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PART B: FORMATION EVALUATION

Please provide short and precise answers, one to two lines per point. You will not get any points for vague, lengthy, or unreadable answers even if they do contain relevant information hidden somewhere in them.

The interpreted figure sheets are to be handed in together with the rest of your answers.

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1. What do abbreviations LWD, MWD, WL mean? *(3 p.)*
   Explain the difference between Net Sand and Net-to-gross Ratio. *(2 p.)*

2. Give a precise definition of Poiseuille flow. *(3 p.)*
   Darcy's law is applicable to flows in porous media only at certain conditions. Specify at least two of them. *(2 p.)*

3. What is the difference between drainage and imbibition? *(1 p.)*
   How is capillary pressure useful for estimation of HC volumes in place? And which capillary pressure curve is relevant for that analysis? *(2 p.)*
   Define free water level and oil-water-contact. *(2 p.)*

4. Sketch invasion in a gas-bearing formation where a well is drilled using oil-based mud. Indicate phases, saturations and composition in the different zones. *(3 p.)*
   Name two disadvantages of invasion. *(1 p.)*
   How can these negative effects be minimized? *(1 p.)*

5. Name two cases when the caliper readings are larger than the bit size. *(2 p.)*
   Name two cases when the caliper log readings are less than the bit size. *(2 p.)*
   What is the response of caliper log to a porous and permeable formation? *(1 p.)*

6. Name two *classes of lithology* that typically produce high GR readings. *(2 p.)*
   Name two *lithologies* producing low GR readings. *(2 p.)*
   How does GR log response to caving? *(1 p.)*

7. What is the difference between GR and SGR logs? *(2 p.)*
   What is the main application of GR log? *(1 p.)*
   What is the main use of SGR log? *(1 p.)*
   Explain the concept "vertical resolution". *(1 p.)*

Well Testing: Problem 2 (12 pts)

The following sub problems concern relationships between key parameters and computed results from well test analyses.

a) If a review of a reported analysis shows that a thickness of 30 ft had been used instead of the correct value 30 m, how will this affect estimates of permeability, skin and radius of investigation? Note: 1 ft = 0.3048 m. (4 pts)

b) If in addition to incorrect unit for the thickness it was found that the compressibility listed as 8E-5 1/psi should have been 8E-5 1/bar, how will this affect the estimates of the same three parameters (with both corrections)? Note: 1 psi = 0.0689476 bar. (4 pts)

c) Consider a gas well in a drainage area with $\frac{1}{2}\ln\frac{4A}{e^{\gamma}C_A r_w^2} = 9.2$. If the well has a D factor of 5E-5 1/(Sm3/d), at what rate will the total skin effect be reduced by 40% if a static skin factor of 3 is reduced to 1? How much will the drawdown be reduced (in %) at the same rate with this skin reduction? Can use identities from reservoir limit analysis as reference. (4 pts)

STANDARD EQUATIONS WELL TESTING

$$p_D = \frac{kh}{18.66qB\mu}\Delta p$$ (SI units, oil; field units: 18.66 → 141.2)

$$t_D = \frac{0.000355kt}{\phi\mu c_t r_w^2}$$ (SI units, oil and gas; field units: 0.000355 → 0.000264)

$$C_D = \frac{C}{2\pi\phi h c_t r_w^2}$$ (SI units, oil and gas; field units: $C \rightarrow 5.615C$)

$$C = \frac{qB}{24}\frac{t}{\Delta p} = c_{wb}V_{wb}$$

$$\Delta p = m't = \frac{qB}{24C}t$$

$$m = \frac{21.49qB\mu}{kh}$$ (SI units; field units: 21.49 → 162.6)

$$S = 1.151\left(\frac{p_i - p_{1hr}}{m} - \log\frac{k}{\phi\mu c_t r_w^2} + 3.098\right)$$ (SI units, DD data; field units: 3.098 → 3.227)

$$S = 1.151\left(\frac{p_{1hr} - p_{wf,s}}{m} - \log\frac{t}{t+1} - \log\frac{k}{\phi\mu c_t r_w^2} + 3.098\right)$$ (SI units, BU data)

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FACULTY OF
SCIENCE
AND TECHNOLOGY

RE-SIT EXAM: PET 670 Formation Evaluation and Well Testing

DATE: February 14, 2018

DURATION: 4 hours

"TOOLS" ALLOWED: Standard simple calculator

THE SET CONSISTS OF: 5 (part A) + 6 (part B) pages

You need to score at least 40 % points in each part (A and B) to pass the exam.

