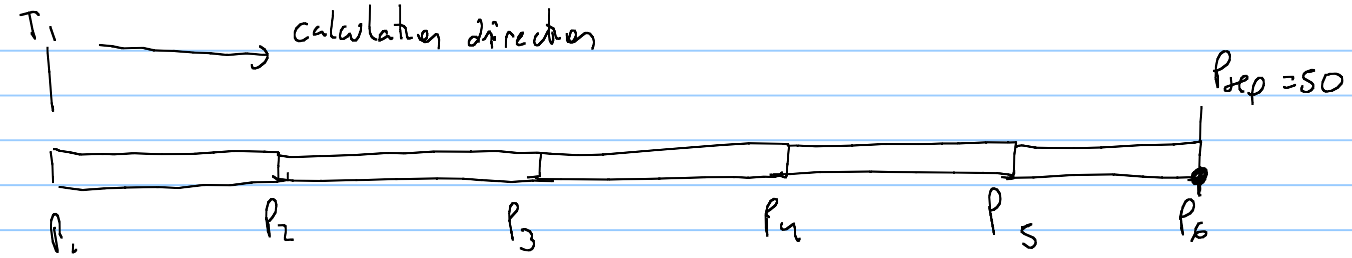
Δx = 10000 m

home exercise
Δx = 1000 m

q_o = 100000 stb/d



B_o, ρ_o, μ_o.



p calculation direction

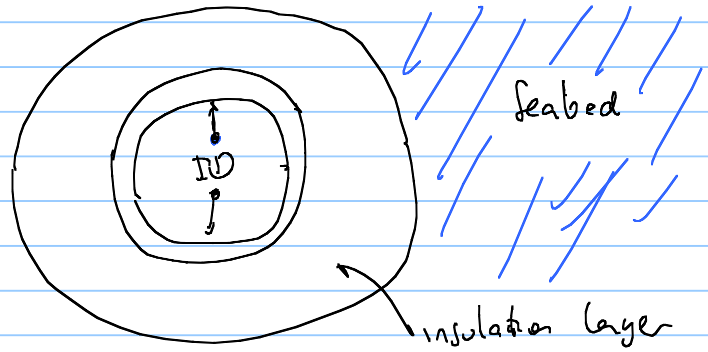
$$P_5 = P_{sep} + \left.\frac{\partial p}{\partial x}\right| \cdot \Delta x$$

$f(\mu_{o6}, \rho_{o6}, B_{o6})$

$f(T)$ $f(B_o)$

$f(p, T)$

Cross section of pipe



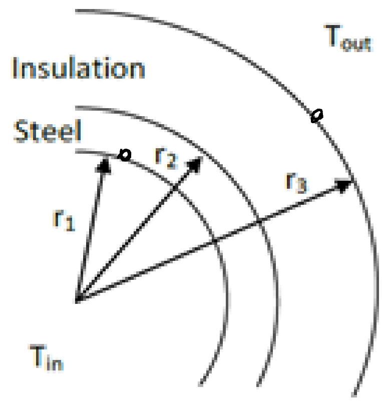
T = 14°C

@ T = 20°C $\mu_o \approx 2000$ cp

too high!

The overall heat transfer coefficient based on the pipe outer area is defined as:

$$\frac{1}{U} = \left(\frac{r_{pipe\_inner}}{h_{out} \cdot r_{insulation\_outer}} + \frac{\ln\left(\frac{r_{insulation\_outer}}{r_{pipe\_outer}}\right) \cdot r_{pipe\_inner}}{k_{insulation}} + \frac{\ln\left(\frac{r_{pipe\_outer}}{r_{pipe\_inner}}\right) \cdot r_{pipe\_inner}}{k_{pipe}} + \frac{1}{h_{inner}} \right)$$



$$T_{fluid} - T_1 = \dot{q}$$

$$(T_1 - T_2) = \dot{q}$$

$$(T_2 - T_3) = q$$

$$(T_3 - T_{out}) = q$$

$$\dot{q} = 2\pi r_3 \cdot L \, U \left(T_{fluid} - T_{amb} \right)$$

Short derivation of Temperature equation for liquid flow in pipe

$$\frac{d\dot{q}}{dl} = \left[\frac{dh}{dl} + \left(\frac{v\,dv}{dl}\right)^{\to 0} + \frac{dz}{dl}^{\to 0}\cdot g\right]\dot{m}$$

$$\frac{d\dot{q}}{dl} = \frac{dh}{dl}\,\dot{m}$$

for liquid $dh = C\,dT$

$T_{fluid} = T$

$$d\dot{q} = dl \cdot 2\pi r_3 \cdot U \cdot (T - T_{amb})$$

$$(T_{amb} - T)\,2\pi r_3 U = \frac{dT}{dl}\cdot C\dot{m}$$

$$A = \frac{C\dot{m}}{2\pi r_3 U}$$

$$T_{amb} - T = \frac{dT}{dl}\,\frac{C\cdot\dot{m}}{2\pi r_3 U}$$

$$\frac{dT}{dl} + \frac{T}{A} - \frac{T_{amb}}{A} = 0 \qquad \text{multiply by } e^{+l/A}$$

