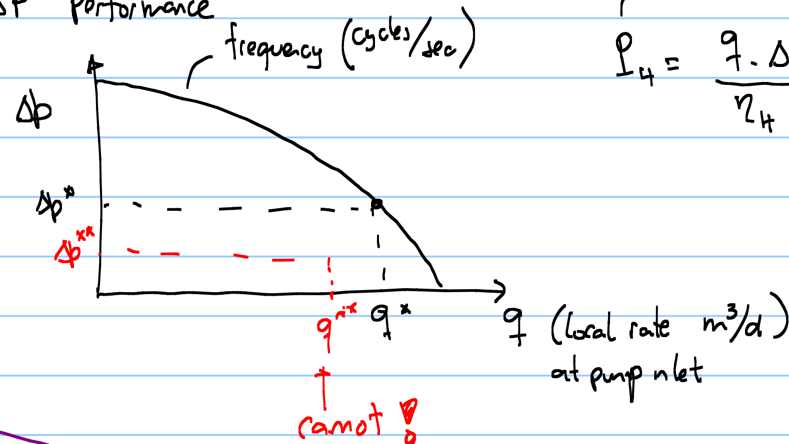
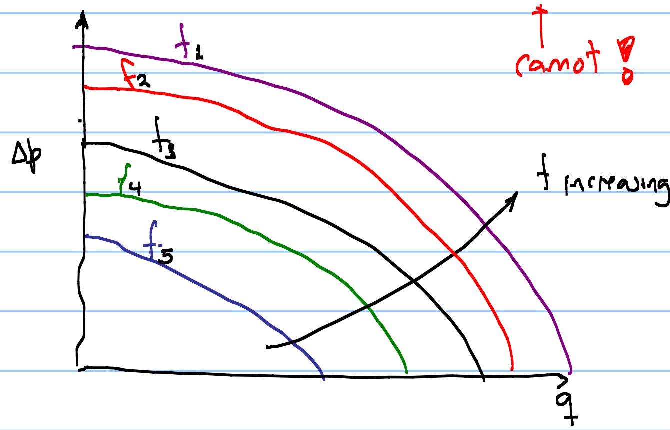
Day 7

electric submersible pump
ESP Performance

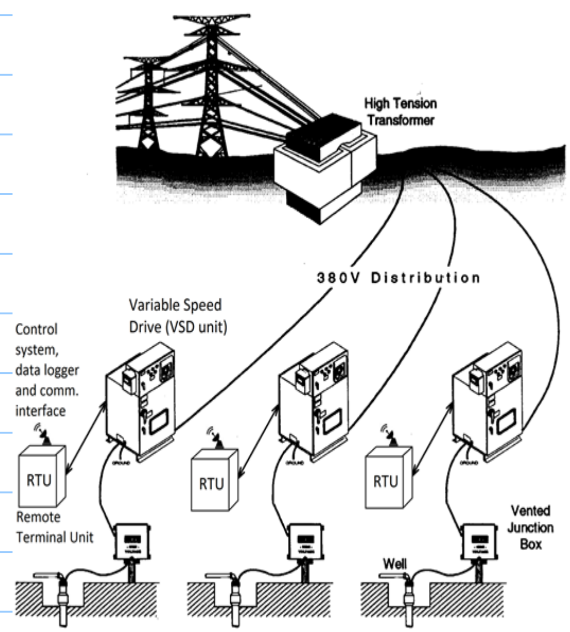
motor power (fixed)

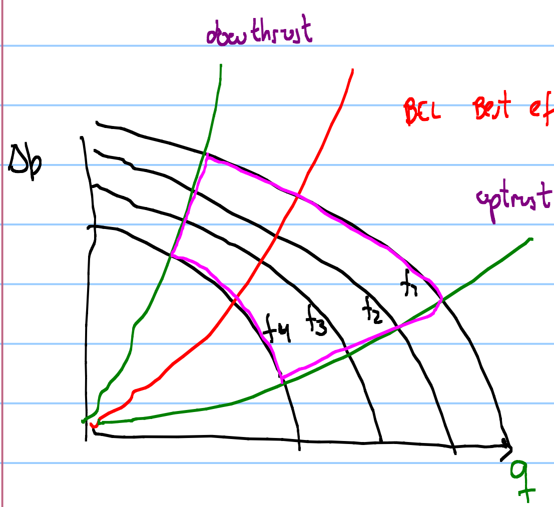
$$P_H = \frac{q \cdot \Delta p}{\eta_H}$$





