PET 200 – Prod. olje & Gass

Eksamen 23. Nov. 2016 (ORD.)

Løsn. forslag Oppg 1

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a)

$$v_{max} = K \cdot \sqrt{\frac{\rho_L - \rho_g}{\rho_g}} \quad , \quad \dot{q}_g = v_{max} \cdot A_{Tot.}$$

$D_S = 0.96\ m = 0.96 \cdot 3.2808 = 3.15\ ft$

$L_S = 4\ m = 4 \cdot 3.2808 = 13.12\ ft$

$$A_{tot} = \begin{cases} \frac{\pi}{4} \cdot 0.96^2 = 0.724\ m^2 \\ \frac{\pi}{4} \cdot 3.15^2 = 7.79\ ft^2 \end{cases}$$

Oljetetthet er oppgitt: $\underline{\rho_L = 840\ kg/m^3}$

Gasstetthet: $\rho_g = \frac{1}{v_g} = \frac{P}{ZRT}$

$$R = \frac{8.314\ J/mol\,K}{\gamma_g \cdot Mw_a} = \frac{8.314\ J/mol\,K}{\underbrace{0.69 \cdot 29\ g/mol}_{(20.01\ g/mol)}} = 0.415 \frac{J}{g\,K} = \underline{415 \frac{J}{kg\,K}}$$

Mw_a = Molvekt for luft = 29 g/mol

$$\rightarrow \rho_g = \frac{5 \cdot 10^5\ Pa\ (= N/m^2)}{0.98 \cdot 415 \frac{J}{kg\,K} \cdot \underbrace{(55 + 273.15)\ K}_{= 328.15\,K}} = \underline{3.75\ kg/m^3}$$

$$\rightarrow v_{max} = 0.45\ ft/s \cdot \sqrt{\frac{840 - 3.75}{3.75}} = \underline{6.72\ ft/s = 2.05\ m/s}$$

②

Gass kapasitet: $\dot{q}_g = 6.72\ ft/s \cdot 7.79\ ft^2 = \underline{\underline{52.35\ ft^3/s}}$

$2.05\ m/s \cdot 0.724\ m^2 = \underline{\underline{1.48\ m^3/s}}$

b) Væske volum: $V_L = \frac{1}{2} \cdot A_{tot} \cdot L_S = \begin{cases} \frac{1}{2} \cdot 7.79\ ft^2 \cdot 13.12\ ft \\ \frac{1}{2} \cdot 0.724\ m^2 \cdot 4\ m \end{cases}$

$= \underline{51.10\ ft^3}$

$\underline{\underline{1.45\ m^3}}$

Væske kapasitet: $\dot{q}_L = \frac{V_L}{\tau}$, $\tau = 1\ min = 60\ s$

(Trykkfeil i oppg: $\tau = 12$ min ☹)

$q_L = \frac{51.1\ ft^3}{60\ s} = \underline{\underline{0.85\ \frac{ft^3}{s}}}$

$= \frac{1.45\ m^3}{60\ s} = \underline{\underline{0.024\ m^3/s}}$

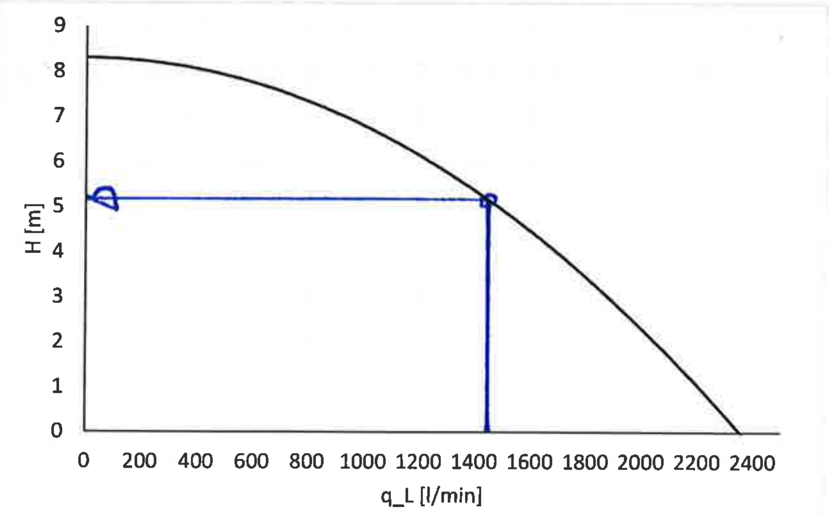
QED.