$$\frac{dT}{dl}e^{l/A} + T e^{l/A}\frac{1}{A} = T_{amb}\frac{1}{A}e^{l/A}$$

$$\frac{d}{dl}\left(e^{l/A}\cdot T\right) = \frac{T_{amb}}{A}e^{l.A}$$

$$\int_0^l d\left(e^{l/A}\cdot T\right) = \int_0^l \frac{T_{amb}}{A}e^{l/A}\,dx$$

$$e^{l/A}\,T(l) - T(l=0) = \left(e^{l/A}T_{amb} - T_{amb}\right)$$

$$\boxed{T(l) = \left(T(l=0) - T_{amb}\right)e^{-l/A} + T_{amb}}$$

```
Function unburied_pipeline_TiL(Te, Ti0, L, A)
unburied_pipeline_TiL = Te + (Ti0 - Te) * Exp(-L / A)
End Function
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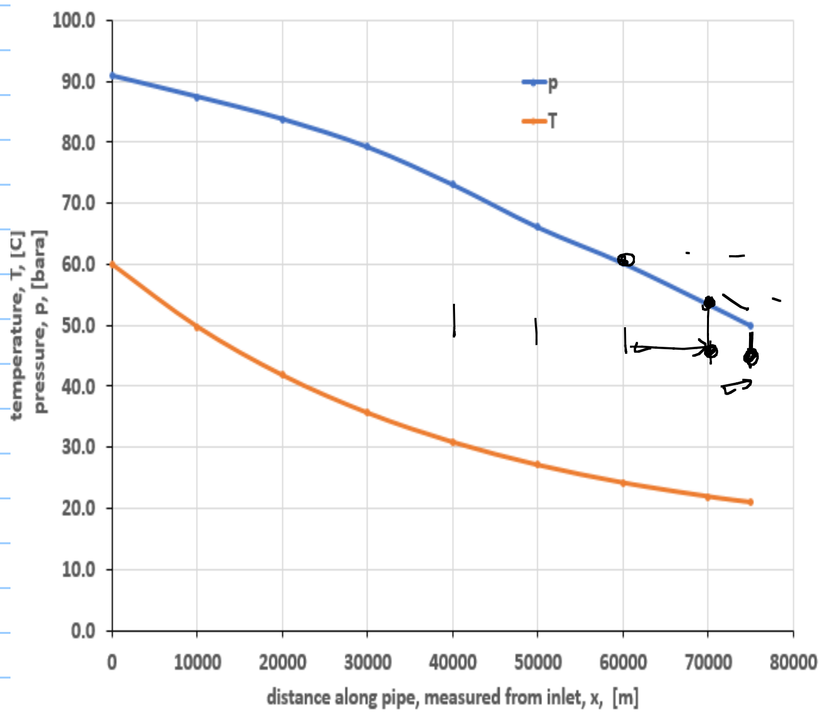
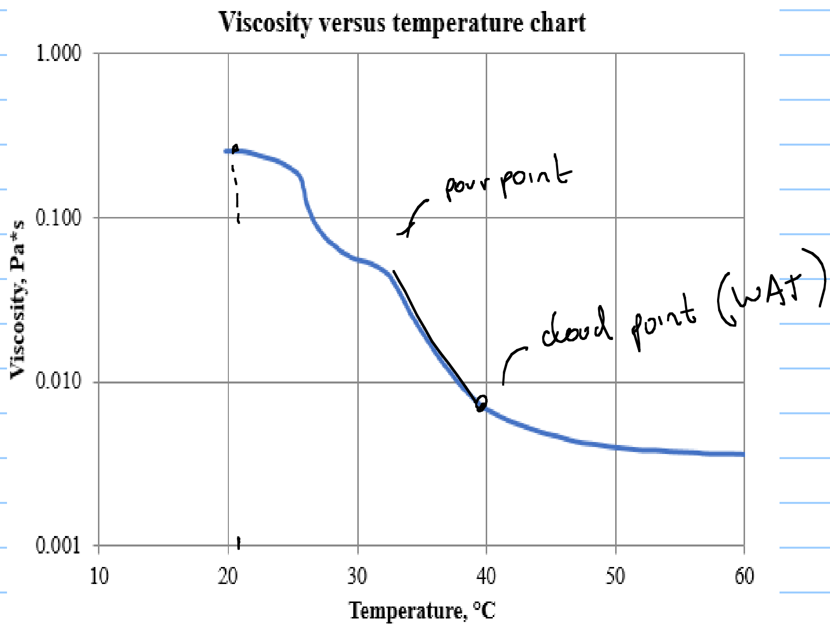
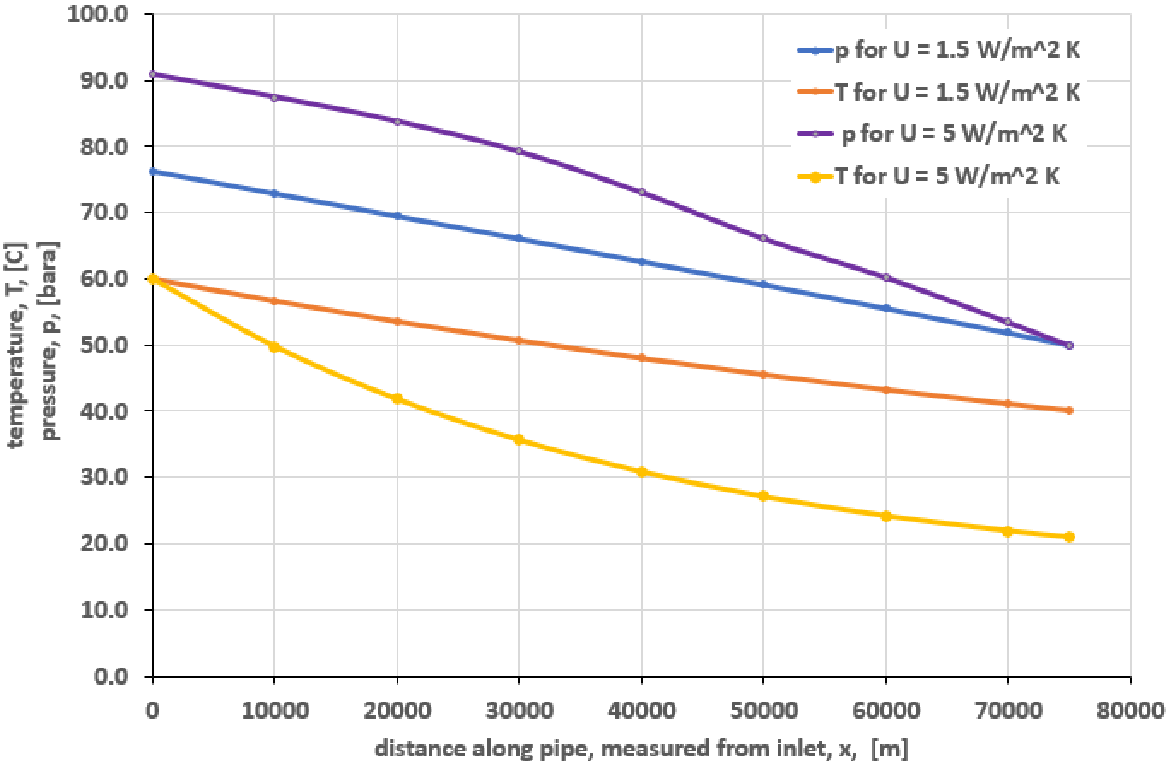
$$B_o = \frac{V_o}{V_{\bar{o}}} \qquad q_o = B_o \cdot q_{\bar{o}}$$

Distance from pipe inlet	T	Bo	deno	visco	qo	p
[m]	[C]	[m^3/Sm^3]	[kg/m^3]	[Pa s]	[m^3/d]	[bara]
0	60.0	1.028	730.2	0.004	16338.4	90.9
10000	49.8	1.021	734.9	0.004	16235.9	87.5
20000	41.8	1.016	738.4	0.006	16158.4	83.8
30000	35.6	1.013	741.1	0.017	16099.6	79.2
40000	30.8	1.010	743.1	0.053	16054.9	73.1
