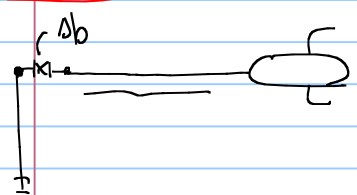
- Methods to prolong plateau production
- Orientation for solving problem 2 exercise set 3
  - Single phase pressure drop
  - oil water mixtures (emulsion)
  - ESP constraints
- compression?

Method to prolong plateau production:

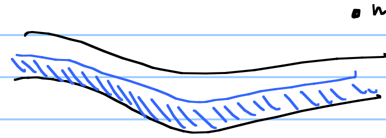
Short comment on discount factor

1661.70 USD / 661 $\quad \dfrac{1}{(1+0.07)^3} = 0.81(1.70) =$

- increase number of wells ($)
- Adding energy to system
  - → boosting (compressing, pumping)
  - → Artificial lift (ESP) ($)

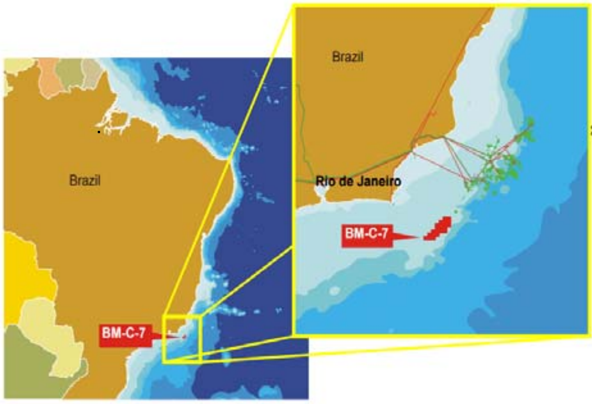


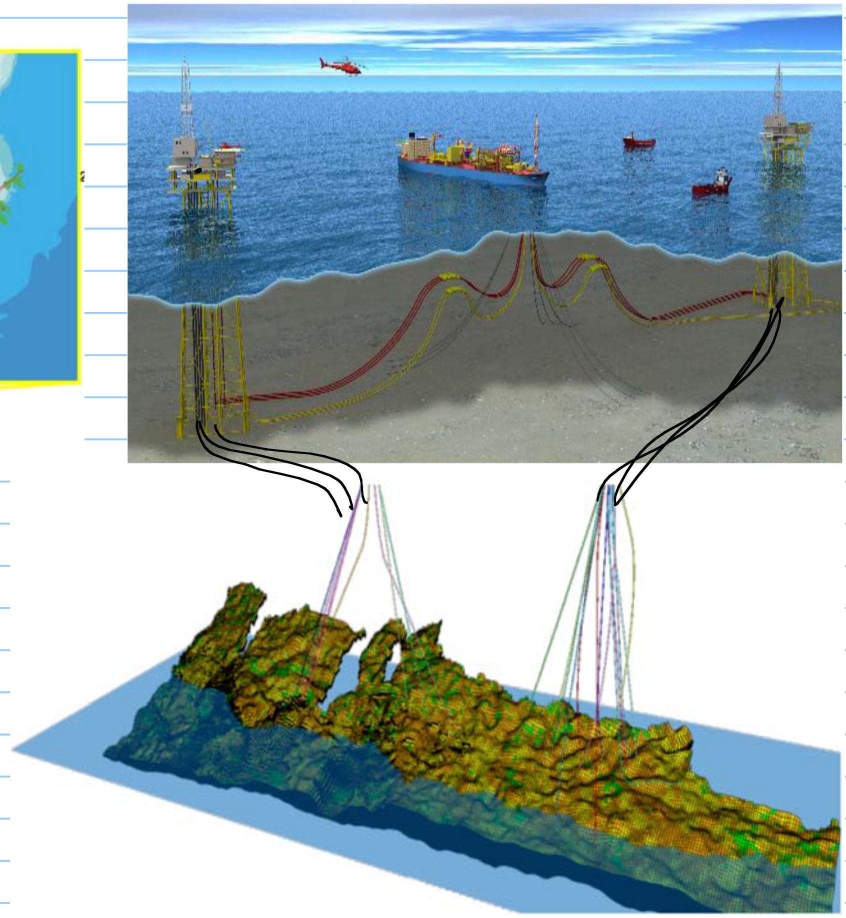
- making "C" bigger: fracturing, well stimulation
- making "C_T" bigger → increase tubing size $
  - → remove solid deposition