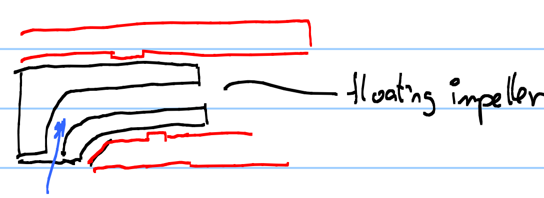
$30\ hz \leq f \leq 70\ hz$



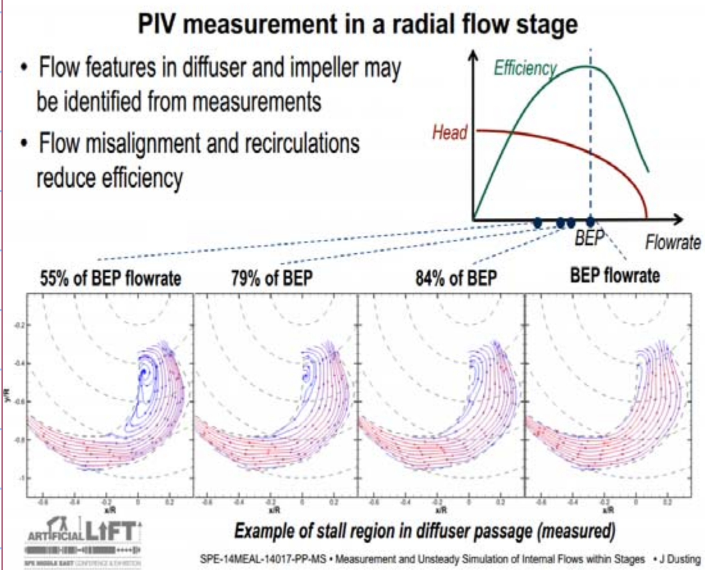


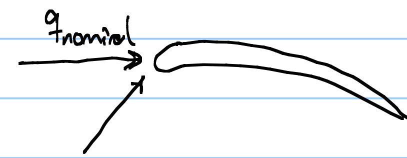
BEL Best efficiency line η_H is maximum!

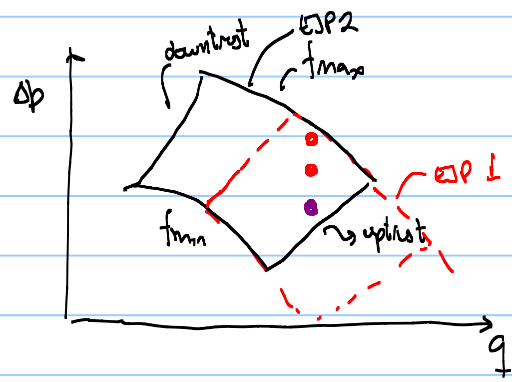
$$P_H = \frac{q \cdot \Delta p}{\eta_H}$$

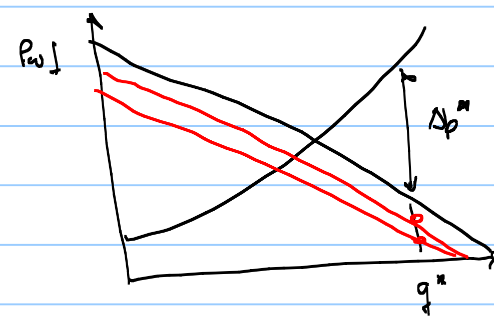


the uptrust and downtrust limits are to avoid excessive impeller wear (and damage) AND to maintain high efficiency!

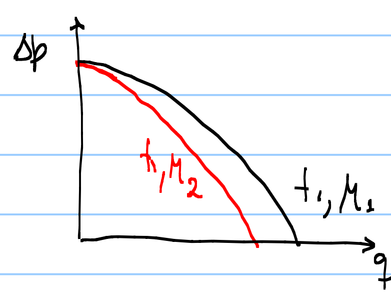


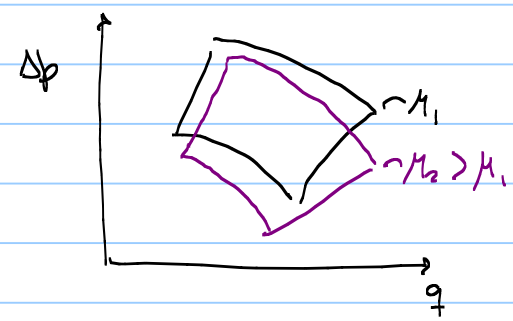


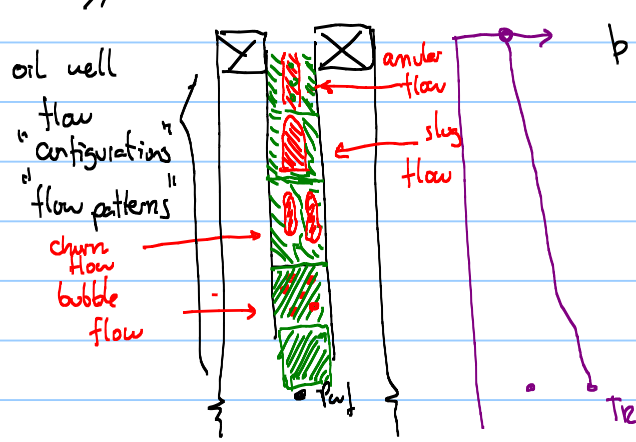


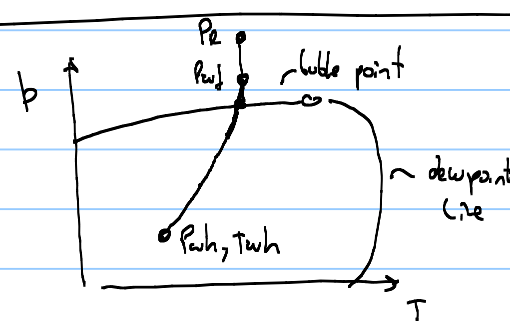


Pump performance is affected by viscosity!