50000	27.1	1.008	744.7	0.083	16020.7	66.1
60000	24.2	1.006	745.9	0.212	15994.6	60.2
70000	21.9	1.005	746.9	0.244	15974.4	53.5
75000	21.0	1.004	747.3	0.252	15966.2	50





Comparing pipelines with different heat transfer coefficients (insulation)



saving in pump power by insulating better the pipe !

$$P = q\,\Delta p = (15\cdot 10^5\,Pa)\cdot \frac{15966.2\ m^3/s}{3600\cdot 24}$$

$$P_{hyd} = 0.28\ MW$$

$$P_{actual} = \frac{P_{hydra}}{\eta} = \frac{0.28}{0.7} =$$

$$P_{actual} = 0.4\ MW$$

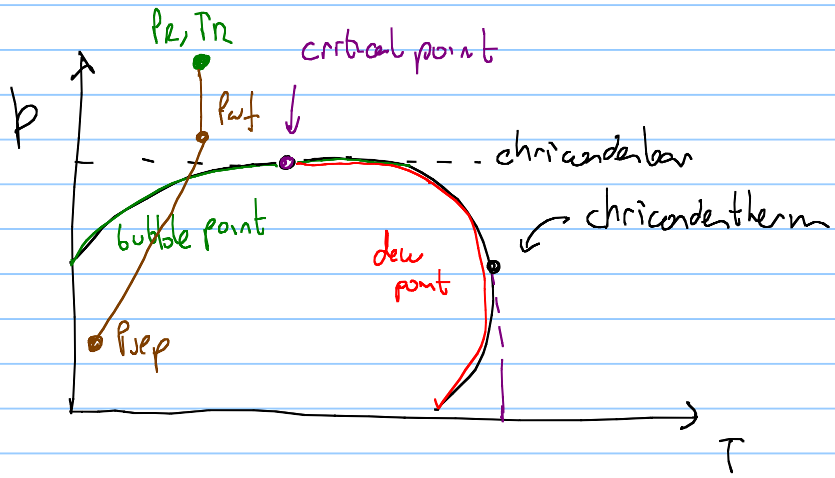