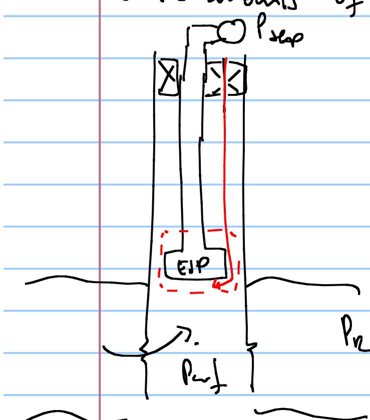
- making C_{FL} bigger → increase pipe size
  - → perform pigging
- decrease P_{sep} ~ careful with requirement of process plant
- Pressure support mechanism
- Re-distribution of production among well: careful with max allowable drawdown ($P_R - P_{wf}$), q_{max}

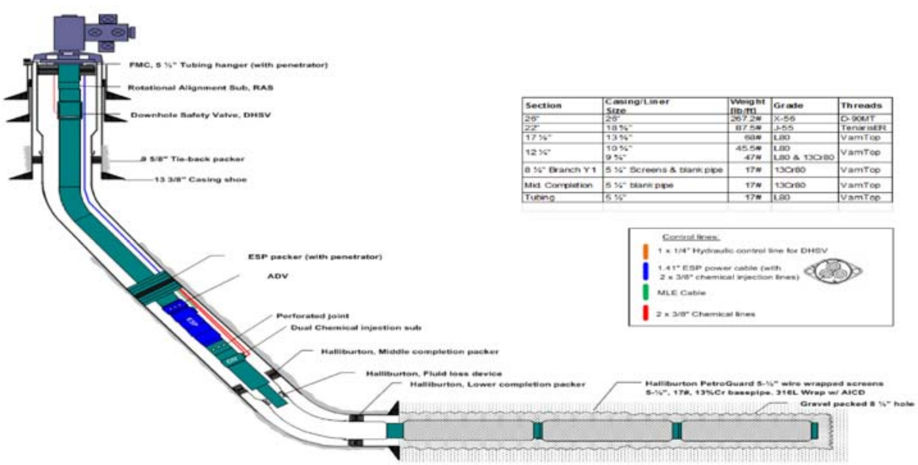
- Problem 2 of exercise set 3.





- the amounts of oil and water are changing with time





Section	Casing/Liner Size	Weight [lb/ft]	Grade	Threads
26"	26"	267.2#	X-56	D-90MT
22"	18 5/8"	87.5#	J-55	TenarisER
17 ½"	13 3/8"	68#	L80	VamTop
12 ¼"	10 ¾" 9 5/8"	45.5# 47#	L80 L80 & 13Cr80	VamTop
8 ½" Branch Y1	5 ½" Screens & blank pipe	17#	13Cr80	VamTop
Mid. Completion	5 ½" blank pipe	17#	13Cr80	VamTop
Tubing	5 ½"	17#	L80	VamTop

$P_{suction} = P_{inlet}$ pump

$P_R \to P_{wf}$ IPR equation $\underbrace{q_{liq}}_{q_{oil}+q_w} = J\left(P_R - P_{wf}\right)$

$P_{wf} \to P_{suc}$

(1) $\to$ (2)

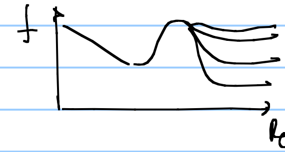
$h_1 = h_2$

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_f$$

single phase and incompressible fluid

$$h_f = f \frac{L}{\phi} \cdot \frac{v^2}{2g}$$

moody friction factor



line P_1

$v_2 \simeq v_1$

$$P_1 = (z_2 - z_1) \cdot \rho g + f \frac{L}{\phi} \frac{v^2}{2} \cdot \rho + P_2$$

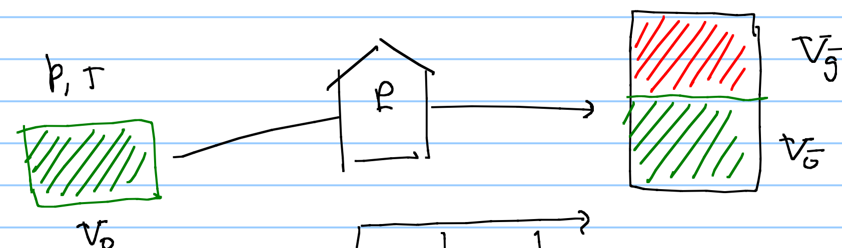
$$v = \frac{q}{A} = \frac{q\,4}{\pi \phi^2}$$

