PET 200 – Prod. Olje & gass

Eksamen 23. Nov 2015 (ORD)

Løsningsforslag, Oppg. 1

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a) Konstant D_i, neglisjerbar høydeforskjell:

$$\Delta p = (p_1 - p_2) = \Delta p_f = \frac{1}{2}\rho u^2 \cdot f_D \frac{L}{D}$$

$$q = \frac{3000\ m^3/d}{24 \cdot 3600} = 0.0347\ m^3/s$$

$$u = \frac{4q}{\pi D_i^2} = \frac{4 \cdot 0.0347\ m^3/s}{\pi \cdot (0.15\ m)^2} = \underline{1.96\ m/s}$$

$$\Rightarrow \Delta p = \frac{1}{2} \cdot 750 \frac{kg}{m^3} \cdot (1.96\ m/s)^2 \cdot 0.02 \cdot \frac{25\,000\ m}{0.15\ m}$$

$$= 4\,802\,000\ Pa = 48.02\ bar$$

$$\rightarrow p_1 = 48.02 + 1.0 = \underline{\underline{49.02\ bar}}$$

b) $p_0 = 12.5\ bar$ $p_1 = 49.02\ bar$

$$\Delta p_p = 49.02 - 12.5 = 36.52\ bar = \underline{36.52 \cdot 10^5\ Pa}$$

$$\Delta p_p = \rho g H_p \rightarrow H_p = \frac{36.52 \cdot 10^5\ N/m^2}{750\ kg/m^3 \cdot 9.81\ m/s^2} = \underline{\underline{496.4\ m}}$$

c) Kompressor arbeid: $W_c = \frac{W_{is}}{\eta_{is}}$

$$W_{is} = p_1 v_1 \frac{k}{k-1}\left[\left(\frac{p_2}{p_0}\right)^{\frac{k-1}{k}} - 1\right]$$

$$v_1 = \frac{ZRT_1}{p_1} \Rightarrow p_1 v_1 = ZRT_1$$

$$R = \frac{R_0}{M_W} = \frac{8.314 \text{ J/mol K}}{\gamma \cdot 29 \text{ g/mol}} = 0.4038 \text{ J/g K} = \underline{403.8 \text{ J/kg K}}$$

(γ = 0.71)

$$p_1 v_1 = 0.9 \cdot 403.8 \frac{\text{J}}{\text{kg K}} \cdot \underbrace{(35 + 273.15)}_{308.15 \text{ K}} = 111988 \frac{\text{J}}{\text{kg}}$$

$$\left(v_1 = \frac{111988 \text{ Nm/kg}}{64 \cdot 10^5 \text{ N/m}^2} = 0.0175 \text{ m}^3/\text{kg} \right)$$

$$k = 1.3 - 0.31 \cdot (0.71 - 0.55) = \underline{1.25}$$

$$W_{is} = 111988 \cdot \frac{1.25}{0.25} \cdot \left[\left(\frac{170}{64}\right)^{\frac{0.25}{1.25}} - 1\right] = \underline{120822 \frac{\text{J}}{\text{kg}}}$$

Masse strøm:

$$\dot{m} = q_{st} \cdot \rho_{st} = 10^6 \frac{\text{Sm}^3}{\text{d}} \cdot \frac{101325 \text{ N/m}^2}{1 \cdot 403.8 \text{ J/kg K} \cdot 288.15 \text{ K}}$$