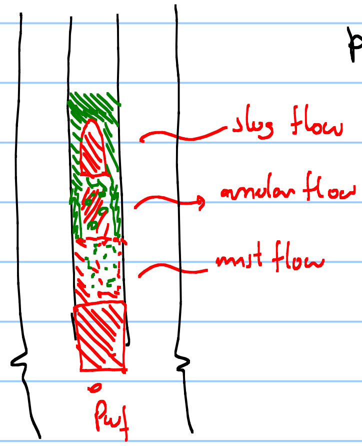


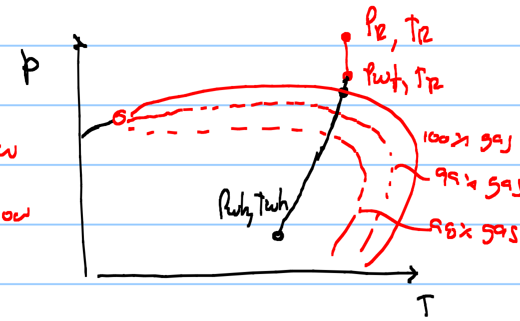






gas wells



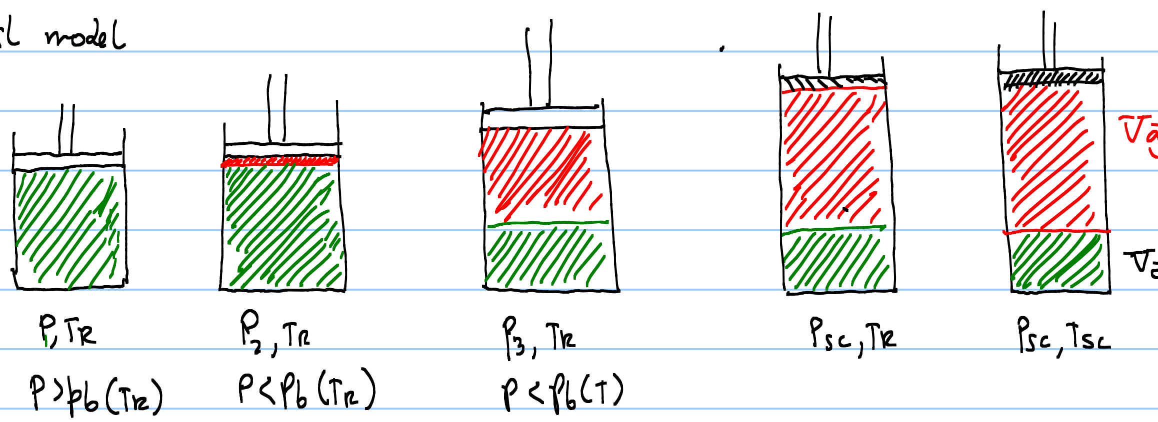


find amount of oil and gas at any position in tubing ($q_o, q_g (P,T)$)

for single phase oil $q_o(P,T) = B_o \cdot q_{\bar{o}}$

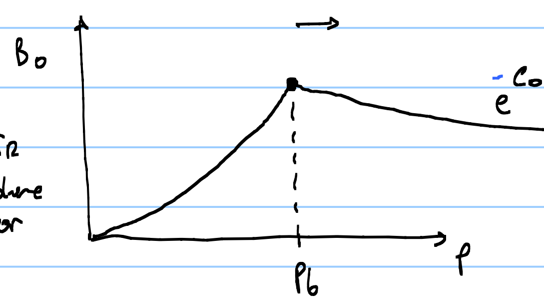
for single phase gas $q_g(P,T) = B_g \cdot q_{\bar{g}}$

Black oil model



$$B_o = \frac{V_o(P,T)}{V_{\bar{o}}}$$

oil volume factor, if $P = P_R$ $T = T_R$ oil formation volume factor



$$C_o = -\frac{1}{V_o}\frac{\partial V_o}{\partial P}$$ compressibility

$$V_o = V_{\bar{o}} \cdot B_o$$

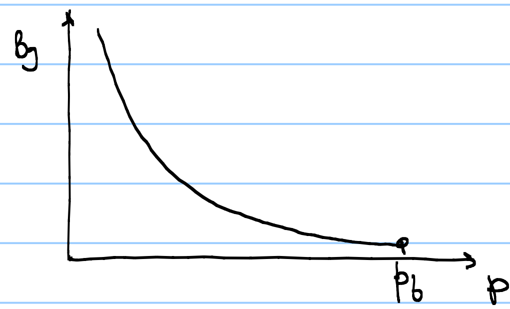
$$C_o = -\frac{1}{B_o \cancel{V_{\bar{o}}}} \frac{dB_o}{\partial P} \cancel{V_{\bar{o}}} \qquad -\int_{P_b}^{P} C_o \, dP = \int_{B_{ob}}^{B_o} \frac{dB_o}{B_o}$$

