LØSNINGSFORSLAG
PET 120
VÅR 2020

OPPGAVE 1

a) Produsert olje ved vanngjennombrudd:

Først må vi finne tiden det tar til vanngjennombrudd:

$$\underline{\underline{t_{BT}}} = \frac{L}{v_{Swf}} = \frac{L}{\frac{q_t}{\phi A}\left(\frac{df_w}{dS_w}\right)_{Swf}} = \frac{120\,m}{\frac{150\,m^3/d}{0.25 \cdot 1000\,m^2} \cdot 2.06} = \underline{97\text{ dager}}$$

$$q_t = q_w = Q_w \cdot B_w = 150\,Sm^3/d \cdot 1.0\,m^3/Sm^3 = \underline{150\,m^3/d}$$

$f_{wf} = 0.74$, $S_{wf} = 0.52$, stigningstall til tangent:

$$\frac{0.74 - 0}{0.52 - 0.16} = 2.06$$

Produsert olje: $\underline{\underline{N_p}} = \frac{q_w \cdot t_{BT}}{B_o} = \frac{150\,m^3/d \cdot 97\,d}{1.50\,m^3/Sm^3}$

$$= \underline{\underline{9700\,Sm^3}}$$

b) Oljeutvinning som % av produserbar olje:

Produserbar olje: $\frac{\phi A L(1 - S_{wi} - S_{or})}{B_o}$

$$= \frac{0.25 \cdot 1000\,m^2 \cdot 120\,m \cdot (1 - 0.16 - 0.21)}{1.50\,m^3/Sm^3} = \underline{12600\,Sm^3}$$

$$\text{Utvinningen} = \frac{9700\,Sm^3}{12600\,Sm^3} \cdot 100 = \underline{\underline{77.0\,\%}}\text{ av produserbar olje}$$

c) Produsert olje etter 2 år med vanninjeksjon:

$t = 2$ år $= 2 \cdot 365 = 730$ dager.

Etter 730 dager er vannmetningen rund brønnen lik S_{wp}'.

Denne metningen (planet med vannmetning S_{wp}') har beveget seg fra injektor til produsent med en hastighet beskrevet med B-L ligningen.

$$t = \frac{L}{v_{swp}} \Rightarrow v_{swp} = \frac{L}{t}$$

$$\frac{q_t}{\phi A} \cdot \left(\frac{df_w}{dS_w}\right)_{Swp} = \frac{L}{t}$$

$$\left(\frac{df_w}{dS_w}\right)_{Swp} = \frac{L \phi A}{q_t \cdot t} = \frac{120\,m \cdot 0.25 \cdot 1000\,m^2}{150\,m^3/d \cdot 730} = \underline{0.28}$$

Stigningstallet til tangenten som skal skjære fraksjonsstrømskurven i punktet (S_{wp}', f_{wp}') skal være 0,28.

Man tegner en linje som skal parallell-forskyves til tangering med fraksjonsstrøms-kurven.

Man leser så av S_{wp}, f_{wp} og $\bar{S}_w$.