(p_{st} = 101325 N/m², T_{st} = 288.15 K)

$$= 870827 \text{ kg/d} = \underline{10.08 \text{ kg/s}}$$

Alt: $$\dot{m} = \frac{10^6 \text{ Sm}^3/\text{d} \cdot 0.71 \cdot 29 \text{ kg/kmol}}{23.64 \text{ Sm}^3/\text{kmol}} = 870981 \text{ kg/d}$$

$$= \underline{10.08 \text{ kg/s}}$$

$$\left(q_r = 10.08 \text{ kg/s} \cdot 0.0175 \text{ m}^3/\text{kg} = 0.1764 \text{ m}^3/\text{s} \right)$$

$$W_c = \frac{\dot{m} \cdot w_{is}}{\eta_{is}} = \frac{10.08\ \frac{kg}{s} \cdot 111\,988\ \frac{J}{kg}}{0.86} = 1312604\ \frac{J}{s}$$

$$= \underline{\underline{1312.6\ kW}}$$

d) Weymouth lign. snudd mhp. P_2:

$$\left(\frac{q_{sc} \cdot p_{sc}}{1.185 \cdot 10^7\ T_{sc}}\right)^2 = \frac{(P_1^2 - P_2^2) \cdot D^{5.333}}{\gamma L T z}$$

$$\rightarrow (P_1^2 - P_2^2) = \frac{\gamma L T z}{D^{5.333}} \cdot \left(\frac{q_{sc} \cdot p_{sc}}{1.185 \cdot 10^7\ T_{sc}}\right)^2$$

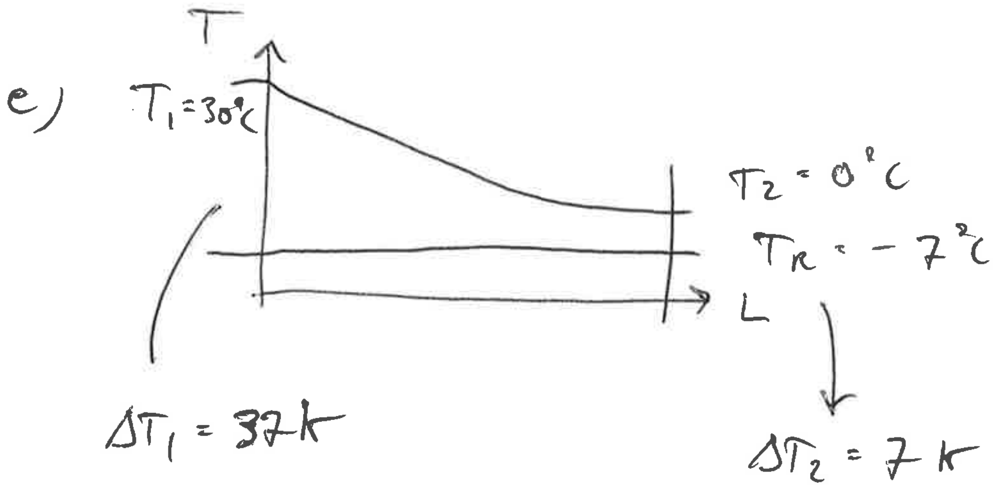
$$\rightarrow P_2 = \left[17000^2\ kPa - \frac{0.71 \cdot 300\,000\ m \cdot \overbrace{(30 + 273.15)}^{303.15\ K} \cdot 0.9}{(0.2\ m)^{5.333}} \times \left(\frac{10^6\ Sm^3/d \cdot 101.325\ kPa}{1.185 \cdot 10^7 \cdot 288.15\ K}\right)^2\right]^{1/2}$$

Hvilken temp. som skal ligge til grunn var strengt tatt ikke oppgitt eksplisitt i oppgaven, så ethvert valg e godkjent her :)

(svaret e relativt robust for temperaturen)

$$= 3962\ kPa = \underline{\underline{39.6\ bar}}$$

e)



$$LMTD = \frac{37 - 7}{\ln\left(\frac{37}{7}\right)} = \underline{\underline{18.02\ K}}$$

f) $\dot{Q} = \dot{m}\, c_p \cdot (T_1 - T_2) = U \cdot A \cdot LMTD$

$$\rightarrow A = \frac{3.5\ kg/s \cdot 2000\ J/kgK \cdot (30 - 0)\ K}{190\ W/m^2K \cdot 18.02\ K}$$

$$= \underline{\underline{61.3\ m^2}}$$

Solution POG Exam H2015 (Part – 2)