$$\ln\left(\frac{B_o}{B_{ob}}\right) = -C_o(P - P_b)$$

$$B_o = B_{ob} \cdot e^{-C_o(P-P_b)}$$

$$B_g(p,T) = \frac{V_g(p,T)}{V_{\bar{g}}}$$

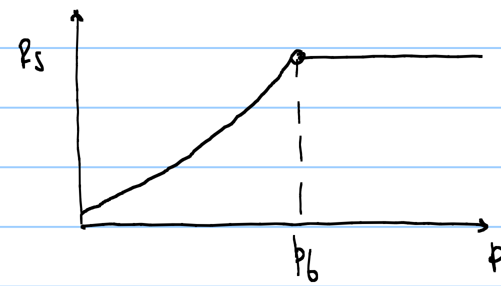
gas volume factor
formation volume factor

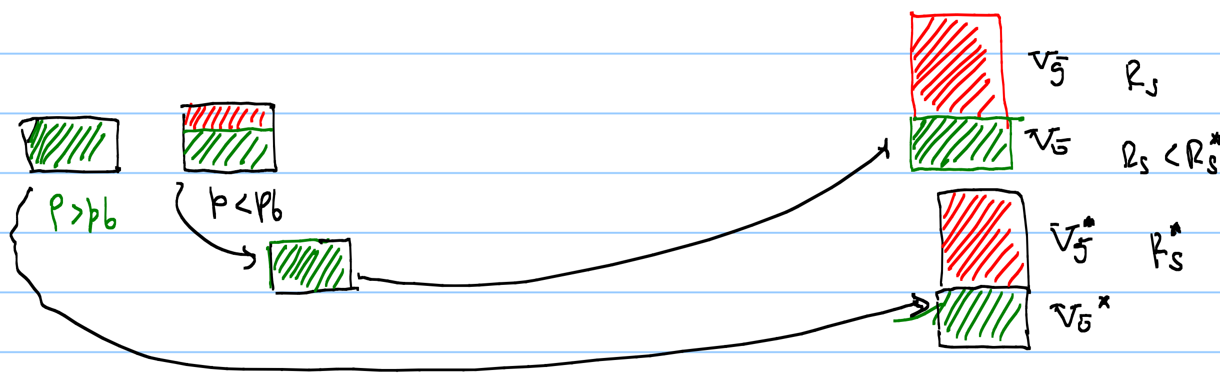


$$B_g = \frac{p_{sc}}{p}\frac{T}{T_{sc}} Z$$

$$R_s = \frac{V_{\bar{g}}}{V_{\bar{o}}}$$

solution gas-oil ratio





$q_o = ?$

$q_g = ?$

$$V_{\bar{o}} = \frac{V_o}{B_o} \quad \longrightarrow \quad q_{\bar{o}} = \frac{q_o}{B_o}$$

$$V_{\bar{g}} = R_s \cdot V_{\bar{o}} + \frac{V_g}{B_g}$$

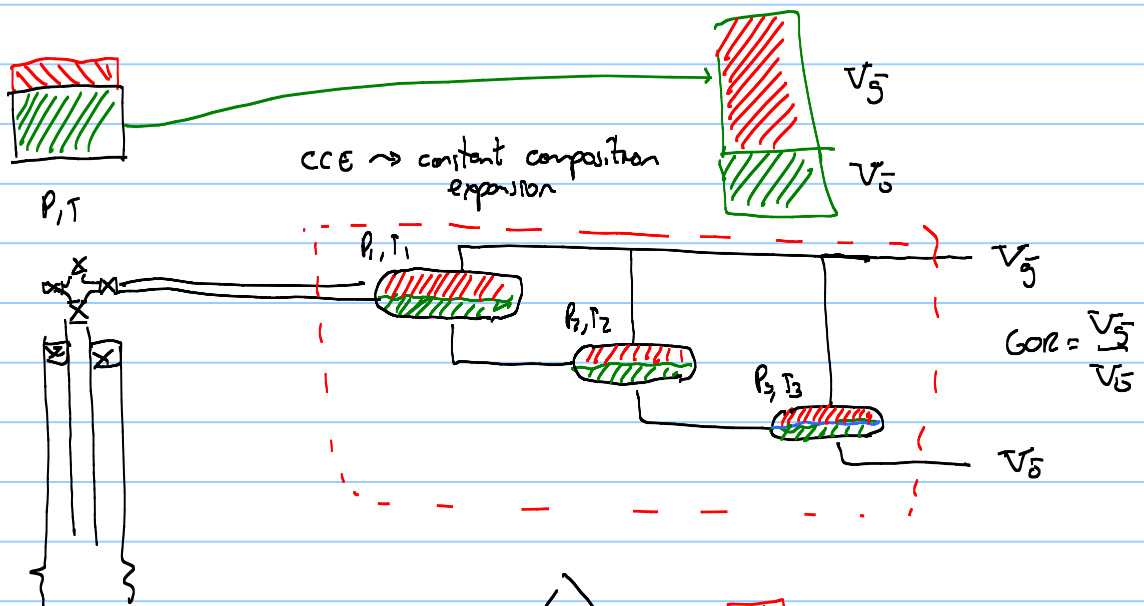
$$V_{\bar{g}} = R_s \cdot \frac{V_o}{B_o} + \frac{V_g}{B_g} \qquad q_{\bar{g}} = \frac{R_s}{B_o} q_o + \frac{q_g}{B_g}$$