c) Trykk differanse over pumpen: $\Delta p_P = \rho g H$

$H = H(q_L)$; $q_L = 0.024\ m^3/s \cdot 1000\ l/m^3 \cdot 60\ s/min$

$= \underline{1440\ l/min}$

$\Rightarrow H \approx 5.2\ m$



$\Delta p_p = 840\ kg/m^3 \cdot 9.81\ \frac{m}{s^2} \cdot 5.2\ m = \underline{42850\ Pa}$

Hydrostatisk trykk differanse: $\Delta p_H = \rho g h$

$= 840\ kg/m^3 \cdot 9.81\ \frac{m}{s^2} \cdot 3\ m = \underline{24721\ Pa}$

Absolutt trykk = Trykk i tank + $\Delta p_H + \Delta p_p$

$= 5 \cdot 10^5 + 24721 + 42850 = 567571\ Pa$

$= \underline{\underline{5.67\ bar}}$

d) Friksjonstrykktap: $\Delta p_f = \frac{1}{2} \rho u^2 f_D \frac{L}{D}$

$u = \frac{q_L}{Area} = \frac{4 \cdot 0.024\ m^3/s}{\pi \cdot (0.1\ m)^2} = \underline{3.06\ m/s}$

$\Delta p_f = \frac{1}{2} \cdot 840 \frac{kg}{m^3} \cdot (3.06\ m/s)^2 \cdot 0.019 \cdot \frac{80\ m}{0.1\ m} = \underline{59777\ Pa}$

$\underline{\underline{\Delta p_f = 0.598\ bar}}$

Trykk v/ $L = 80\ m$:

$p = 5.67 - 0.598 = \underline{\underline{5.07\ bar}}$

↑ (utløp av pumpe)

e) $$w_s = P_1 v_1 \cdot \frac{\kappa}{\kappa - 1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{\kappa-1}{\kappa}} - 1\right]$$

↙

$$P_1 \cdot v_1 = R \cdot T_1 = 8.314 \frac{J}{mol\,K} \cdot 328.15\,K = 2728 \frac{J}{mol}$$

$$\rightarrow w_s = 2728 \cdot \frac{1.3}{0.3} \cdot \left[(3.1)^{\frac{0.3}{1.3}} - 1\right] = \underline{\underline{3527 \frac{J}{mol}}}$$

f) Gassmengde = gasskapasitet:

$$\dot{q}_g = 1.48\ m^3/s \Rightarrow \dot{m} = 1.48\ m^3/s \cdot 3.75\ kg/m^3$$

(Reelle m^3) ↑ ρ_s

$$= 5.55\ kg/s$$

Varme: $\dot{Q} = \dot{m} \cdot c_p \cdot (T_o - T_i)$ (Neg. fordi varme fjernes)

$$\Rightarrow T_o = T_i + \frac{\dot{Q}}{\dot{m} c_p} = 153^\circ C + \frac{-1400\ kJ/s}{5.55\ kg/s \cdot 2.25 \frac{kJ}{kg\,K}}$$

$$\Rightarrow \underline{\underline{T_o = 40.9^\circ C}}$$

Alt: $\dot{q}_g = 0.3\ kmol/s \rightarrow \dot{m} = 0.3\ kmol/s \cdot 20.01\ g/mol = 6.0\ kg/s$