$S_{wp} = 0.70$

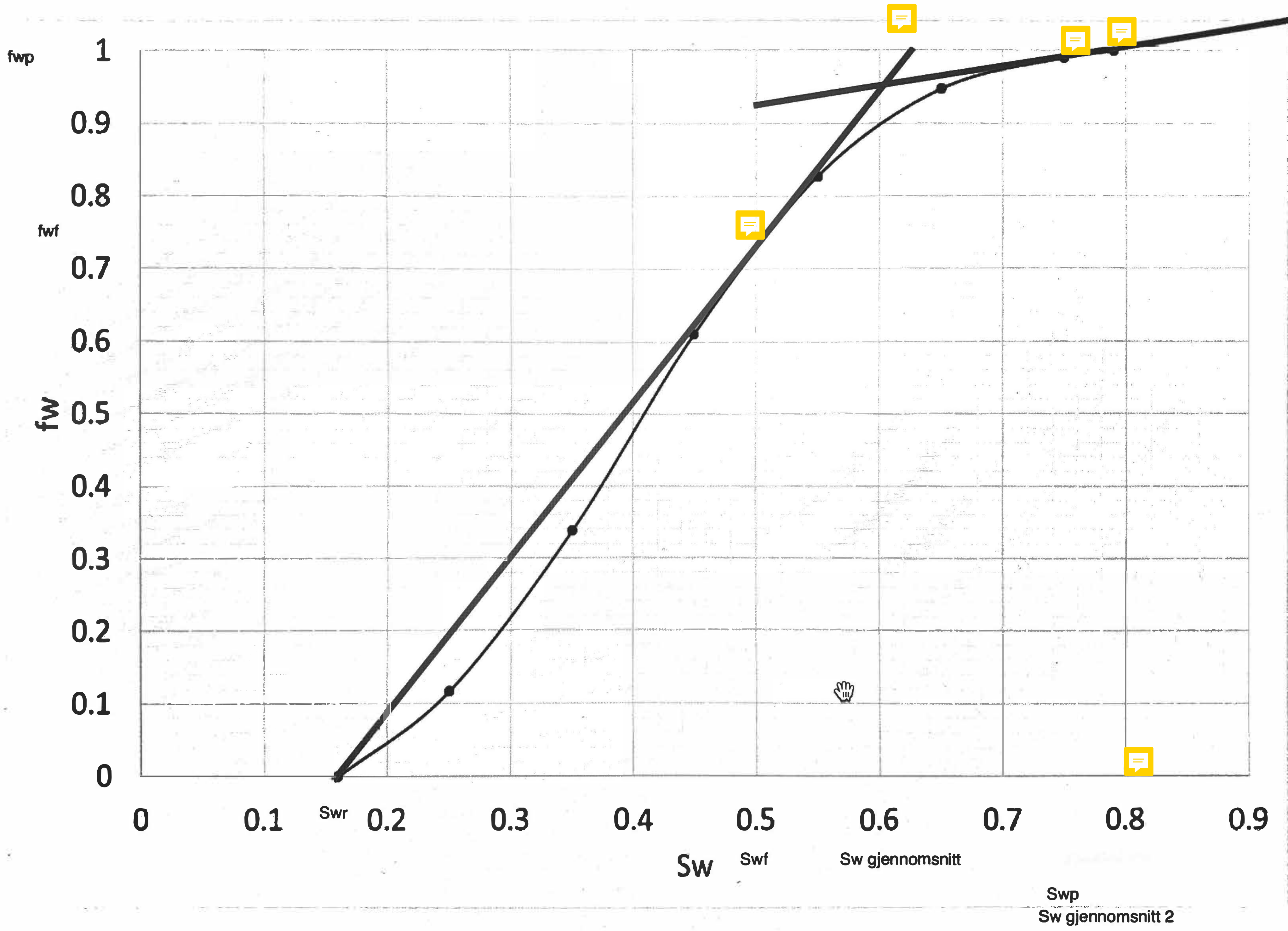
$f_{wp} = 0.97$

$\bar{S}_w = 0.76$

$$\underline{\underline{N_p}} = \frac{\phi A L (\bar{S}_w - S_{wi})}{B_o} = \frac{0.25 \cdot 1000\,m^2 \cdot 120\,m \cdot (0.76 - 0.16)}{1.50\,m^3/Sm^3}$$

$$= \underline{\underline{12000\ Sm^3}}$$

Attachment 2



d) $$\underline{\underline{WOR}} = \frac{Q_w}{Q_o} = \frac{\frac{q_w}{B_w}}{\frac{q_o}{B_o}} = \frac{\cancel{q_t} \cdot f_{wp} \cdot B_o}{\cancel{q_t} \cdot (1 - f_{wp}) \cdot B_w}$$

$$= \frac{0{,}97 \cdot 1{,}50 \ m^3/Sm^3}{(1 - 0{,}97) \cdot 1{,}0 \ m^3/Sm^3} = \underline{\underline{48{,}5 \ Sm^3/Sm^3}}$$