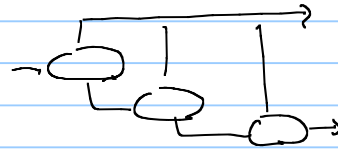
eq. 1

$$P_1 = (z_2 - z_1) \rho g + f \frac{L}{\phi} \rho \frac{8 q^2}{\pi^2 \phi^5} + P_2$$

pipe equation for single phase flow

q is the local rate @ P, T IS NOT the same as $q_{\bar{o}}$ $q_{\bar{w}}$ $q_{\bar{L}}$





oil volume factor $B_o = \dfrac{V_{\bar{o}}(P,T)}{V_{\bar{o}}(P_{sc}, T_{sc})}$ → 1.8 volatile oils

1 for dead oil

for this exercise $B_o = 1$ for all P, T

$B_w = 1$

$q_o = q_{\bar{o}}$

$q_w = q_{\bar{w}}$

$q_L = q_{\bar{L}}$

$P_{wf} \rightarrow P_{wc}$ use eq. 1 with $P_1 = P_{wf}$, $P_2 = P_{wc}$

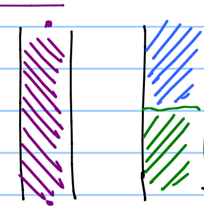
$q = q_{liq}$

$$\rho = \rho_{mix} = \rho_o(\alpha_o) + \rho_w(\alpha_w) = \rho_o(1 - \alpha_w) + \rho_w \cdot \alpha_w$$

```
'Function to calculate average properties of an oil water mixture given the water cut
Function Avprop(WC, Po, Pw)
'Average property Avprop
'WC water cut (not in porcentage)
'Po property of oil
'Pw property of water

Avprop = (WC * Pw) + ((1 - WC) * Po)
End Function
```

↳ volume fraction $\alpha_o = \dfrac{q_o}{q_o + q_w}$

$$\alpha_w = \frac{q_w}{q_o + q_w}$$

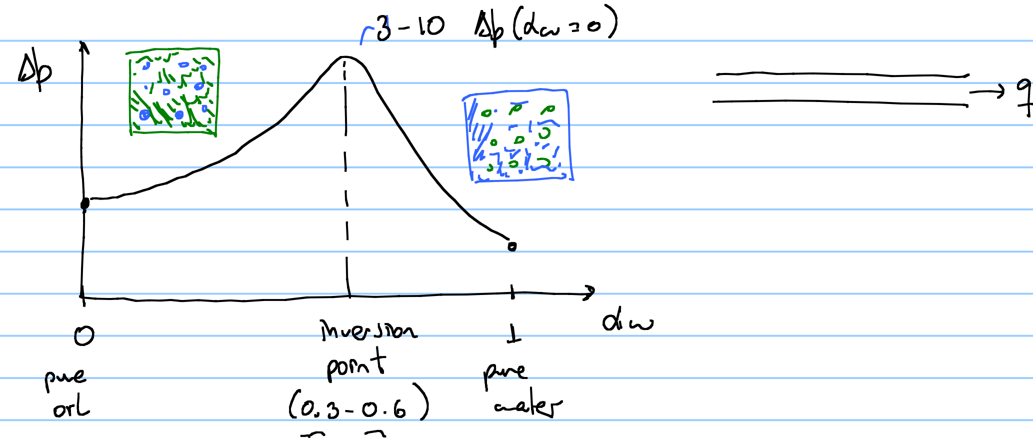


water cut $wc = \dfrac{q_{\bar{w}}}{q_{\bar{o}} + q_{\bar{w}}}$ for our exercise $wc = \alpha_w$

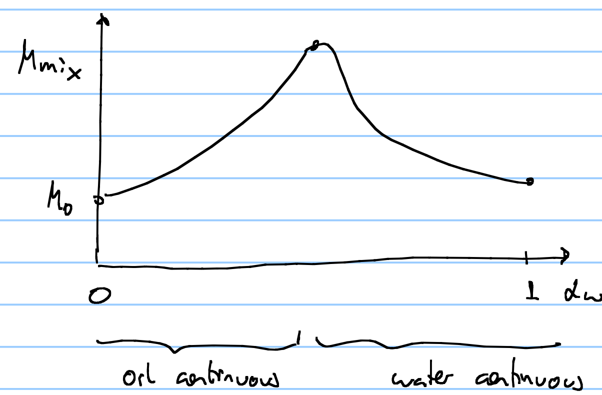
we need viscosity for Reynolds number to estimate f

some people use $\mu_m = \mu_o(1-\alpha_w) + \mu_w(\alpha_w)$ not accurate for emulsions

emulsion



during the life of the field typically WC increases. If there is risk of emulsion this must be taken into account !