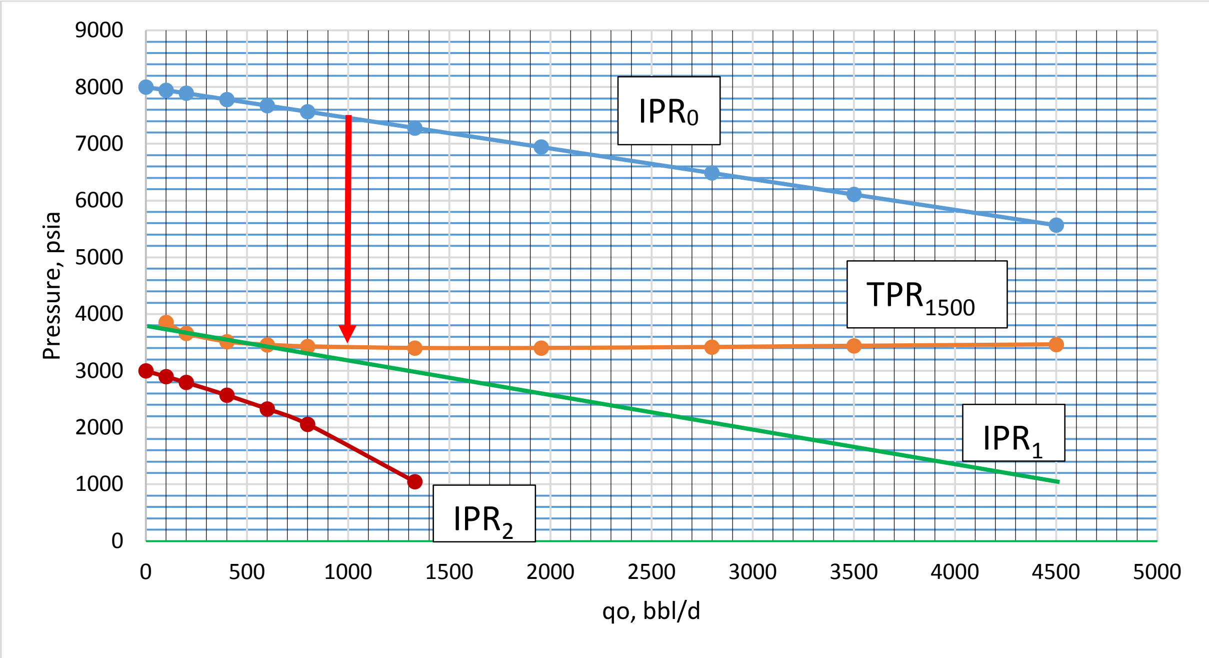
Question 2:

a. Natural drive regimes for: **Oil reservoir a)** include (i) Gas cap dive, (ii) Oil Expansion drive (if Pi > Pb), (iii) Solution gas drive (When Pi drops below Pb).
   Oil reservoir b) include (i) Solution gas drive, (ii) Oil expansion drive, (iii) water drive.
   Gas reservoir c) Gas expansion drive,
   Gas reservoir d) i)gas expansion drive and, ii) water drive.
b. Between reservoirs **a** and **b**: Water drive in reservoir **b** would give a higher recovery (40% - 50% recovery) compared with gas cap drive in reservoir a, which gives about 25% recovery.
   Between reservoir **c** and **d**; gas expansion drive in reservoir **c** would give higher recovery (80%), compared with water drive in reservoir d (60%).
c. All wells should be centered, perforations should also be centered. For reservoir a, the perforations must lie well below the gas cap. Perforations should be such that the obtained flow rate into the well is not too large or too small. [See fig. 1.3, 1.4, 1.5 in textbook; and lecture #1 – natural drive mechanisms - for fitting examples].
d. Reservoir **a)** gas breakthrough or gas coning; b) water breakthrough or water coning; c) in efficient recovery rate; d) water coning or ingress to the reservoir may cause barriers of water columns, which impede gas production.
e. Horizontal wells are recommended for reservoir with (i) Thin oil zones; (ii) Low permeability; (iii) very low productivity, like heavy oil reservoirs
f. Downhole safety valve (DSV) and production packer.