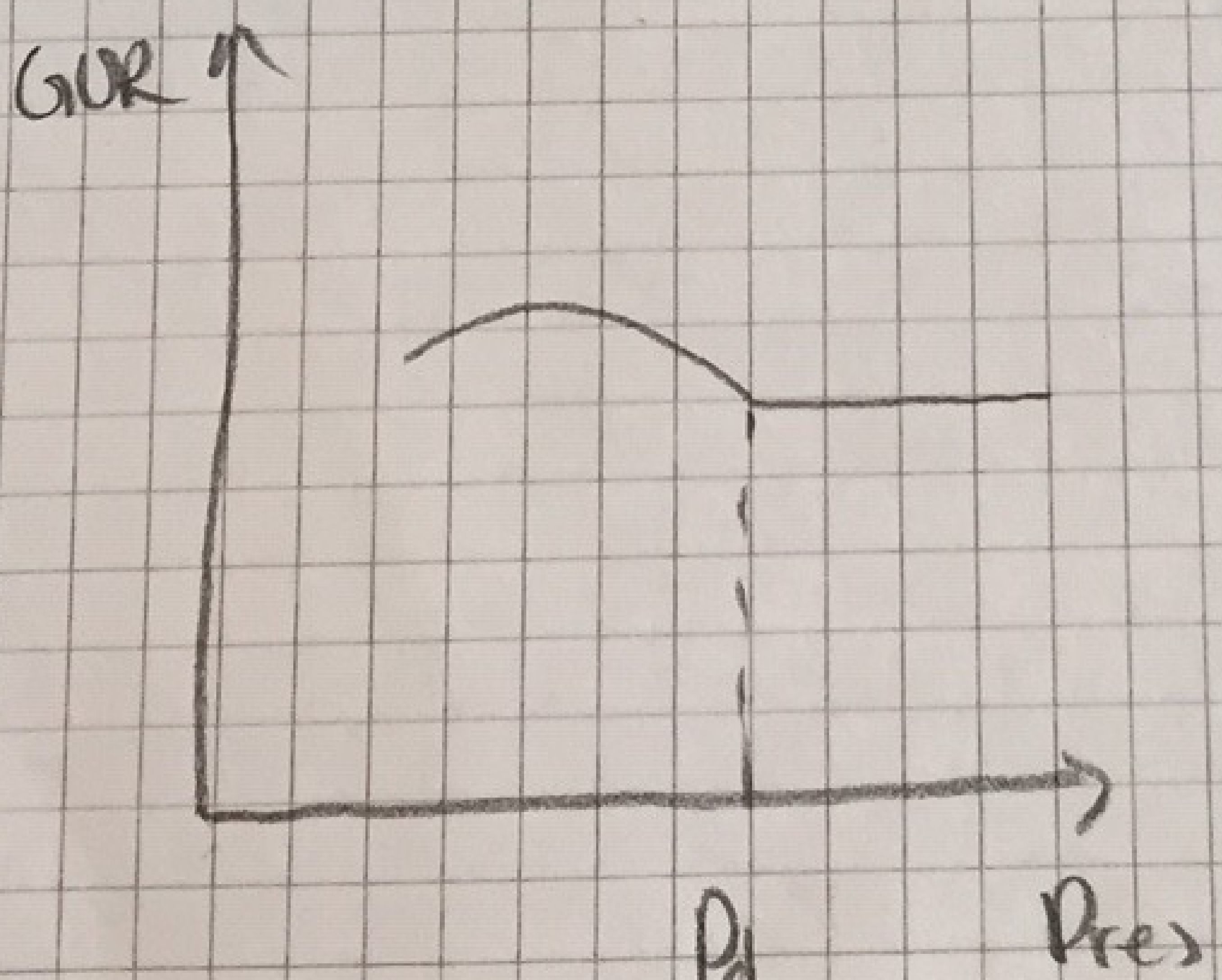
OPPGAVE 2

a) Reservoarfluidets faseoppførsel i reservoaret:

Ved $P > P_d$ er reservoarfluidet enfase gass.

Ved $P < P_d$ vil en del av gassen kondensere og danne en væskefase. Oljemetningen er lav og denne fasen er ofte immobil.
Væskefraksjonen øker og når et maksimum før den igjen avtar.

Ved overflaten produseres det for det meste gass, men også noe lett olje / kondensat.