Richardson equation

$\mu_m = \mu_o \cdot e^{C_o \alpha_w}$ $\mu_m = \mu_w \cdot e^{C_w(1-\alpha_w)}$

```
Function Rich_emul_visc(muo, muw, alphaw, expo, expw, alphaw_cutoff)
If alphaw > alphaw_cutoff Then
    Rich_emul_visc = muw * Exp(expw * (1 - alphaw))
Else
    Rich_emul_visc = muo * Exp(expo * (alphaw))
End If

End Function
```

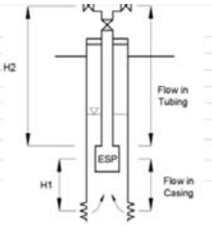
$P_R \rightarrow P_{wf} \rightarrow$ IPR

$P_{wf} \rightarrow P_{wh} \rightarrow$ single phase Δp with ρ_{mix}, μ_{mix}

$P_{wh} \rightarrow P_{dis}$ / P_{outlet} $\rightarrow$ single phase Δp with ρ_{mix} μ_{mix}

method 1 : equilibrium removing ESP

Wells	p_R	J, for total liquid flow	h1	h2	d1	d2	Pumpname	Stages
-	bara	Sm^3/d/bar	m	m	m	m	-	-
1	231	14	380	1960	0.24	0.14	Centrilift 675	78



	Water	Oil	
Fluid Density	1025	897	[kg/m^3]
Richardson Emul. exp.	13	3.215	
Viscosity	1.00E-03	0.1	[Pa s]
α_w cut off	0.60		
Roughness tubing and lines	0.00010	m	
Bubble point pressure [bara]	30	[bara]	

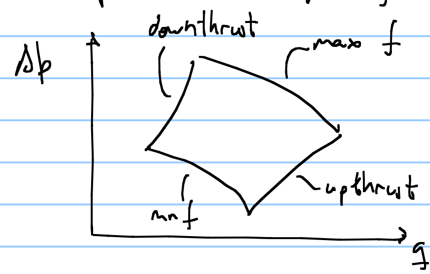
Required pressure at pump intake 36

Mechanic efficiency 0.95
Max pump power [hp] 950

Date	p_R	WC	Average density	Effective viscosity	q_{tot}	p_{wf}	q_o	q_w	p_{suc}	p_{disc}	Δp_{ESP}	Δh_{ESP}	p_{wh}	Pump power	Hydraulic Effic
[years]	bara	[-]	kg/m^3	Pa s	Sm^3/d	bara	Sm^3/d	Sm^3/d	bara	bara	bara	m	bara	[hp]	[%]
1.7													7		
7.5													7		
14.1													7		
25.0													7		

how to know if the pump works?

- $P_{disch} > P_{suc}$
- $P_{suc} \geq P_b$
- the operational point should fall on the operational envelope of pump