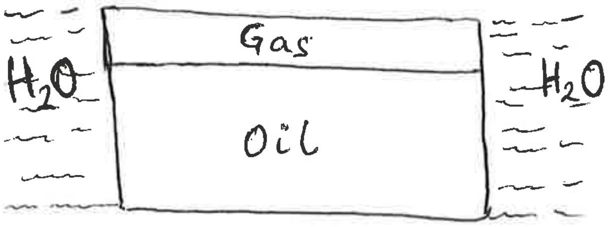
$\left(= \frac{kg}{kmol}\right)$

$$\rightarrow T_o = 153 - \frac{1400}{6 \cdot 2.25} = \underline{\underline{49.3^\circ C}}$$

Solution POG (PET 200) Exam H 2016

Oppgave 2:

a) Reservoir



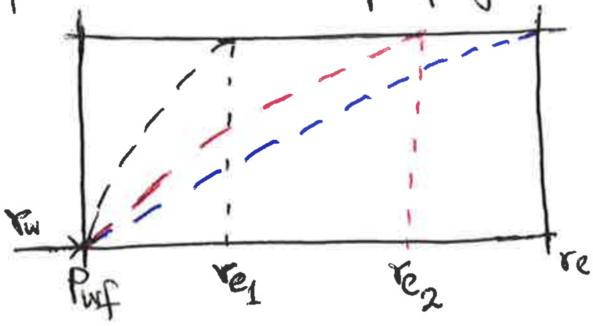
The reservoir Has a gas-cap and water at the edge of the reservoir boundaries.

i) Natural drive mechanisms of this reservoir are:

- Oil Expansion drive
- Gas-cap drive
- Edge-water drive
- Dissolved gas drive (assuming some of the gas is dissolved in the oil at initial reservoir conditions).

ii) At the beginning of production, at star-up of the well, we always have "Transient flow".

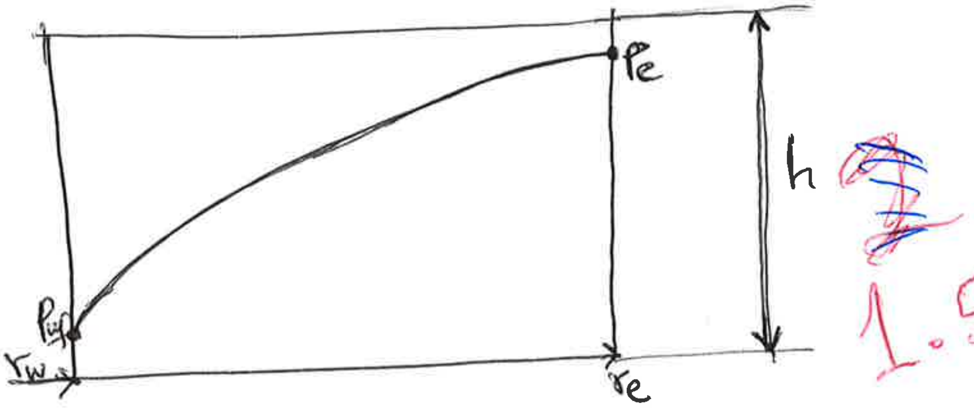
The pressure wave propagation for transient flow:



iii) It will take some time, from a few months, to a couple of years, for the pressure waves during transient flow to develop from the reservoir, to the reservoir boundaries. At this point, the pressure at every point in the reservoir will be constant, if we have strong pressure support from an aquifer. The flow regime now is "Steady-State".

L2

Pressure wave propagation for "steady-state" flow:



1.5

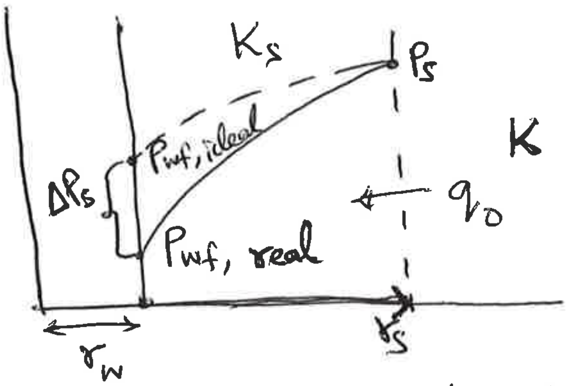
(b) i) To establish a flow-path between the well and the reservoir, 1 a "perforation" job must be done.