GOR ~ 3000 - 30000 SCF/SBL

b) $\underline{GOR_2} = \frac{V_g}{V_{STO}} = \frac{V_g}{\frac{n_{STO} \cdot M_{STO}}{\rho_{STO}}} = \frac{L_1 \cdot V_2 \cdot V_m}{\frac{L_1 \cdot L_2 \cdot L_3 \cdot 191,49}{814,9 \ kg/m^3}} = \underline{\underline{167,3 \ Sm^3/Sm^3}}$

c) $\underline{GOR_{TOT}} = \frac{V_{g,TOT}}{V_{STO}} = \frac{n_g \cdot V_m}{\frac{n_{STO} \cdot M_{STO}}{\rho_{STO}}} = \frac{(1 - n_{STO}) \cdot V_m}{\frac{n_{STO} \cdot M_{STO}}{\rho_{STO}}}$

$= \frac{(1 - L_1 \cdot L_2 \cdot L_3) \cdot V_m}{L_1 \cdot L_2 \cdot L_3 \cdot 191,49} \cdot 814,9 \ kg/m^3 = \underline{\underline{1629,7 \ Sm^3/Sm^3}}$

d) Produksjon av gass og olje $P_i \rightarrow P_d$

Fluidet er enfase gass ved $P > P_d$, derfor bruker vi:

Antall mol produsert = Antall mol initielt − antall mol igjen

$\Delta n_{prod} = n_i - n_d$

$= \frac{P_i V_i}{Z_i R T_{res}} - \frac{P_d V_d}{Z_d R T_{res}}$ $\quad V_i = V_d = HCPV$ konstant

$\underline{HCPV} = V_b \cdot \phi \cdot (1 - S_{wi}) = 2 \cdot 10^6 m^3 \cdot 0,24 \cdot (1 - 0,12)$

$= \underline{422\,400 \ m^3}$

$\Delta n_{prod} = \frac{600 \ bar \cdot 100 \frac{kPa}{bar} \cdot 422\,400 m^3}{1,446 \cdot 8,3145 \frac{kPa \, m^3}{kgmol \cdot °K} \cdot (100 + 273,15)°K} - \frac{492 \ bar \cdot 100 \frac{kPa}{bar} \cdot 422\,400 m^3}{1,26 \cdot 8,3145 \frac{kPa \, m^3}{kgmol \, °K} \cdot (100 + 273,15)°K}$

$= 5\,649\,204,3 \ kgmol - 5\,316\,170,3$

$= \underline{333\,034 \ kgmol}$

$\underline{\underline{\text{Produsert gass}}} = \Delta n_{prod} \cdot (1 - n_{STO}) \cdot V_m = 7\,416\,561,3 \ Sm^3$

$= \underline{\underline{7,42 \cdot 10^6 \ Sm^3 = V_g}}$

$\underline{\text{Produsert olje}}$: $GOR = \frac{V_g}{V_{STO}}$

$\underline{\underline{V_{STO}}} = \frac{V_g}{GOR} = \frac{7\,416\,561,3 \ Sm^3}{1629,7 \ Sm^3/Sm^3} = \underline{\underline{4550,9 \ Sm^3}}$

e) $\underline{\underline{IGIP}} = n_i \cdot n_g \cdot V_m = n_i \cdot (1 - n_{STO}) \cdot V_m$

$= 5649204{,}3 \text{ kgmol} \cdot (1 - 0{,}2495 \cdot 0{,}6124 \cdot 0{,}3806) \cdot 23{,}6447 \text{ Sm}^3/\text{kgmol}$

$= 125\,805\,984{,}4 \text{ Sm}^3 = \underline{\underline{125{,}8 \cdot 10^6 \text{ Sm}^3}}$

$\underline{\underline{IOIP}} = \dfrac{IGIP}{GOR_{tot}} = \dfrac{125\,805\,984{,}4 \text{ Sm}^3}{1629{,}7 \text{ Sm}^3/\text{Sm}^3} = \underline{\underline{77\,195{,}8 \text{ Sm}^3}}$

f) 1. Utvinningsgrad av gass ned til P_d:

$\dfrac{V_g}{IGIP} \cdot 100\% = \dfrac{7\,416\,561{,}3 \text{ Sm}^3}{125\,805\,984{,}4 \text{ Sm}^3} \cdot 100\% = \underline{\underline{5{,}9\,\%}}$

Utvinningsgrad av olje ned til P_d:

$\dfrac{V_{STO}}{IOIP} \cdot 100\% = \dfrac{4550{,}9 \text{ Sm}^3}{77\,195{,}8 \text{ Sm}^3} = \underline{\underline{5{,}9\,\%}}$

Like verdier pga konstant komposisjon over P_d

2. Total utvinningsgrad av reservoarfluid fra P_i til P_a

Fra P_i til P_d har det blitt produsert 330034 kgmol av reservoarfluidet.

Ved P_d er det 5 316 170,3 kgmol igjen.