- Non-newtonian fluids
  - Some oil + water emulsions
  - drilling muds

Not covered in this course!!

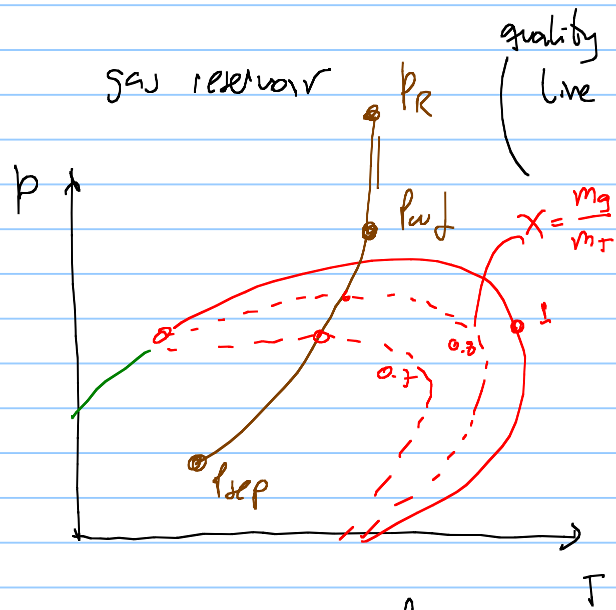
Multiphase flow in wellbores:

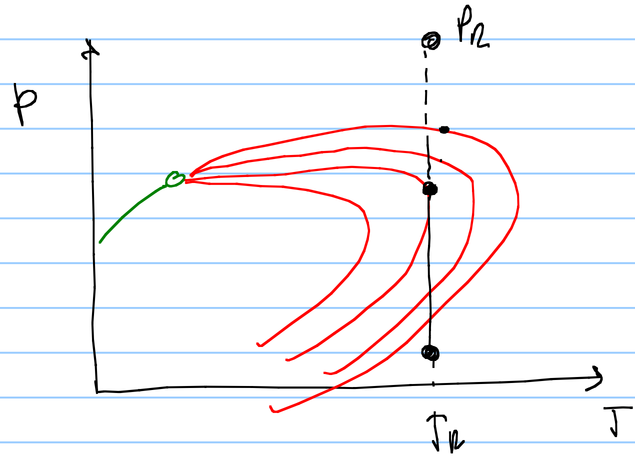
Phase diagram of reservoir fluids

oil reservoir composition z_i



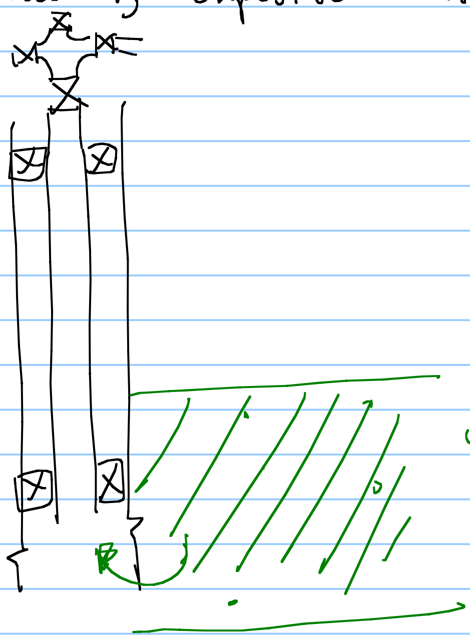
gas reservoir





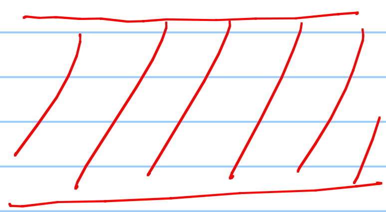
retrograde condensation

well flowing composition with time



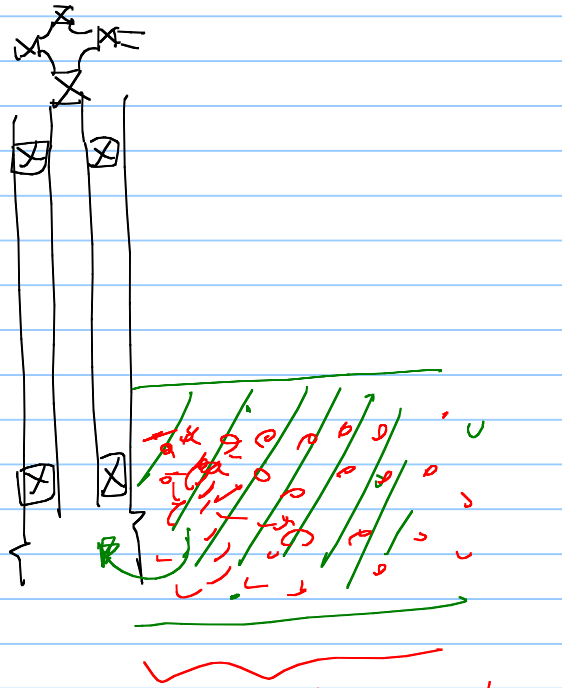