Short description: Perforation is done with the use of "shaped charges", which are assembled in a "perforating gun". The perforating guns carrying the "shaped charges" are run into the well, and set within specific intervals within the pay-zone of the reservoir. Next, the "shaped charges" are detonated, to produce penetrating jet that cuts through the casing, and cement, into the reservoir. 2

ii) The perforating gun may be "wireline" conveyed, or "tubing" conveyed. 1 In the case of highly deviated wells, and horizontal wells, peforation may also be done via "Coiled tubing".

(c) i) Skin effect is defined as any additional resistance to flow from the reservoir into the well. 1
Skin Effect is normally felt with the near-wellbore area of the reservoir as a reduction in permeability or increased pressure drop.

e ii) Given :



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Pressure drop in the skin zone, due to skin ΔP_s?

$$\Delta P_s = P_{wf,ideal} - P_{wf,real} \quad -(1)$$ 0.5

for the same flowrate through the reservoir, q_o,

For ideal flow: ↳ without skin

$$q_o = \frac{K \cdot h \, (P_s - P_{wf,ideal})}{141.2 \, B_o \mu_o \cdot \ln \frac{r_s}{r_w}} \quad (2)$$

$$P_{wf,ideal} = P_s - \frac{q_o \cdot 141.2 \, B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K \cdot h} \quad (3)$$ 1.5

For real flow: ↳ with skin

$$q_o = \frac{K \cdot h \, (P_s - P_{wf,real})}{141.2 \, B_o \mu_o \cdot (\ln \frac{r_s}{r_w} + S)} \quad (4)$$

$$P_{wf,real} = P_s - \left[\frac{q_o \cdot 141.2 \, B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K \cdot h} + \frac{q_o \cdot 141.2 \, B_o \mu_o \cdot S}{K \cdot h} \right] \quad (5)$$ 1.5

i.e $\Delta P_s = P_{wf,ideal} - P_{wf,real} = P_s - \frac{q_o \cdot 141.2 \, B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K \cdot h}$

$- P_s + \frac{q_o \cdot 141.2 \, B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K \cdot h} + \frac{q_o \cdot 141.2 \, B_o \mu_o \cdot S}{K \cdot h}$

$$\Delta P_s = \frac{q_o \cdot 141.2 \cdot B_o \mu_o \cdot S}{K \cdot h}$$ 1

L4

C iii) Hawkin's formular for skin factor: Now we consider reduction of permeability in the skin zone due to formation damage or skin effect.

For ideal flow = No damage:

$$P_s - P_{wf,ideal} = \frac{q_o \cdot 141.2 B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K \cdot h}$$

$$P_{wf,ideal} = P_s - \frac{q_o \cdot 141.2 B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K \cdot h}$$

1

For real flow = with Damage:

$$P_s - P_{wf,real} = \frac{q_o \cdot 141.2 B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K_s \cdot h}$$

$$P_{wf,real} = P_s - \frac{q_o \cdot 141.2 B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K_s \cdot h}$$

1

$$\Delta P_s = P_{wf,ideal} - P_{wf,real} = \frac{q_o \cdot 141.2 B_o \mu_o \cdot S}{K \cdot h}$$

as found from (C ii). 0.5

Thus:

$$\frac{q_o \cdot 141.2 B_o \mu_o \cdot S}{K \cdot h} = P_s - \frac{q_o \cdot 141.2 B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K h} - P_s + \frac{q_o \cdot 141.2 \cdot B_o \mu_o \cdot \ln \frac{r_s}{r_w}}{K_s \cdot h}$$

1

LS

$$\frac{S}{K} = -\frac{\ln\frac{r_s}{r_w}}{K} + \frac{\ln\frac{r_s}{r_w}}{K_s}$$

$$S = K \cdot \left(\frac{1}{K_s} - \frac{1}{K}\right) \cdot \ln\frac{r_s}{r_w}$$

1

$$S = \left(\frac{K}{K_s} - 1\right) \cdot \ln\frac{r_s}{r_w}$$ – Hawkin's formular for skin factor.