Ved P_a har vi produsert 54,56 % av disse, noe som tilsvarer:

$5\,316\,170{,}3 \cdot 0{,}5456 = 2\,900\,502{,}5$ kgmol

Totalt produsert antall mol $= 2\,900\,502{,}5 + 330\,034{,}0$

$= 3\,230\,536{,}5$ kg mol $= \Delta n_{tot}$

$\dfrac{\Delta n_{tot}}{n_i} \cdot 100\% = \dfrac{3\,230\,536{,}5}{5649204{,}3} \cdot 100\% = \underline{\underline{57\,\%}}$

Oppgave 3

a) Porosity of the core sample:

$$\varphi = \frac{V_p}{V_b}, \tag{1}$$

where V_p – volume of interconnected pores in the core sample (pore volume), V_b – bulk volume of the sample.

$$V_p = \frac{m_{sat} - m_{dry}}{\rho_l}, \tag{2}$$

where m_{sat} - weight of 100% water saturated sample in air, m_{dry} - weight of dry sample in air, ρ_l - density of saturated liquid (water).

For the cylindrical core sample:

$$V_b = \frac{\pi d^2 l}{4}, \tag{3}$$

where d – core diameter, l – core length.

Substitute Eq. (2) and (3) into Eq. (1):

$$\varphi = \frac{4 \cdot (m_{sat} - m_{dry})}{\rho_l \pi d^2 l} = \frac{4 \cdot (182 - 150)}{1.02 \cdot 3.14 \cdot 3.8^2 \cdot 7.6} \approx 0.36$$

In this case, the effective porosity is calculated, since when the core sample is saturated/flooded with water, only the interconnected pores are filled.

b) Water permeability using "plotting technique":

$$k = a\frac{\mu l}{A}, \tag{4}$$

where a – trend line slope coefficient (from the plot, $a = 0.0934$), μ – viscosity of water, l – core length, A – cross-sectional area of the core.

$$k = a\frac{\mu l}{A} = a\frac{4\mu l}{\pi d^2} = 0{,}0934 \cdot \frac{4 \cdot 0.9 \cdot 7.6}{3.14 \cdot 3.8^2} \approx 0.06\, Da = 60\, mDa$$

The calculated permeability is absolute, since the sample is saturated with one phase.

c) Initial water saturation:

$$S_{wi} = \frac{V_{wi}}{V_p} = \frac{V_p - V_{wp}}{V_p} = 1 - \frac{V_{wp}}{V_p}, \tag{5}$$

where V_{wi} – volume of water inside the core after oil flooding, V_p – pore volume, V_{wp} – volume of water produced during oil flooding.

$$V_p = \frac{m_{sat} - m_{dry}}{\rho_l} = \frac{182 - 150}{1.02} \approx 31.4\, ml$$

$$S_{wi} = 1 - \frac{21}{31.4} \approx 0.33$$

Initial oil saturation:

$$S_{oi} = 1 - S_{wi} = 1 - 0.33 = 0.67$$

d) 1. Residual oil saturation:

$$S_{or} = (1 - S_{wi}) - \frac{V_{op}}{V_p} = S_{oi} - \frac{V_{op}}{V_p}, \tag{6}$$

where S_{wi} – initial water saturation, V_{op} – volume of oil produced during recovery test, V_p – pore volume of the core.

Oil recovery factor:

$$RF = \frac{Amount\ of\ produced\ oil}{Original\ Oil\ in\ Place\ (OOIP)} = \frac{V_{op}}{S_{oi} \cdot V_p}, \tag{7}$$

Amount of produced oil:

$$V_{op} = \frac{RF}{100\%} \cdot S_{oi} \cdot V_p \tag{8}$$

Substitute Eq. (8) into Eq. (6):

$$S_{or} = S_{oi} - \frac{\frac{RF}{100\%} \cdot S_{oi} \cdot V_p}{V_p} = S_{oi} - \frac{RF}{100\%} \cdot S_{oi} = S_{oi} \cdot \left(1 - \frac{RF}{100\%}\right)$$

$$S_{or} = 0.67 \cdot (1 - 0.4) \approx 0.4$$

2. The efficiency of oil displacement by water from the pore space of a rock is determined by the interaction of capillary and viscous forces.

