NATIONAL EXAMS – May 2002

98-PET-A6 : Reservoir Mechanics

3 HOURS DURATION

NOTES:

If doubt exists as to the interpretation of any question, the candidate is urged to submit a clear statement of any assumptions made along with the answer paper.

2. The candidate must answer problems 1 and 2, and can choose any three of the remaining six problems. Only the first three questions, in addition to problems 1 and 2, will be marked.

3. Candidates may use one of two calculators, the Casio or Sharp approved models. This is closed book examination.

4. All questions have equal value.

5. Equations sheet, conversion factors and useful charts are enclosed. Please use the graph paper provided where warranted.

PROBLEM 1 (20 points total, each question worth 4 points)

Answer the following questions, with the aid of a drawing/graph if necessary:

What are saturated and undersaturated oil reservoirs?

2. Define hydraulic diffusivity.

3. Which type of decline predicts a pessimistic forecast, and which one an optimistic forecast? Provide reasons.

4. Why is a material balance analysis called a zero-dimensional analysis? Express the necessary and sufficient conditions that a material balance analysis should be subject to.

5. What is the difference between a cumulative drive index and an incremental drive index?

PROBLEM 2 (20 points)

The following flow-test data have been obtained from a fractured well in a solution-gas drive reservoir. This well has produced for five weeks. It drains about 40 acres and has a well radius of 0.3 ft.

well pressure, p_w (psig)	oil rate, q_o (STB/day)
2,687	92
2,395	178
2,010	291
1,650	345
1,215	377

The undamaged permeability to oil as determined form a pressure buildup DST is 20.7 md, and B_o is 1.23. The net thickness is 15 ft, and the reservoir oil viscosity is 1.22 cp. Plot the productivity index versus p_w. What is the damage ratio based on the straight-line portion of the data? Estimate the maximum pumping rate.

Determine the maximum producing rate indicated by each data point in the table above. What is the maximum producing rate based on the Vogel IPR curve? What is the producing rate if the producing bottom-hole pressure can only be lowered to 525 psig?

PROBLEM 3 (20 points)

The following information is available about a producing reservoir:

- original oil in place (from geologic data) = 10^9 stb
- there is no original gas cap or water drive
- there are 60 producing wells

- average reservoir depth = 6500 ft
- initial reservoir pressure = 2930 psia
- interstitial water saturation = 14%
- average specific gravity of the produced gas = 0.72
- bottom hole flowing pressure = 1500 psia
- producing wellbore pressure under artificial lift conditions = 200 psia
- allowable producing rate for the reservoir = 15,000 stb/day
- initial measured productivity index = 0.75 bbl/day/psi/ well

The following results are obtained from performance prediction calculations:

pressure P_e (psia)	producing GOR R_p (scf/stb)	oil saturation S_o (%)	cum. oil production N_p (stb×10⁶)	oil formation volume factor B_o (rb/stb)	oil viscosity μ_o (cp)	effective oil permeability k_o (D)
2930 (P_i)	1350	86.0	0	1.429	0.406	0.075
2600	1350	86.0	1.391	1.444	0.372	0.075
2400	1350	86.0	2.270	1.462	0.330	0.075
2100 (P_b)	1350	86.0	3.456	1.480	0.310	0.075
1800	19456	81.7	7. 420	1.468	0.383	0.059
1500	3739	75.8	12.229	1.440	0.488	0.039
1200	6502	70.8	15.721	1.399	0.637	0.029
1000	8585	67.5	17.124	1.360	0.749	0.023
700	13510	62.4	18.981	1.287	0.950	0.018
400	17225	57.3	20.604	1.202	1.253	0.014

Determine the pressure below which this reservoir will no longer be able to sustain the allowable producing rate. State your assumptions, and show your calculations.

PROBLEM 4 (20 points)

A new oil well produced 500 stb/d for 3.5 days. It then was shut in for a pressure buildup test, where the following data were recorded:

time after shut-in (hours)	p_{ws} (psig)
0	1,150
2	1,794
4	1,823
8	1,850
16	1,876
24	1,890
48	1,910

For this well, net sand thickness h is 25 ft, formation volume factor B_o is 1.33 rb/stb, porosity ϕ is 0.21, total compressibility c_t is 20×10^{-6}, oil viscosity μ_o is 1.05 cp, and wellbore radius r_w is 0.3 ft. From these data, estimate formation permeability k, initial reservoir pressure p_i, and skin factor s. What assumption have you made about distance from tested well to reservoir boundaries?