Part A : Well Testing

Relevant formulas and relations (for Part A) are found at page 3 and 4 of Part A.

Well Testing: Problem 1 (18 pts)

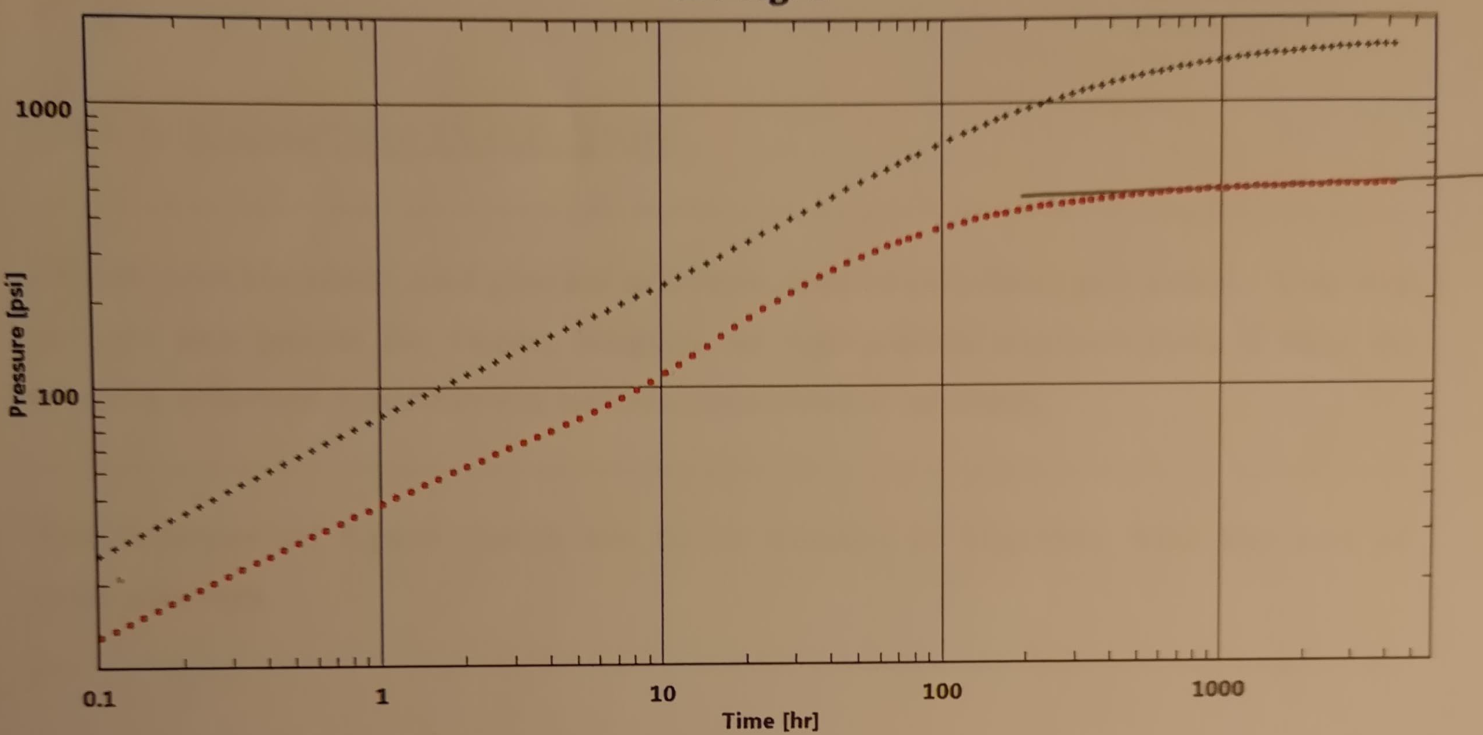
Data from an extended buildup in a horizontal well with two fractures 180 ft apart are listed below with key parameters in Table 1 and pressure data in Table 2 (reduced). Assume the fractures to be identical and perpendicular to the wellbore with infinite conductivity and that there is no direct flow to the wellbore. With infinite conductivity we just have two identical standard vertical fractures. With 720 hours production at 960 STB/D prior to shut-in, use the available data along with Fig. 1 to answer the questions and carry out the analyses below.