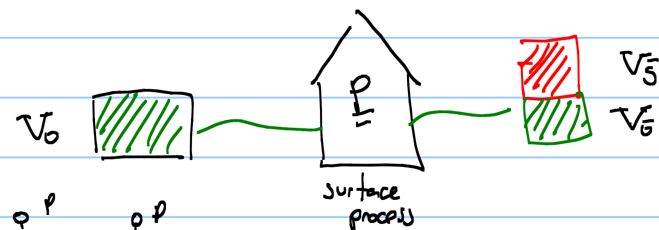
$$\begin{Bmatrix} q_{\bar{o}} \\ q_{\bar{g}} \end{Bmatrix} = \begin{bmatrix} 1/B_o & 0 \\ R_s/B_o & \frac{1}{B_g} \end{bmatrix} \begin{Bmatrix} q_o \\ q_g \end{Bmatrix}$$

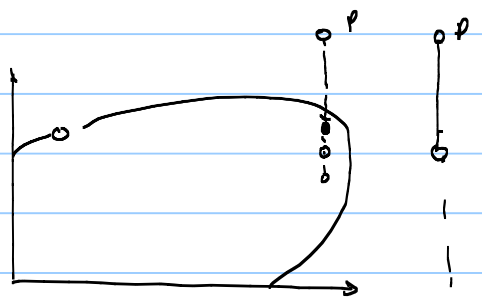
$f(p,T)$

$$\begin{Bmatrix} q_o \\ q_g \end{Bmatrix} = \begin{bmatrix} B_o & 0 \\ -R_s B_g & B_g \end{bmatrix} \begin{Bmatrix} q_{\bar{o}} \\ q_{\bar{g}} \end{Bmatrix}$$

$$q_g = B_g q_{\bar{g}} - R_s q_{\bar{o}} B_g$$

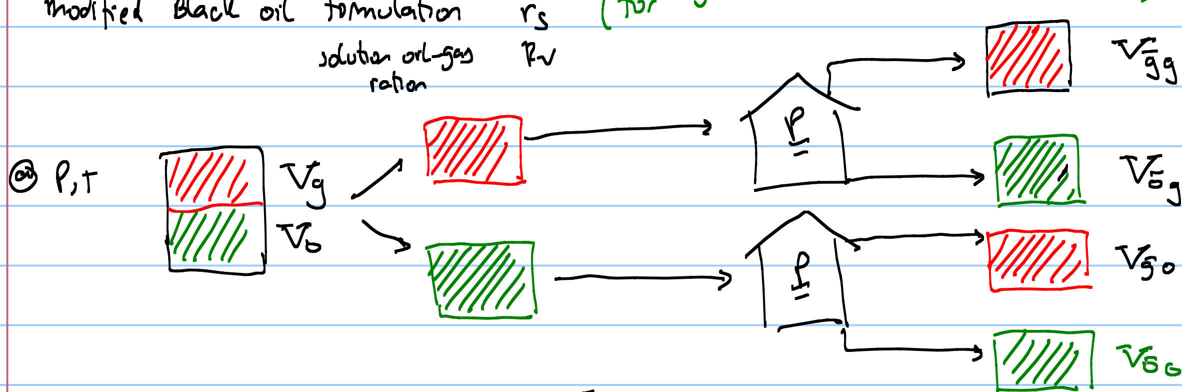






modified Black oil formulation r_s (for gas condensate and volatile oil)

solution oil-gas ration R_v



$$B_o = \frac{V_o}{V_{\bar{o}o}} \qquad B_g = \frac{V_g}{V_{\bar{g}g}}$$

$$V_{\bar{o}} = V_{\bar{o}o} + V_{\bar{o}g}$$

$$R_s = \frac{V_{\bar{g}o}}{V_{\bar{o}o}} \qquad r_s = \frac{V_{\bar{o}g}}{V_{\bar{g}g}}$$

$$V_{\bar{g}} = V_{\bar{g}g} + V_{\bar{g}o}$$

$$V_{\bar{o}} = \frac{V_o}{B_o} + r_s \cdot V_{\bar{g}g} = \frac{V_o}{B_o} + r_s \frac{V_g}{B_g}$$

$$V_{\bar{g}} = \frac{V_g}{B_g} + R_s V_{\bar{o}o} = \frac{V_g}{B_g} + R_s \frac{V_o}{B_o}$$

$$\begin{Bmatrix} q_{\bar{o}} \\ q_{\bar{g}} \end{Bmatrix} = \begin{Bmatrix} \frac{1}{B_o} & \frac{r_s}{B_g} \\ \frac{R_s}{B_o} & \frac{1}{B_g} \end{Bmatrix} \begin{Bmatrix} q_o \\ q_g \end{Bmatrix}$$