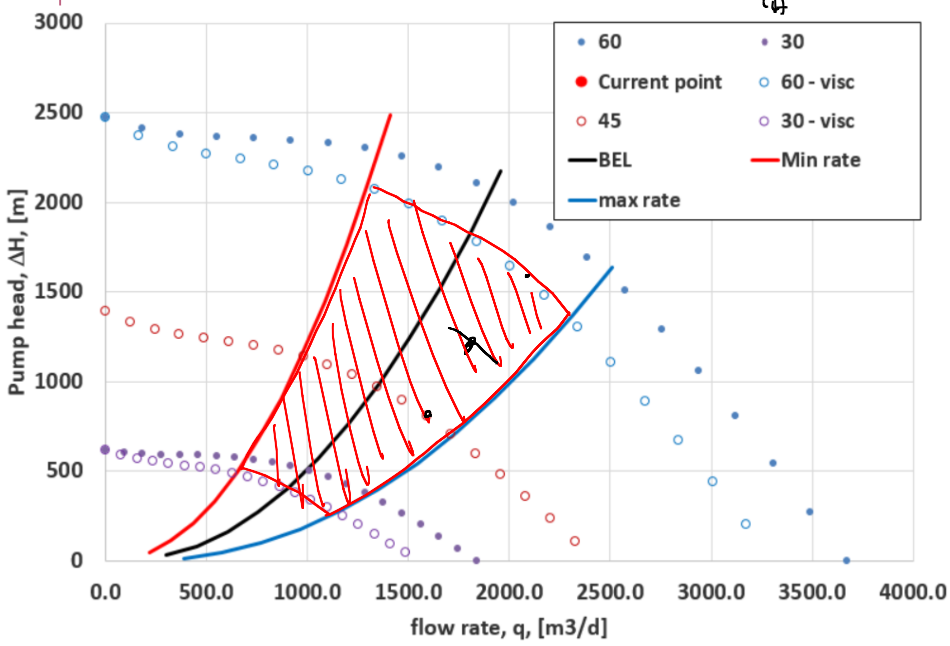
- Power required ≤ Power motor

in consistent units

$$P = \frac{\Delta p \cdot q}{\eta_H \cdot \eta_m}$$

assume $\eta_m = 1$

$$\frac{P_a}{\eta_H} \cdot m^3/s$$



Δp q

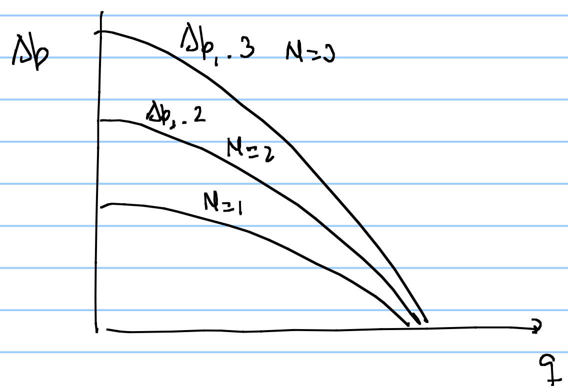
$$\Delta h = \frac{\Delta p}{\rho}$$

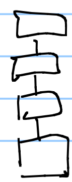
the map depends on viscosity

function for hydraulic efficiency $N=78$ $q_{BEP} = 1987$.

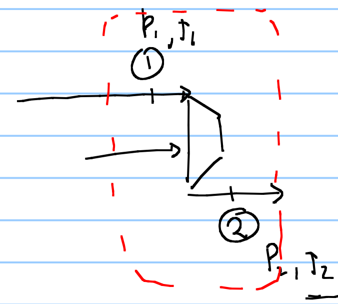
q_{Liqu} / 60, f (from interpolation)

```
Function pumpeffic_visc(Q, f, fref, N, den, visc, Q_BEP_fref, a5, a4, a3, a2, a1, b5, b4, b3, b2, b1)
'Function to return the efficiency of the pump [in %] if the following arguments are provided:
'Q Flow through pump, [m^3/d]
'visc,fluid viscosity, [Pa s]
'Q_BEP_fref,flow rate at best efficiency point for reference frequency, [m^3/d]
'den, fluid density, [kg/m^3]
'N number of pump stages
'f pump frequency [Hz]
'fref pump reference frequency [Hz] of the original curve
'a5, a4, a3, a2, a1 fitting coefficients of the H vs Q curve to a fourth order polynomial of one ESP stage with H in m and Q in m^3/d
'b5, b4, b3, b2, b1 fitting coefficients of the effic vs Q curve to a fourth order polynomial of one ESP stage with effic in % and Q in m^3/d

Q_BEP = Q_BEP_fref * f / fref
H_BEP = pumphead(Q_BEP, f, N, fref, a5, a4, a3, a2, a1)
B = Bparameter(den, visc, H_BEP, Q_BEP, f)
If B <= 1 Then
    pumpeffic_visc = ((a5 * ((Q * fref / f) ^ 4)) + (a4 * ((Q * fref / f) ^ 3)) + (a3 * ((Q * fref / f) ^ 2)) + (a2 * (Q * fref / f)) + a1)
ElseIf B > 1 And B < 40 Then
    Ceffic = B ^ (-0.0547 * (B ^ 0.69))
    CQ = 2.71 ^ (-0.165 * (Log10(B) ^ 3.15))
    QW = Q / CQ
    pumpeffic_visc = Ceffic * ((b5 * ((QW * fref / f) ^ 4)) + (b4 * ((QW * fref / f) ^ 3)) + (b3 * ((QW * fref / f) ^ 2)) + (b2 * (QW * fref / f))
ElseIf B >= 40 Then
    pumpeffic_visc = "ERROR, too viscous flow"
End If


End Function
End Function
```