3. The parameter used to characterize the competition between these forces is called a <u>capillary number</u>.

e) The core plug is water-wet, determined by the end-point relative permeability to water and oil, and that the curves are intersecting at Sw>0.5. See book Zolotukhin and Ursin chapter on rock wettability and relative permeability.
In a water-wet system water is located on pore walls and oil is located in the middle of the pores.

OPPGAVE 3

f) 1. Vis at $m = 0.18$

$$\underline{\underline{m}} = \frac{G\,B_{gi}}{N \cdot B_{oi}} = \frac{V_b \cdot \bar{\Phi} \cdot (1-S_{wi})}{V_b \cdot \bar{\Phi} \cdot (1-S_{wi})} = \frac{0.22 \cdot 10^8}{1.2 \cdot 10^8} = \underline{\underline{0.18}}$$

2. Produsert gass ved nåværende P_{res}:

$R_p = 1100$ SCF/STB

$$R_p = \frac{G_p}{N_p} \Rightarrow G_p = R_p \cdot N_p = 1100\ \text{SCF/STB} \cdot 5 \cdot 10^6\ \text{STB}$$

$$\underline{\underline{G_p}} = \underline{\underline{5.5 \cdot 10^9\ \text{SCF}}}$$

g) $F = N(E_o + mE_g + E_c) + W_e \cdot B_w$

$F = N_p\left[B_o + (R_p - R_s)B_g\right] + W_p \cdot B_w$

$$N = \frac{N_p\left[B_o + (R_p - R_s)B_g\right] + W_p \cdot B_w - W_e \cdot B_w}{(E_o + m\,E_g + E_c)}$$

$\underline{E_o} = (B_o - B_{oi}) + (R_{si} - R_s)\,B_g$

$= (1.33 - 1.35) + (600 - 500) \cdot 0.0015 = \underline{0.13}$

$\underline{E_g} = B_{oi}\left(\frac{B_g}{B_{gi}} - 1\right) = 1.35 \cdot \left(\frac{0.0015}{0.0011} - 1\right) = \underline{0.49091}$

$E_c = B_{oi}(1+m)\left(\frac{c_w S_w + c_f}{1 - S_w}\right)\Delta p$

$= 1.35 \cdot 1.18 \cdot \left(\frac{0 \cdot S_w + 0}{1 - S_w}\right) \cdot (3000 - 2500) = \underline{\underline{0}}$

$$N = \frac{N_p[B_o + (R_p - R_s)B_g] + W_p B_w - W_e B_w}{(E_o + mE_g + E_c)}$$

$$= \frac{5 \cdot 10^6 [1{,}33 + (1100 - 500) 0{,}0015] + (0{,}2 \cdot 10^6 - 3 \cdot 10 \cdot 10^6) \cdot 1.00}{(0.13 + 0.18 \cdot 0.49091 + 0)}$$

$$= \frac{8\,350\,000}{0.2183638} = \underline{38.24 \cdot 10^6 \text{ STB}}$$

Recovery factor:

$$\frac{N_p}{N} = \frac{5 \cdot 10^6 \text{ STB}}{38{,}24 \cdot 10^6 \text{ STB}} \cdot 100\% = \underline{\underline{13.1\ \%}}$$

h) Utstrekningen på reservoaret:

$$V_o^R = V_o^S \cdot B_o = N \cdot B_{oi} = 38{,}24 \cdot 10^6 \text{ STB} \cdot 1{,}35 \frac{\text{bbl}}{\text{STB}}$$

$$= \underline{51\,624\,000 \text{ bbl}}$$

$$V_o^R = V_b \cdot \Phi \cdot (1 - S_{wi}) = A \cdot h \cdot \Phi \cdot (1 - S_{wi})$$

$$A = \frac{V_o^R}{h \cdot \Phi \cdot (1 - S_{wi})} = \frac{51\,624\,000 \text{ bbl} \cdot 5{,}615 \text{ ft}^3/\text{bbl}}{100 \text{ ft} \cdot 0.20 \cdot (1 - S_{wi})}$$

$$A = \frac{14\,493\,438}{(1 - S_{wi})} \text{ ft}^2$$

Antar en $S_{wi} = 0{,}20$

$$\Rightarrow \underline{\underline{A}} = \frac{14\,493\,438}{(1 - 0{,}20)} = \underline{\underline{18.2 \cdot 10^6 \text{ ft}^2}}$$