C iv) Note: This problem is given as a bonus to all due to a mix-up in language. Intent was to calculate the permeability impairment ~~factor~~ $\frac{K}{K_s}$; not damage ratio $\frac{1}{E_F}$.

From Hawkin's formular:

$$S = \left(\frac{K}{K_s} - 1\right) \cdot \ln\frac{r_s}{r_w}$$

i.e

$$\frac{K}{K_s} = \frac{S}{\ln\frac{r_s}{r_w}} + 1$$

$r_s = \left(2 + \frac{4.5}{12}\right) ft = 2.375 ft$ 1

$r_w = \frac{4.5}{12} = 0.375 ft$; $S = 18$

$$\frac{K}{K_s} = \frac{18}{\ln\left(\frac{2.375}{0.375}\right)} + 1 = 10.752$$ 1

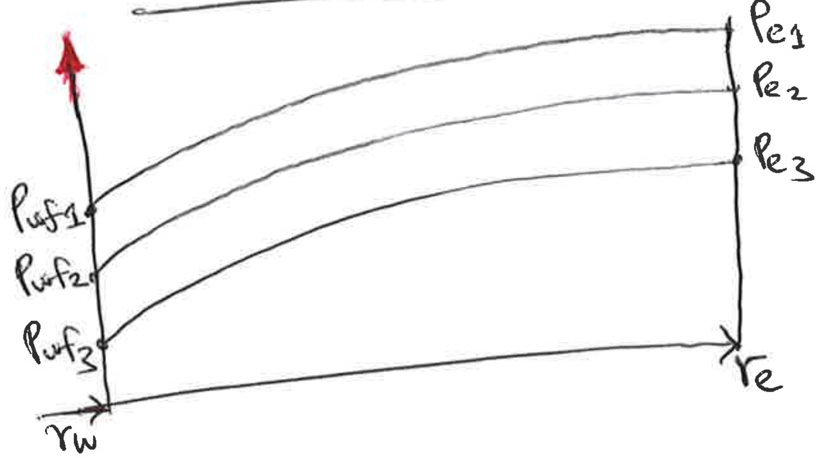
L6

Oppgave 3:

a i) $\frac{K}{K_s} = 10.752 \Rightarrow K_s = \frac{K}{10.752} = \frac{120\ mD}{10.752}$

$K_s = 11.16\ mD$ 1

ii) The flow regime when the flowrate is kept constant with dropping reservoir pressure is "Pseudo-steady state" flow. 1



2

iii) We have reservoir properties, so, for Pseudo-steady state flow:

$$J = \frac{q}{P_e - P_{wf}} = \frac{Kh}{141.2 B_o \mu_o \cdot \left(\ln \frac{r_e}{r_w} - 0.75 + S\right)}$$

2 $$= \frac{120 \times 100}{141.2 \times 1.2 \times 1.2 \times \left(\ln\left(\frac{1000}{0.375}\right) - 0.75 + 18\right)}$$

$$= 2.35\ \frac{Stb}{day}/psia$$

(b) Given: $P_b = 5500$ psia; $P_e = 8000$ psia

$J = 2.35\ \frac{Stb}{day}/psia$

i) $A, B > P_b$; a single phase oil flow:

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Oppgave 3: Continued

b) i.e $q_o = J \cdot (P_e - P_{wf})$

$$P_{wf} = P_e - \frac{q_o}{J}$$

$$A = 8000 - \frac{450}{2.35} = 7808.5 \text{ psia}$$ 1

$$B = 8000 - \frac{2500}{2.35} = 6936.2 \text{ psia}$$ 1

$$C = q_b = J \cdot (P_e - P_b) = 2.35(8000 - 5500)$$

$$= 5875 \text{ stb/d}$$ 1

At D and E, $P < P_b$; we have partial 2-phase flow from the reservoir.