undersaturated oil $z_i = f(t)$?

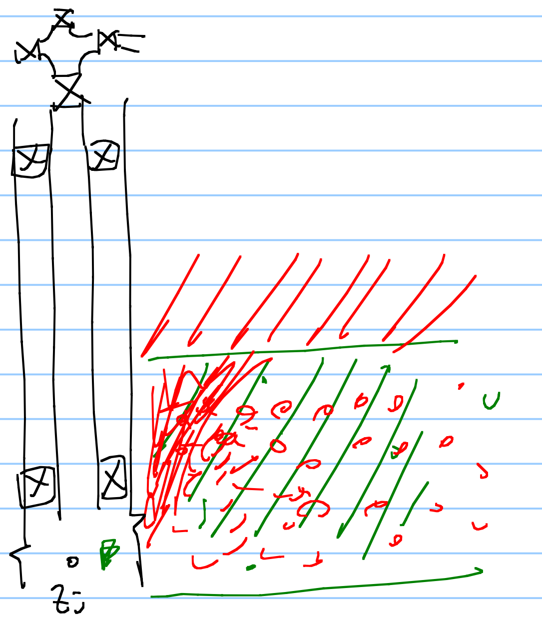
$P_{wf} > P_b(T_R)$



undersaturated gas z_i is constant

$P_{wf} > P_d(T_R)$



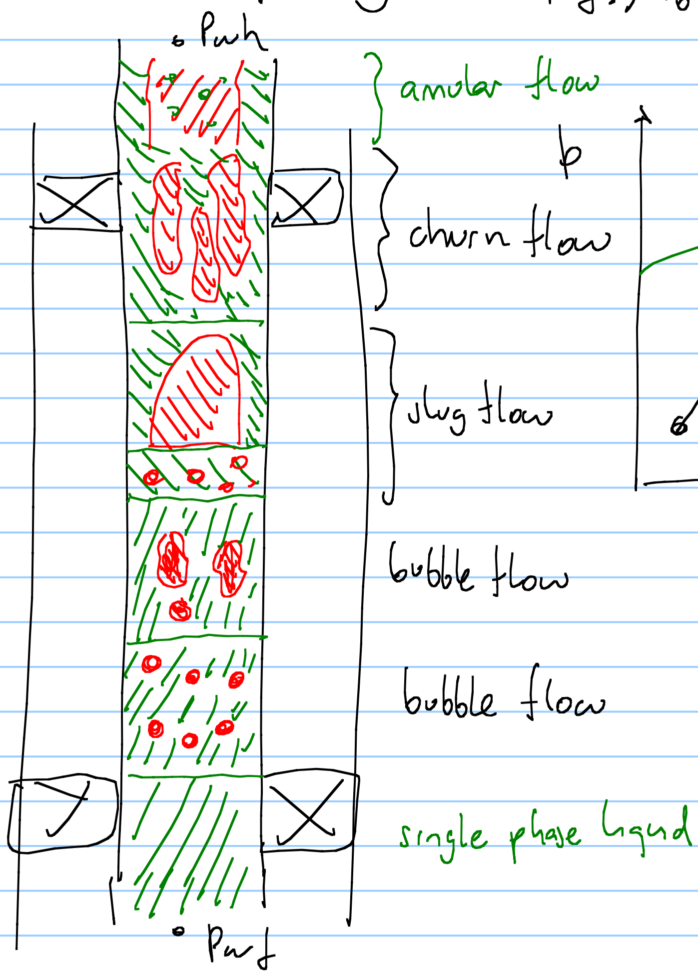


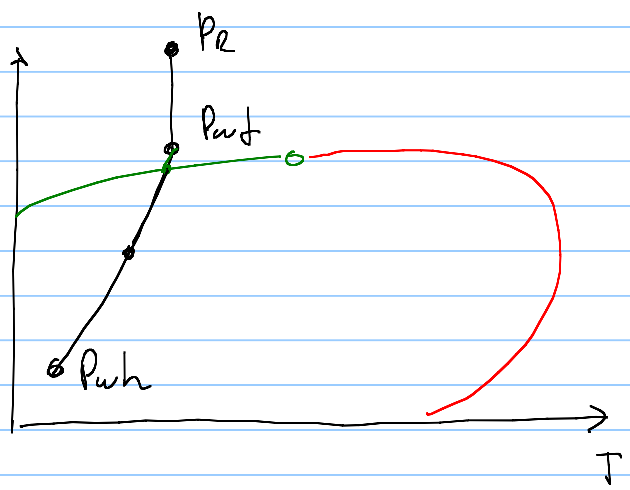
gas coning $z_i = f(t)$

$S_g \uparrow$ with time

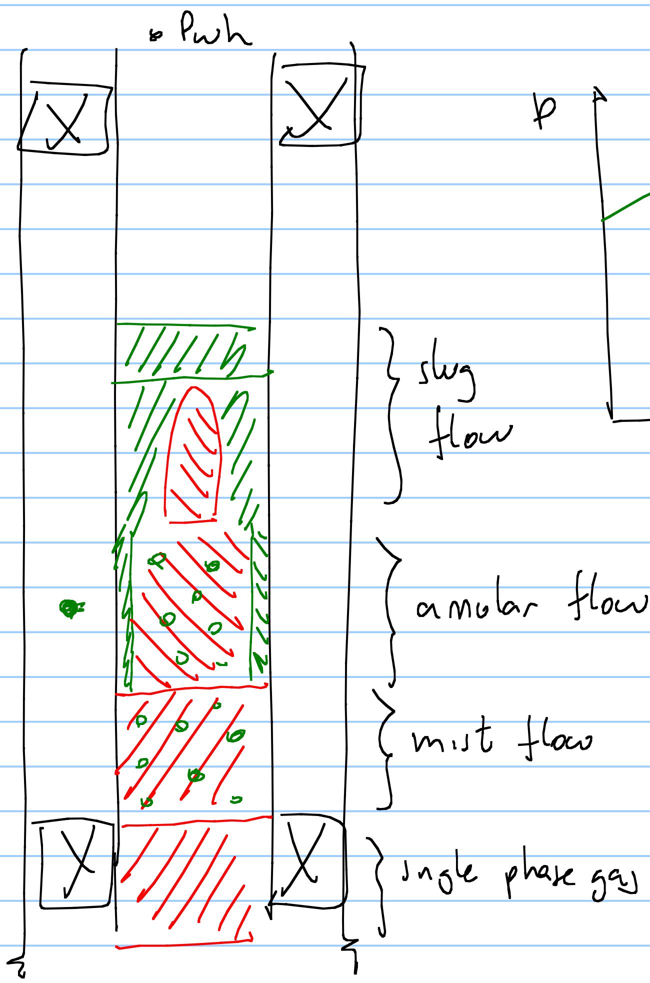
GOR also increases, z_i is $f(t)$

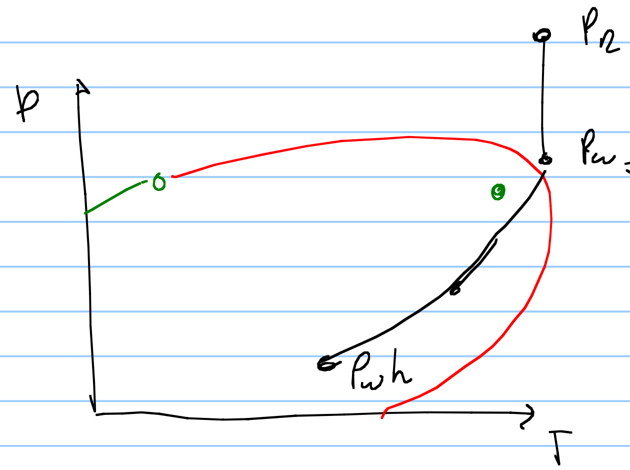
for wellbore producing with $P_{wf} \geq P_b(T_R)$





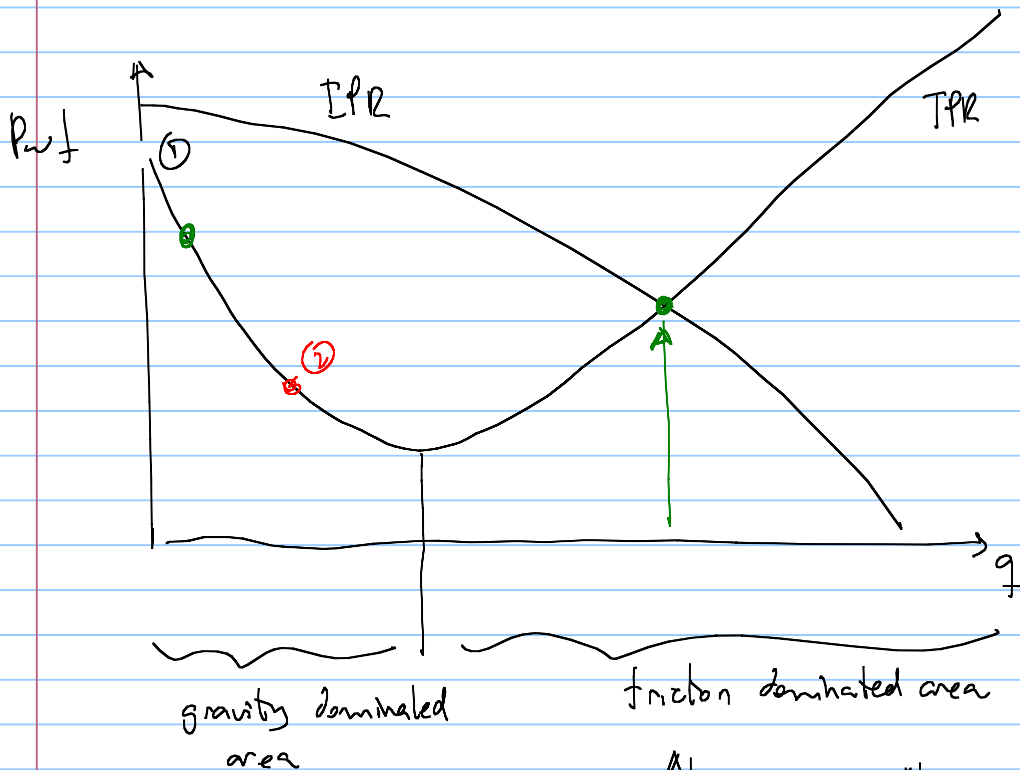
for gas well