Compression (gas)



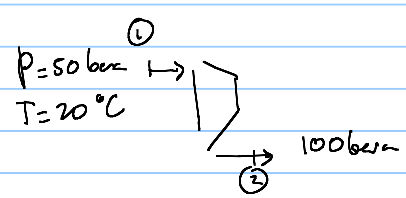
$$\dot{Q} - \dot{W} = \dot{m}(e_1 - e_2)$$

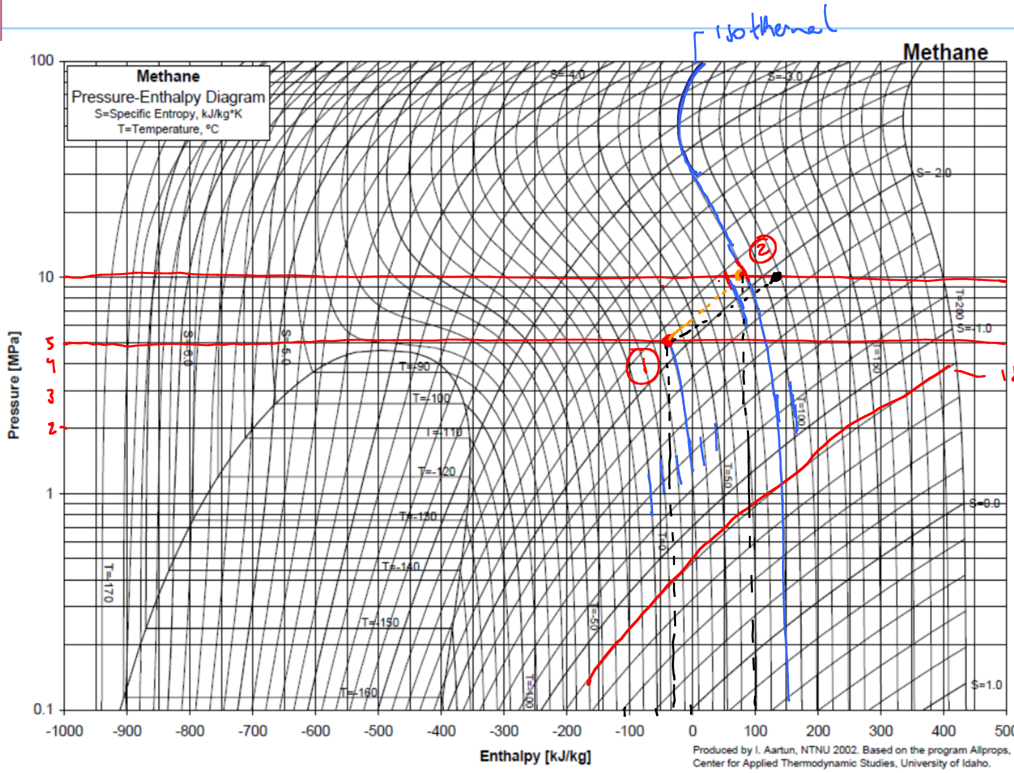
$$\cancel{\dot{Q}} - \dot{W} = \dot{m}\left(\cancel{\frac{v_1^2}{2g}} + \cancel{z_1} + h_1 - \cancel{\frac{v_2^2}{2g}} - \cancel{z_2} - h_2\right)$$

0

$$\underline{\dot{W}} = \dot{m}\,\underline{(h_1 - h_2)}$$

for Gullfaks exercise





50 bar → MPa
5 MPa

P_{dis} = 100 bara
10 MPa

isoentropy lines

$T_2 \simeq 85°C$

$$\dot{W}_s = \dot{m}(h_{2s} - h_1)$$

$$\dot{W}_s = 78 \frac{kg}{s} \cdot \left(100 \frac{kJ}{kg} + 25\ kJ/kg\right) = 9837 \frac{kJ}{s} =$$

9.8 MW

$q_g = 10E6\ Sm^3/d$

$\rho_g = 0.68\ kg/m^3$

$$\dot{m}_g = 10E6 \cdot 0.68 \ \frac{1\ d}{24\ h} \ \frac{1\ h}{3600\ s} = 78\ kg/s$$