PROBLEM 5 (20 points)

Calculate the initial gas in place in a closed reservoir if, after producing 500 MMscf, the reservoir pressure has declined to 2940 psia from an initial pressure of 3040 psia. Reservoir temperature is 175°F, and the gas gravity is 0.61 (assume methane and ethane only). The molecular weight of air is 29 lbm/lb mol. Standard conditions are 14.7 psia and 60°F. Other useful parameters are:

component	molecular weight (lbm/lb mol)	critical temperature (°R)	critical pressure (psia)
methane	16.04	343.37	667.8
ethane	30.07	550.09	707.8

If the reservoir pressure measurement were incorrect and should have been 2840 psia instead of 2940 psia, what would have been the true value of initial gas in place? What is the percentage error involved?

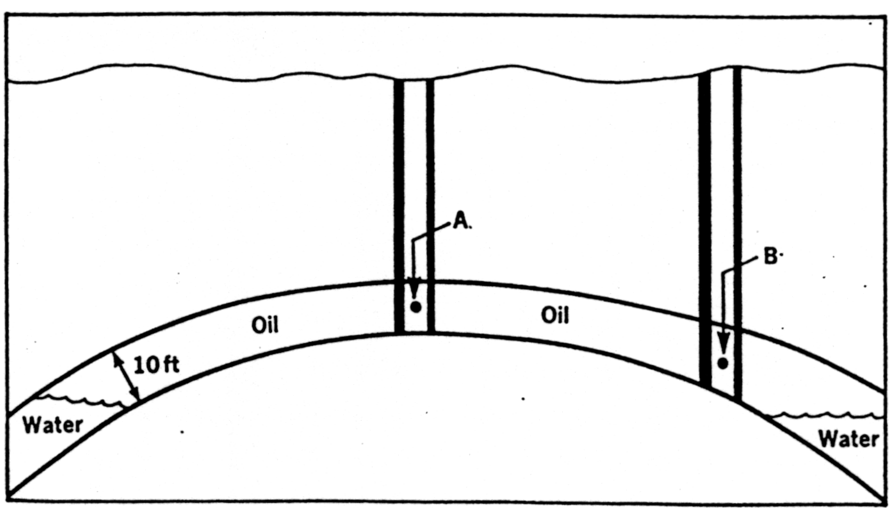
PROBLEM 6 (20 points)

A production model is needed for an exploration prospect. Geologists estimate that the prospect will have an ultimate recovery of 200 million barrels of oil. From time zero (today), it is anticipated that it will be five years before a discovery is made, with another five years required to complete full development of the field. Production will begin one year after the discovery is made (assume a starting rate of 100 BOPD), reaching a peak rate of 60,000 barrels per day when development is complete. Production will be maintained at the peak rate for 5 years, and then decline to an economic limit of 500 barrels of oil per day. Production decline is assumed to be exponential. Also assume that the production during the development period will increase exponentially.

Draw the production forecast graph. Determine the decline rate once the peak rate can no longer be maintained, and the total years from "today" to abandonment.

PROBLEM 7 (20 points)

Consider the following situation where well A is producing and well B, which was a weak producer, was shut-in when water appeared. Water drive activity does not affect the pressures over time. Assume no well damage and radial flow.



The following reservoir data are given:

- permeability to oil = 95 md
- reservoir oil viscosity = 0.715 cp
- well radius = 0.4 ft
- effective drainage radius = 4000 ft
- reservoir thickness = 10 ft
- depth of well A = 4500 ft subsea
- depth of well B = 5500 ft subsea
- reservoir oil specific gravity = 1.0
- saturation pressure = 2,000 psi
- flowing BHP at well A = 2,250 psi
- shut-in BHP at well B = 3,000 psi

What is the producing rate in reservoir barrels per day for the dome layout indicated? For the same prevailing pressures, what would be the producing rate if the reservoir were flat (assume that r_e = 3950 ft in this case)?

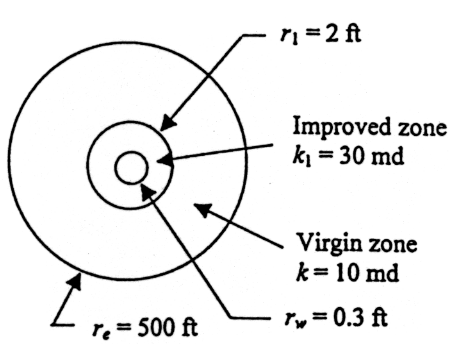
PROBLEM 8 (20 points)

During fracturing/acidizing operations, some portions of the formation around the wellbore are improved. The improved zone in one of those portions has an increased permeability compared to the rest of the formation (virgin zone). One way of characterizing this situation considers an equivalent wellbore radius, r_w', which is greater than the real wellbore radius, r_w, compensating for any reduced pressure drop due to the improved zone with a greater permeability. This way, you consider an equivalent reservoir with the same uniform permeability as that of the virgin zone, but with a wellbore radius r_w'. The external boundary radius, r_e, is identical for both cases.