Question 3:

a. For well test data, $q_{o,test} = J*(p_e - p_{wf,test})$; $J = q_{o,test}/(p_e - p_{wf,test}) = 800/(8000-7567.6) = 1.85$ stb/d/psia
b. Maximum production rate at absolute open flow, $q_{o,max} = q_{o,b} + q_{o,max,add}$.
   $q_{o,b} = J*(pe-pb) = 1.85*(8000-3800) = 7770$ stb/d.
   $q_{o,max,add} = J*p_b/1.8 = 3905.6$ stb/d.
   $q_{o,max} = 7770 + 3905.6 = 11675.6$ stb/d.
c. Plateau rate is the maximum rate at which a well is operated, over a long period of time, during which decreasing reservoir pressure is compensated for by decreasing the wellhead pressure.
d. IPR-curve = $P_{wf,test}$ vs. $q_{o,test}$, TPR-curve = TPR vs. $q_{o,test}$ ($TPR = \Delta P_{test} + P_{wh,min}$).

q_o	$P_{wf,test}$	$P_{wh,test}$	ΔP	TPR_{1500}
STB/d	psia	psia	psia	psia
0	8000			
100.0	7945.9	5592.0	2353.9	3853.9
200.0	7891.9	5732.0	2159.9	3659.9
400.0	7783.8	5770.0	2013.8	3513.8
600.0	7675.7	5717.0	1958.7	3458.7
800.0	7567.6	5638.0	1929.6	3429.6
1330.0	7281.1	5380.0	1901.1	3401.1
1955.0	6943.2	5042.5	1900.7	3400.7
2798.0	6487.6	4569.0	1918.6	3418.6
3500.0	6108.1	4169.0	1939.1	3439.1
4500.0	5567.6	3603.0	1964.6	3464.6



e. $P_{wf0} = P_e – q_{o,1000}/J = 8000 – 1000/1.85 = 7459.5$ psia.

f. First find p_{wf} at $p_{wh,min}$. $P_{wf1} = (p_2 - p_1)*(q_{plat}-q_1)/(q_2 - q_1) + p_1 = (3401.1 - 3429.6)*(1000 – 800)/(1330 – 800) + 3429.6 = 3418.9$ psia.
$p_e = q_{plat}/J + p_{wf1} = 1000/1.85 + 3418.9 = 3959$ psia.
Drop in reservoir pressure = 8000 – 3959 = 4041 psia.
Time to reach minimum wellhead pressure, t = 4041/500 = 8.082 years.

g. We get two intersections. At the second intersection, we have unstable flow. This is because the flowrate is too low leading to liquid entrainment and possible slugging.

h. $P_{wh,min} = C*GOR^m*q_{o,min}/D_{64}{}^n$. $D_{64} = (C*GOR^m*q_{o,min}/p_{wh,min})^{1/n}$ = $(10*1000^{0.546}*600/1500)^{1/1.89} = 15.32$. Choke diameter = 15.32/64 = 0.24 inches.

i. Sonic flow is required at the choke to dampen pressure pulsations and slugging, so that these do not transmit upstream the choke and cause damage to process ant topside equipment.

j. We must first find the critical pressure condition, then find the pressure at the choke outlet.
$(pout/pin)c = (2/k+1)^{k/k-1}$= (2/2.2)1.2/0.2 =0.565.
$p_{out} = p_{wh}*0.565 = 846.7$ psia.