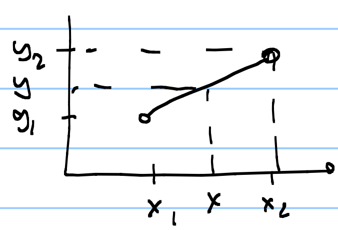
$$\begin{Bmatrix} q_o \\ q_g \end{Bmatrix} = \begin{Bmatrix} \frac{B_o}{1 - R_s \cdot r_s} & -\frac{B_o r_s}{1 - R_s r_s} \\ -\frac{B_g R_s}{1 - R_s r_s} & \frac{B_g}{1 - R_s r_s} \end{Bmatrix} \begin{Bmatrix} q_{\bar{o}} \\ q_{\bar{g}} \end{Bmatrix}$$

Class exercise

Where do black oil properties come from?

- Correlations
  - Standing (crude oils california)
  - Glasø
- field data → correlation
- laboratory data
- PVT simulator
  - EOS (equation of state)
    - Peng Robinson
    - SRK

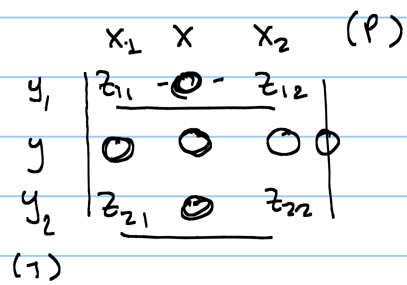
linear interpolation



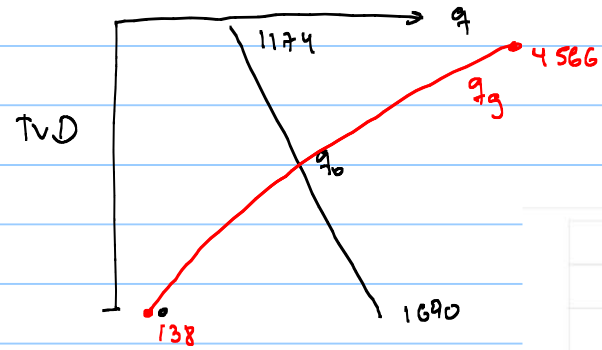
$$\frac{y_2 - y_1}{x_2 - x_1} = \frac{y - y_1}{x - x_1}$$