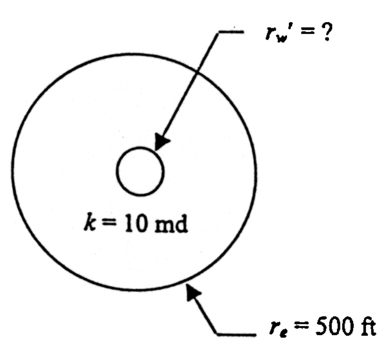
The following information is given for this reservoir:

- virgin zone permeability k = 10 md
- improved zone permeability k_I = 30 md
- improved zone radius r_I = 2 ft
- wellbore radius r_w = 0.3 ft
- external boundary radius r_e = 500 ft

Find r_w' for the equivalent reservoir. Clearly state any assumptions you make. Had you had the ability to increase the permeability of the improved zone with radius r_I as much as you wanted, what would the upper limit of r_w' be? Show analytically.



Actual system



Equivalent system

USEFUL EQUATIONS

$t_a = \frac{\ln(q_i - q_a)}{D}$ $(\Delta p)_{skin} = S\left(\frac{q_o \mu_o B_o}{2\pi kh}\right)$ $T_r = \frac{T}{T_{sc}}$ $G\left(\frac{z}{p}\right) - G\left(\frac{z_i}{p_i}\right) = G_p\left(\frac{z}{p}\right)$

$pV = nzRT$ $E_o = (B_o - B_{oi}) + (R_{si} - R_s)B_g$ $G(B_g - B_{gi}) + W_e = G_p B_g + W_p B_w$

$q = -\frac{kA}{\mu}\frac{dp}{ds}$ $p_r = \frac{p}{p_{sc}}$ $t_D = 2.309\frac{kt}{\phi \mu \bar{c} r_o^2}$ $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ $DR = \frac{k_{nodamage}}{k_{actual}}$

$B_g = \frac{zT}{p}\frac{p_{sc}}{T_{sc}}$ $J_i = \frac{ck_{oi}}{B_{oi}\mu_{oi}}$ $E_{w,f} = \frac{(1+m)B_{oi}(c_w S_{wc} + c_f)\Delta p}{1 - S_{wc}}$ $\bar{k} = \frac{\sum_{j=1}^{n} k_j A_j}{\sum_{j=1}^{n} A_j}$

$k = 162.6\frac{qB_o\mu_o}{mh}$ $F = N_p[B_o + B_g(R_p - R_s)] + W_p B_w = N(E_o + mE_g + E_{w,f}) + W_e B_w$

$\bar{k} = \frac{\ln(r_e/r_w)}{\sum_{j=1}^{n}\frac{\ln(r_j/r_{j-1})}{k_j}}$ $E_g = B_{oi}(B_g - B_{gi})/B_{gi}$ $\Delta p_{flow} = \Delta p_{total} \pm 0.4335\gamma\Delta z$ $N_{Re} = \frac{\rho v d}{\mu}$

$N_{p,a} = \frac{(q_i - q_a)}{D}$ $s = 1.151\left[\frac{(p_{1hr} - p_{wf})}{m} - \log\left(\frac{k}{\phi\mu_o c_t r_w^2}\right) + 3.23\right]$ $J = \frac{q_o}{p_e - p_w}$

$U = 1.119\phi h \bar{c} r_o^2$ $\Delta p_t = \frac{q_{sc}\mu_o B_o}{14.16 k_e h}\left[\ln\left(\frac{14.22 k_e t}{\mu\phi c r_w^2}\right) + 2S\right]$ $q_{sc} = \frac{703kh(p_e^2 - p_w^2)}{\mu T z \ln(r_e/r_w)}$

$p_{wf,j} = C + \frac{\mu}{2\pi kh}\left[q_j \ln r_{w,j} + \sum_{i=1\neq j}^{n} q_i \ln a_{ij}\right]$ $DF = 1 - PR$ $c = -\frac{1}{V}\frac{dV}{dp} = \frac{1}{\rho}\frac{d\rho}{dp}$

$PR = \frac{\ln(r_e/r_w)}{\ln(r_e/r_w) + S}$ $M = \frac{k_w}{\mu_w}\frac{\mu_o}{k_w}$ $p_e = C + \frac{\mu \ln r_e}{2\pi kh}\sum_{i=1}^{n} q_i$ $k = \frac{dW_e/dt}{p_i - p}$

$J = \frac{7.08kh}{B_o\mu_o(\ln(r_e/r_w) - 0.5)}$ $q = \frac{7.08kh(p_e - p_w)}{\mu\ln(r_e/r_w)}$ $q = q_i e^{-Dt}$

$W_e = 2\pi\phi h \bar{c} r_o^2 (\Delta p) W_D(t_D)$ $\Phi = p/\rho + gz$ $MW = \sum n_i MW_i$