k. Ice would form if the temperature at the outlet of the choke is ≤ 0°C, 32 °F, or 492 °R. The temperature at the outlet of the choke $T_{out} = T_{wh}*(pout/pin)c^{k-1/k} = (100 + 460)*(0.565)^{0.2/1.2} = 509.09$ °R. No ice formation

l. Use i) Methanol, ii) MEG (Mono ethylene glycol); some salts and other alcohols or glycols may be used as well.

m. It is not possible to produce from the well *with natural lift* at p_e = 3000psia because the obtainable p_{wf} is too low to lift the oil, as the IPR falls below the TPR curve at the minimum wellhead pressure. The well may be produced though, with the use of *artificial lift*.

n. $q_g = q_{o,min}*(GLR_2 – GLR_1) = 600*(GLR_2 – 1000)$ scf/d.

o. From the gradient curve diagram, $GLR_2 = 1800$. Thus $q_g = q_{o,min}*(GLR_2 – GLR_1) = 600*(1800 – 1000) = 4.8 \times 10^5$ scf/d.

Question 4:

a. Skin factor before acid treatment $S = hk/(141.2*\mu_o*B_o*J) + 0.75 – \ln(r_e/r_w) =$ $100*75/(141.2*1.5*1.7*1.85) + 0.75 – \ln(1000/0.375) = 4.12$.
b. Skin factor after treatment = $100*75/(141.2*1.5*1.7*3) + 0.75 – \ln(1000/0.375) = -0.2$
c. Types of skin include
    1. Perforation skin (from crushing of rock material and plugging from debris during perforation job)
    2. Biological skin (from growth of anaerobic bacteria from injected water)
    3. Skin due to precipitation of asphalthenes or wax
    4. Gravel packing skin
    5. Due to precipitation of salts
    6. Skin due to plugging by reservoir fines
d. Flow efficiency $E_f = 7/(7+S)$. Before treatment $E_f = 7/(7+4.12) = 0.63$. After treatment $E_f = 7/(7-0.2) = 1.03$. Improvement in flow = (1.03 – 0.63)*100% = 40%.
e. The reservoir rock material must be carbonate, because we have negative skin. The acid naturally reacts with the carbonate material; etching out more pores and improving the permeability above the natural permeability with darcy flow.
f. The acid used was (15%) HCL.
g. Fracturing is recommended for reservoirs with very low permeability; like in tight shales or if there is a need to improve the permeability across the entire reservoir.

h.

Regular acid treatment	**Acid fracturing**
1. The acid **goes** in the pore system and **not** into fractures.	1. The acid **goes** in the fractures and **not** into the pore system
2. The pump pressure must be **below** the fracture pressure.	2. The pump pressure must be **above** the fracture pressure.
3. **Low** pump rate and **low** pressure	3. **High** pump rate and **high** pressure
4. The liquid **must** not clog the pores	4. The liquid **should** clog pores temporarily
5. The acid comes a **short distance from the well wall** (1 to 1.5 m max)	5. The acid comes **more than 100 meters from the well**.
6. The treatment **repairs** damaged formation	6. The treatment **increases** the natural permeability
7. Used **both** on sandstone and carbonate / limestone	7. Used **only** on carbonate
8. Used on **both** high- and low permeable reserviors	8. Used **only** on low permeable reservoirs

i. Bridging theory: Particles will bridge on a slot provided the width of the slot is less than two particle diameters. Likewise particles will bridge on a hole if the perforation diameter does not exceed about 3 particle diameters.

$$D_{slot} < 2D_{gravel}$$

$$D_{perforation} \leq 3D_{gravel}$$

j. $d_{50,gravel}$ = 5-6×$d_{50,sand}$ = 0.023 to 0.028 inches.
From the commercial gravel data this falls within mesh size 20-40;
with a $d_{min,gravel}$ = 0.017 and $d_{max,gravel}$ = 0.033 inches.
The gravel-pack screen size is normally 0.5×$d_{min,gravel}$ = 0.5*0.017 = 0.0085 inches.