bilinear interpolation

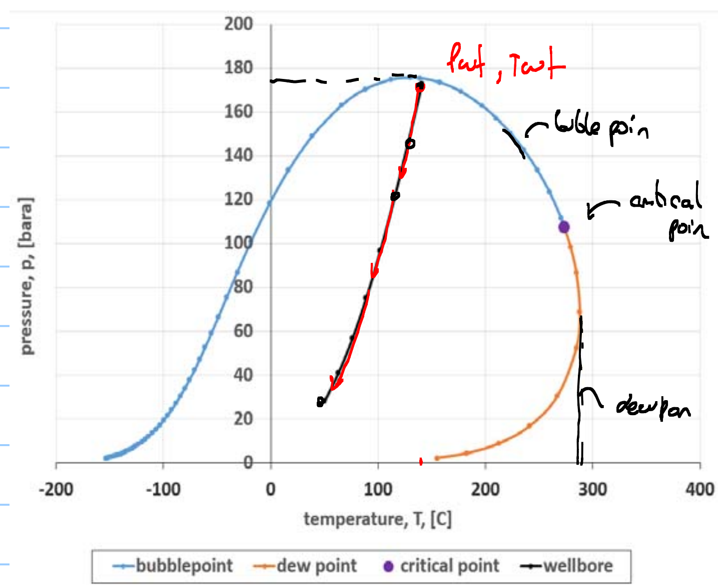
Z BO property



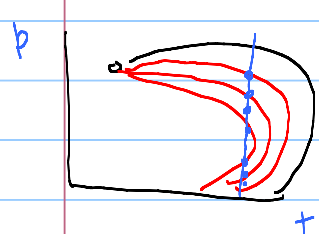
[Sm^3/Sm^3]	155.1													
[m]	0.15													
[m^2]	0.0177													
[m]	1.50E-05													
[deg]	90													
[Sm^3/d]	1000													
[Sm^3/d]	1.55E+05													
		BO table column	3	4	5	6	8	10	7	9	11			
TVD [m]	T [C]	p[bara]	Rs [Sm^3/Sm^3]	rs [Sm^3/Sm^3]	Bo [m^3/Sm^3]	Bg [m^3/Sm^3]	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]	u
0	50.0	28	22.6	1.28E-05	1.18	0.0344						1174.3	4.566E+03	
500	63.0	41.0	33.71	1.25E-05	1.23	0.02						1224.4	2.862E+03	
1000	76.0	56.6	46.82	1.25E-05	1.28	0.02						1283.1	1.791E+03	
1500	89.0	75.2	62.24	1.31E-05	1.35	0.01						1352.5	1.161E+03	
2000	102.0	96.7	79.29	1.45E-05	1.43	0.01						1430.1	7.452E+02	
2500	115.0	120.5	97.44	1.68E-05	1.52	0.01						1514.4	4.721E+02	
3000	128.0	146.1	115.86	2.02E-05	1.60	0.01						1602.1	2.803E+02	
3500	141.0	172.9	133.82	2.46E-05	1.69	0.01						1690.3	1.380E+02	



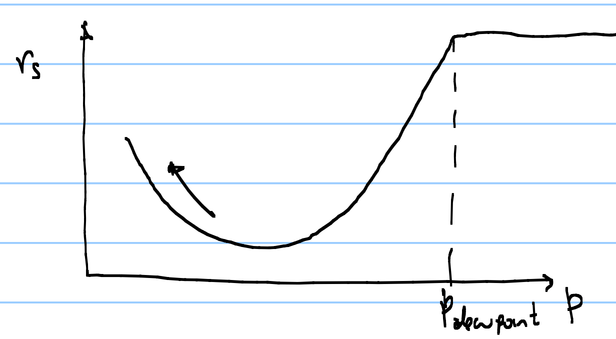
Part of homework!



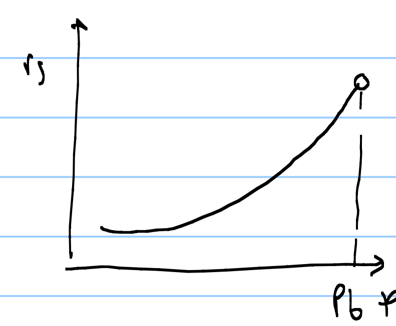
- rs ? vs p



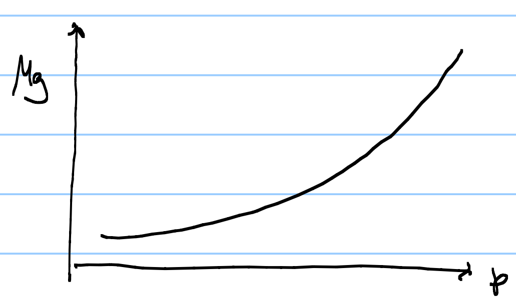
if it is a gas

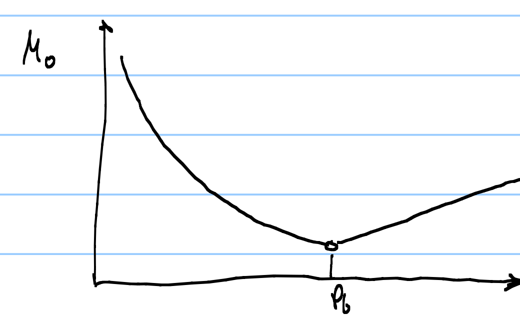


if it is an oil

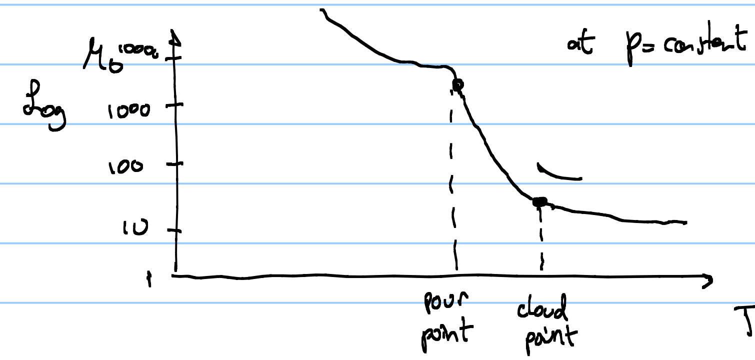


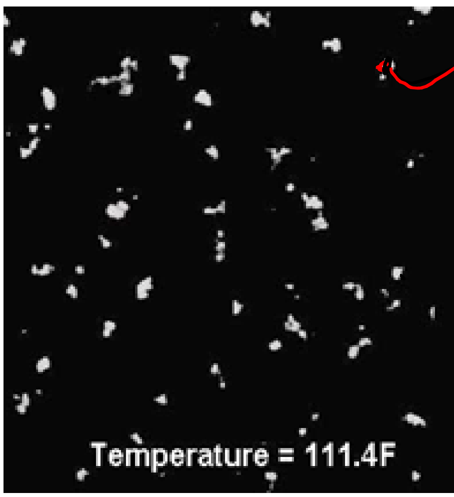
viscosity of gas





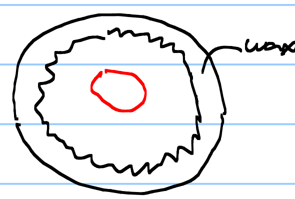
the temperature is what has the biggest effect on oil viscosity