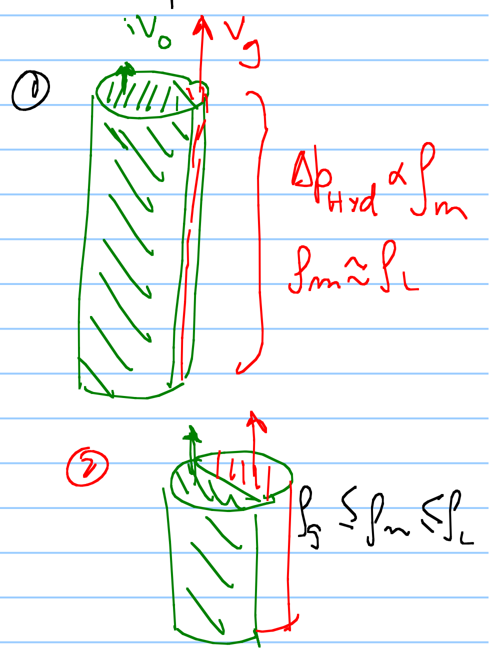




flow pattern ~> flow regime

TPR for multiphase



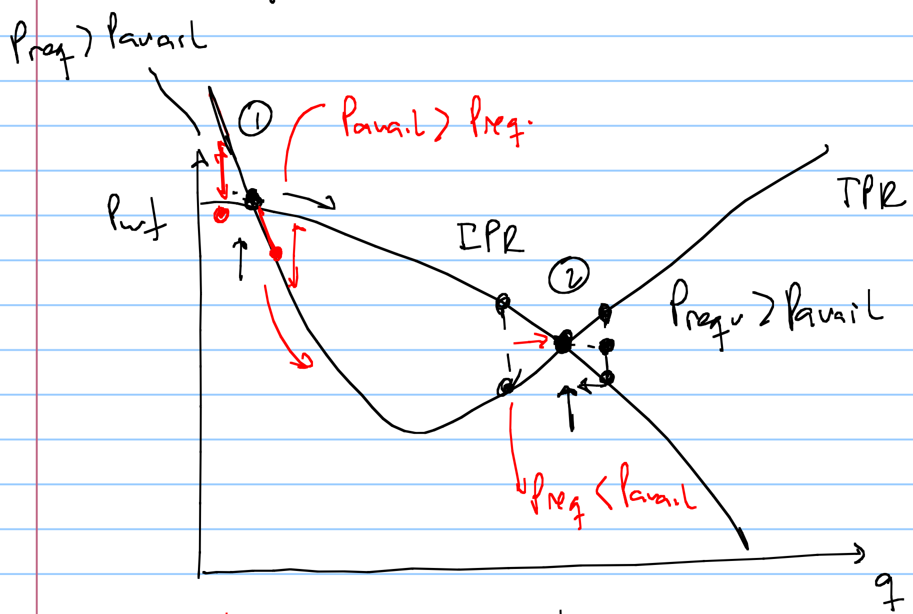


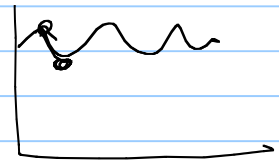
$\Delta p_{friction} \gg \Delta p_{Hydrostatic}$

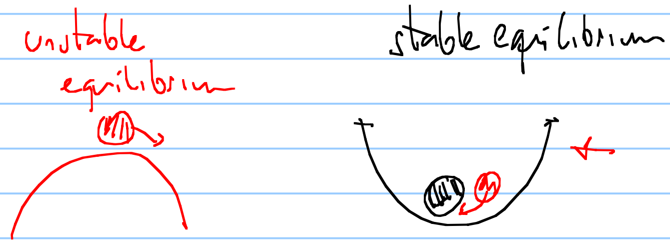
$\Delta p_{Hydros} > \Delta p_{friction}$

$$\Delta p_{TOTAL} = \Delta p_{acc} + \Delta p_{Hydrostatic} + \Delta p_{friction} \quad (9)$$

It is possible to have 2 intersections between TPR-IPR in two phase

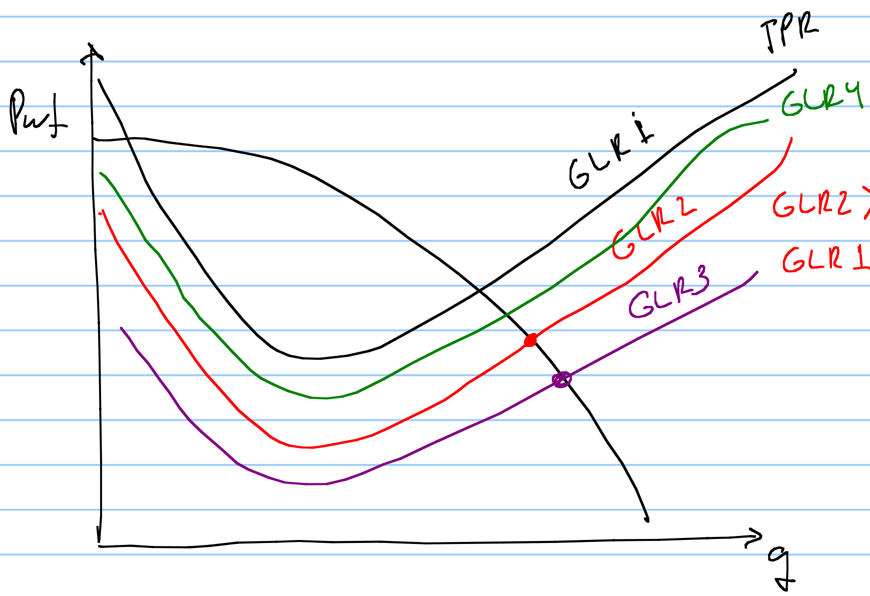