$$q_D = q_b + \frac{J \cdot P_b}{1.8}\left[1 - 0.2\left(\frac{P_{wf,D}}{P_b}\right) - 0.8\left[\frac{P_{wf,D}}{P_b}\right]^2\right]$$

$$= 5875 + \frac{2.35 \times 5500}{1.8}\left[1 - 0.2\left(\frac{2500}{5500}\right) - 0.8\left[\frac{2500}{5500}\right]^2\right]$$

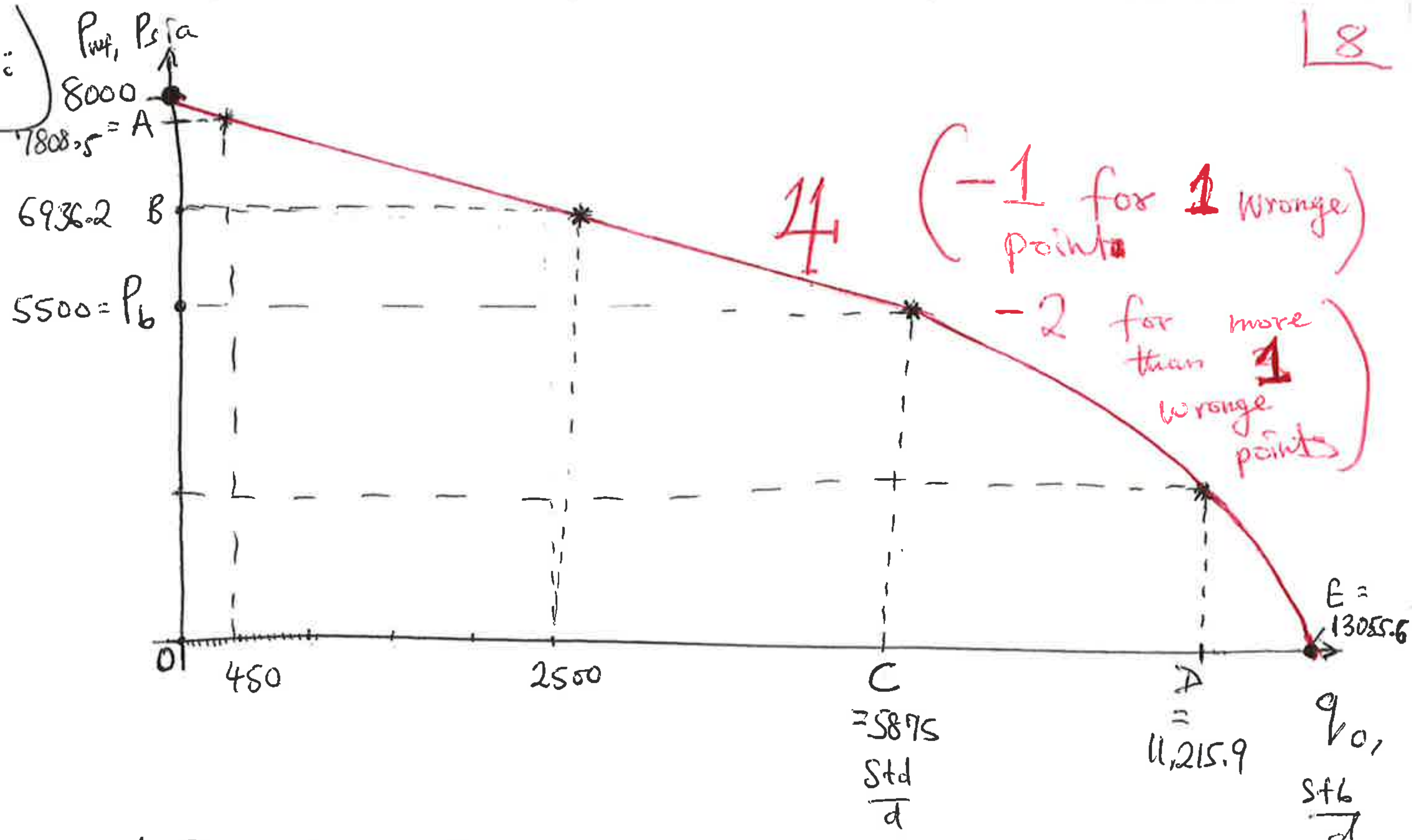
$$D = 11,215.91 \text{ stb/d}$$ 1.5

$$q_E = q_b + \frac{J \cdot P_b}{1.8} = 5875 + 7180.56$$

$$E = 13,055.56 \text{ stb/d}$$ 1.5

L8

b ii)