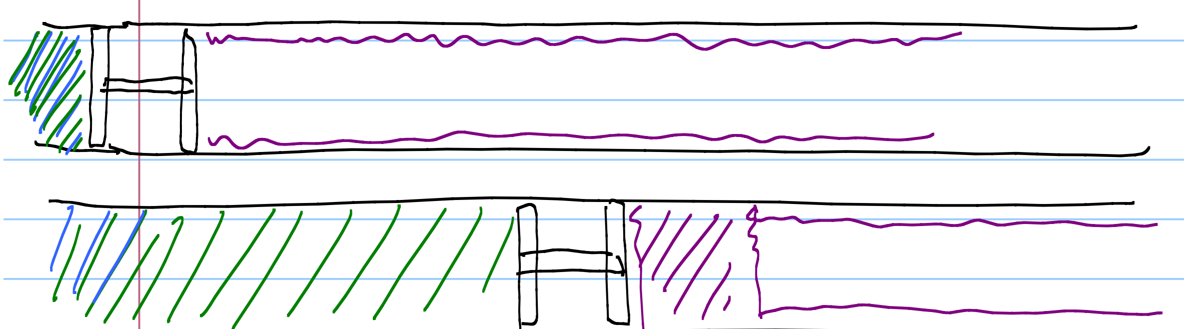


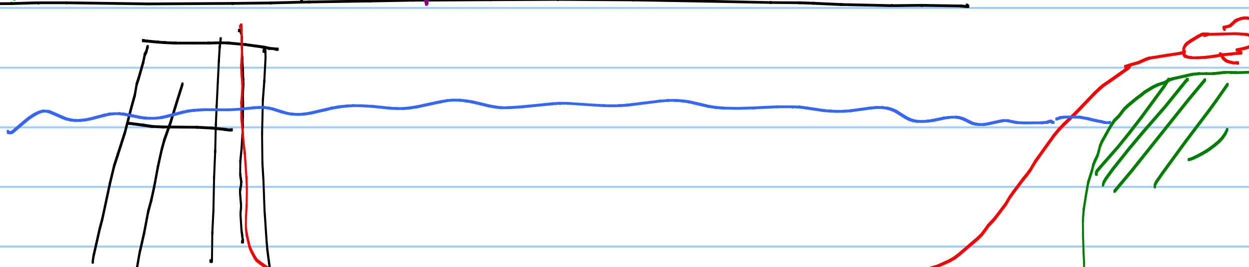
$C_{12} \rightarrow C_{16}$ alkanes

- Careful ↓T ↑μ, ↑↑Δp in flowline
- careful deposition of WAX ⇝ pipe blockage

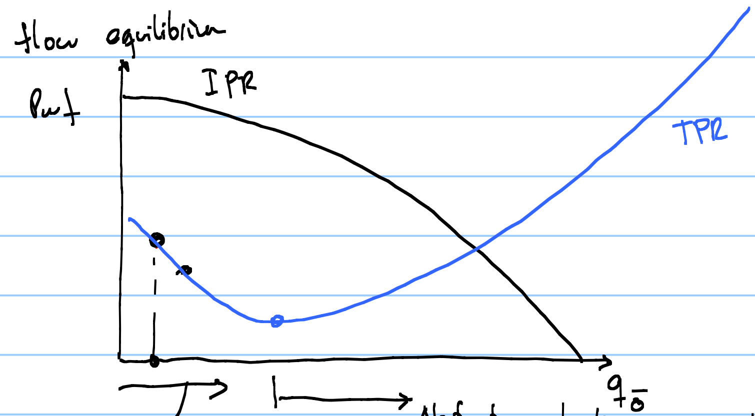


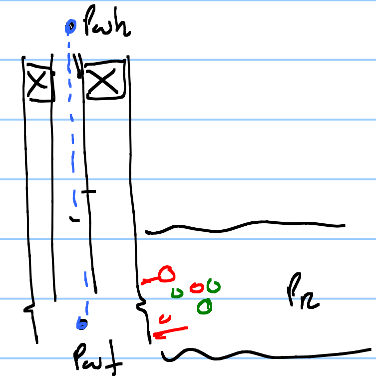
- insulate the pipe
- heat the pipe
- pigging !





flow equilibrium





Δp friction starts being important

when q_o ↑

dominated by gravity

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

↓ ↑

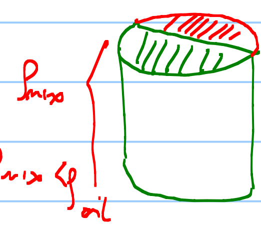
flow dominated by friction

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

↓ ↑↑

$\Delta p \approx \Delta p_{Hydrostatic} = \rho_{mix} \cdot g\, h$

$\rho_{mix} \approx \rho_{oil}$



$\rho_{gas} < \rho_{mix} < \rho_{oil}$