to move from unstable equilibrium to stable equilibrium we need sometimes flow induction methods.

Gilbert 1954 { IPR, TPR, Choke



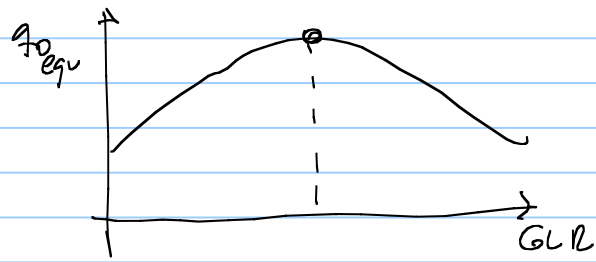
GLR -- gas liquid ratio

↑ GLR $\rho_{mixture}$ ↓

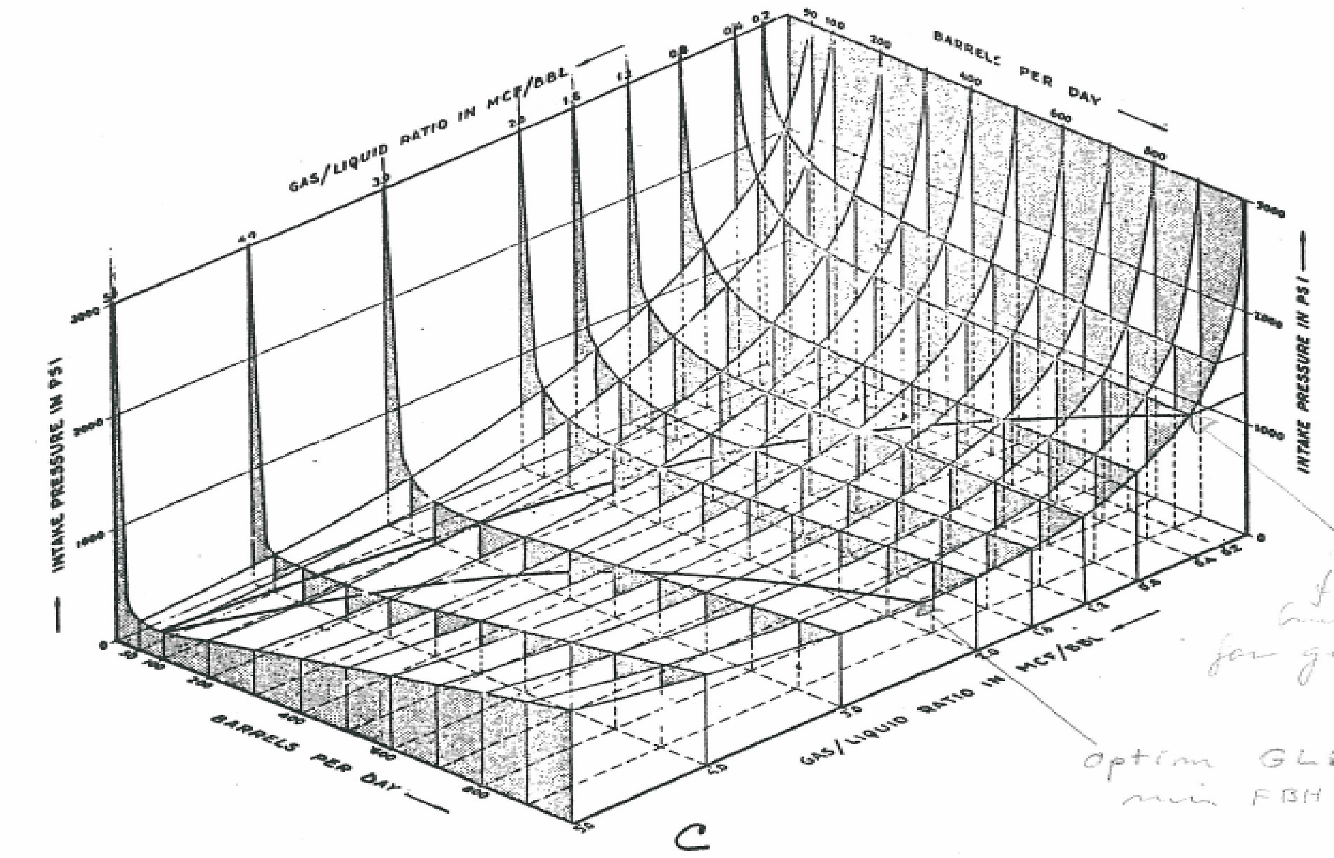
GLR4 > GLR3 > GLR2 > GLR1

$\Delta p_{hydrostatic} < \Delta p_{friction}$

change of trend in the equilibrium rate



Gilbet 1954



THE TWO-PHASE VERTICAL-LIFT FUNCTION FOR 2.875 -INCH TUBING SET AT 8000 FEET (TUBING PRESSURE = ZERO PSI GAUGE)

FIGURE 6