c i) $\Delta P = P_{wf} - P_{wh} \Rightarrow$

$$P_{wf} = \Delta P + P_{wh,min}$$ 1 (for a given minimum wellhead pressure)

ii) Assuming single-phase flow in the well:

$$\Delta P_{total} = \Delta P_{P.E} + \Delta P_F$$

$$= \frac{g}{g_c} \cdot \rho \Delta Z + \frac{2 \cdot f_f \cdot \rho \cdot u^2 \cdot L}{g_c \cdot D}$$ 1

iii)

$$P_{wf} = \frac{g}{g_c} \cdot \rho_o \Delta Z + \frac{2 \cdot f_f \cdot \rho_o u^2 \cdot L}{g_c \cdot D} + P_{wh,min}$$ 1

$$= \Delta P_{P.E} + \Delta P_F + P_{wh,min}$$

$$\Delta P_{P.E} = \frac{g}{g_c} \cdot \rho_o \cdot \Delta Z \; ; \quad \Delta Z = L = 8000 \text{ ft}$$

$$\rho_o = \rho_w \cdot \gamma_o = 62.4 \times 0.78 = 48.672 \frac{lbm}{ft^3}$$ 1

i.e. $$\Delta P_{P.E} = \frac{32.17}{32.17} \times 48.672 \times 8000 = 389{,}376 \frac{lbf}{ft^2} \times \frac{1}{144} \frac{ft^2}{in^2}$$

$$= 2704. \text{ psia}$$ 1

Oppgave 3 :

(iii) Continued :

$$\Delta P_F = \frac{2 f_f \cdot \rho_o \cdot u^2 \cdot L}{g_c \cdot D}$$

f_f ? ; Find N_{Re}; $N_{Re} = \frac{1.48 \cdot \rho_o \cdot q_o}{\mu \cdot D}$

$$= \frac{1.48 \times 46.672 \times 1000}{1.2 \times 2.875} = 20879.6$$ 1

Turbulent flow ... find f_f from Chart, using $\varepsilon = 0.001$ and N_{Re}.

$f_f = 0.0068$ 1

i.e. $$\Delta P_F = \frac{2 \times 0.0068 \times 46.672 \frac{lbm}{ft^3} \times u^2 \frac{ft^2}{s^2} \times 8000\ ft}{32.17 \left[\frac{lbm\ ft}{lbf\ s^2}\right] \times \left(\frac{2.875}{12}\right) ft}$$

$$= 658.84 \cdot u^2 \left[\frac{lbf}{ft^2}\right]$$

$$u = \frac{4Q}{\pi D^2} = \frac{4 \times 1000 \frac{stb}{d}}{3.142 \times \left(\frac{2.875}{12}\right)^2 ft^2} \times \frac{5.6147}{86400} \frac{ft^3}{s} \times \frac{d}{stb}$$

$= 1.44 \frac{ft}{s}$ 1

$$\therefore \Delta P_F = 658.84\,(1.44)^2 \frac{lbf}{ft^2} \times \frac{1}{144} \frac{ft^2}{in^2}$$

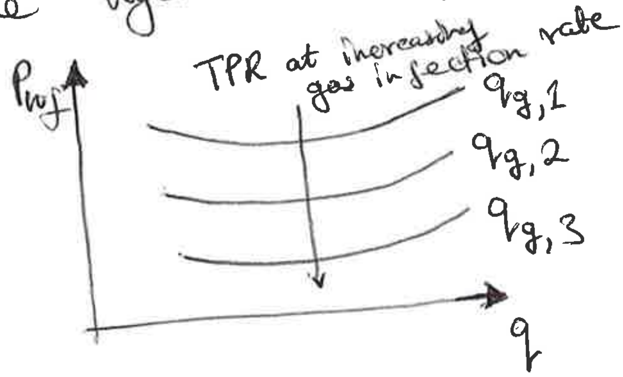
$= 9.5$ psia 1

$P_{wf} = 2704 + 9.5 + 1200 = 3914$ psia 1

Oppgave 4:

a i) Gaslift is the lifting of well fluid through the well to the surface 2 by means of the potential energy of gas.

ii) Gaslift decreases the TPR via a reduction of the density of the well fluid, and thus the hydrostatic pressure drop.



2 $q_{g_3} > q_{g,2} > q_{g1}$.

iii) Gas-lift can be used when the reservoir pressure drops so low that the IPR-curve 1 falls below the TPR-curve at the minimum well-head pressure, $P_{wh,min}$.

iv) $\Delta P = P_{wf} - P_{wh}$. $P_{wh} = 1500$ psi; $GLR_1 = 1000$ scf/stb

With gas injection, we get a new GLR_2,

$= 2000$ scf/stb.

Using the gradient curve diagram, P_{wf} at $GLR_2 = 2500$ psi. 1

Thus $\Delta P = P_{wf} - P_{wh} = 2500 - 1500$
$= 1000$ psia. 1

Gas injection rate

$$q_g = q_l \cdot (GLR_2 - GLR_1)$$
$$= 600 * (2000 - 1000)$$ 1
$$= 6 \times 10^5 \text{ scf/d}.$$

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b i) Acid treatment procedure for:

1. Carbonate reservoir
   - Determine the reservoir rock material so as to estimate dissolving power of the acid
   - Estimate the damage radius 1.5
   - Inject ≈ 15% HCL for acid treatment

2. Sandstone reservoir:
   - Determine reservoir rock material
   - Estimate damage radius 1.5
   - Pre flush with 15% HCL
   - Main wash with 3% HF + 12% HCL
   - Post-flush with 15% HCL.

b ii)

$$E_F = \frac{7}{7+S}$$

Befor treatment:

$$E_f = \frac{7}{7+18} = 0.28$$ 1

After treatment:

$$E_F = \frac{7}{7+3} = 0.7$$ 1

C i) Example of a reservoir for which hydraulic fracturing may be used to improve productivity

— Reservoirs with very low permeability e.g, tight shales. 1

ii) Acid fracturing is used for Carbonate reservoirs 1

iii) Fracture length for:

Elliptical fracture $r_e = \frac{\pi}{4} \cdot \frac{K_f \cdot W}{K_R} = 250\,m$

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Rectangular fracture; $r = \frac{K_f w}{K_R} = r_e \times \frac{4}{\pi}$

$= \frac{4 \times 250}{3.142} = 318.27\,m$ 1

d) i) Flow assurance issues that may occur in oil and gas flow:

- Corrosion → Due to high H_2S, O_2, and CO_2 content. These gas dissolve in water to form acidic solutions that corrode the pipe material. 1
- Wax and Asphalthene precipitation 1 → at low temperatures, wax and asphaltene precipitate due to low solubility.
- Scale - Deposition → 1 Due to changing pressure and temperature in the well which reduces the solubility of scale-forming mineral salts.
- Gas hydrates 1 → Forming of ice-like solid crystals when HC and water flow together at low pressures and high temperatures.

ii) Classification of Oil and Gas field chemicals:

- 0.5 Green chemicals — without any negative environmental impact
- 0.5 Yellow chemicals — with a little negative environmental impact, but considered usable.
- 0.5 Red chemicals — Environmentally hazardous
- Black Chemicals — Prohibited for discharge. 0.5

iii) Gas hydrates are considered the most common flow-assurance issue. 1 Chemicals used for its managements THIs (Methanol, Glycol, Salts), KHI (PVCap, PVP...), AAs ... 1

e - Plug and Abandonment 1

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