a) Fig. 1 shows a log-log plot of the buildup data. Considering the complexity of the well, identify flow regimes visible or indicated in the data, and indicate the range of each (start and end). (3 pts)

b) With Fig. 1 as reference, carry out a standard semi-log analysis of the buildup data based on representative data from Table 2 to compute m, kh, k, Δp_{1hr}, S and Δp_S. (6 pts)

c) Use results from the previous point and representative data from Table 2 to determine the half-length x_f of the fractures. (3 pts)

WT Fig. 1



d) Fig. 1 can be used to identify the onset of fracture interference. Use this observation to determine a new estimate of the formation permeability. (3 pts)

e) Use semi-log analysis to estimate the reservoir pressure. (3 pts)

Table 1 – Input parameters for Problem 1

Formation thickness, h	=	95	ft
Porosity, ϕ	=	0.12	
Viscosity, μ	=	0.35	cp
Total compressibility, c_t	=	$1.1\text{x}10^{-5}$	psi^{-1}
Volume factor, B	=	1.25	RB/STB
Wellbore radius, r_w	=	0.354	ft
Pressure at shut-in, p_i	=	3006.78	psia

Table 2 – Buildup data

Time (hrs)	Pressure (psia)	Time (hrs)	Pressure (psia)
0.058	3025.55	18.34	3313.82
0.073	3027.92	23.09	3352.78
0.092	3030.58	29.07	3397.39
0.116	3033.55	36.60	3447.83
0.146	3036.87	46.08	3504.00
0.183	3040.58	57.94	3565.19
0.231	3044.72	76.66	3646.29
0.291	3049.34	95.38	3713.53
0.366	3054.50	120.3	3787.84
0.461	3060.25	151.5	3863.29
0.580	3066.66	189.0	3936.11
0.730	3073.79	238.9	4012.83
0.919	3081.71	295.1	4080.45
1.157	3090.51	369.9	4150.23
1.457	3100.26	457.3	4212.49
1.834	3111.07	569.6	4272.86
2.309	3123.01	706.9	4327.74
2.907	3136.17	875.4	4377.25
3.660	3150.65	1081.3	4421.32
4.608	3166.57	1337.1	4460.72
5.801	3184.15	1649.1	4494.93
7.303	3203.72	2036.0	4524.84
9.194	3225.79	2510.3	4550.44
11.57	3251.00	3096.8	4572.37
14.57	3280.10	3820.7	4590.94

$$\Delta p_S = \frac{m}{1.151} S$$

$$r_{inv} = 0.0286 \sqrt{\frac{kt}{\phi \mu c_t}}$$ (SI units; field units: 0.0286 → 0.0246)

$$d = 0.01412 \sqrt{\frac{kt}{\phi \mu c_t}}$$ (SI units; field units: 0.01412 → 0.01217)

$$p_i - \overline{p} = \frac{m}{1.151} 2\pi t_{DA}$$

Fractured wells:

$$m' = \frac{0.6236 qB}{h x_f} \sqrt{\frac{\mu}{k \phi c_t}}$$ (SI units; field units: 0.62369 → 4.064)

$$S = \ln \frac{2 r_w}{x_f}$$ (fracture with infinite conductivity)

$$S = \ln \frac{e r_w}{x_f} = \ln \frac{2.718 r_w}{x_f}$$ (fracture with uniform flux)

Reservoir limit analysis:

$$m' = \frac{0.04167 qB}{\phi c_t A h}$$ (SI units; field units: 0.04167 → 0.2339)

$$p_0 = p_i - \frac{18.66 qB\mu}{kh} \left(\frac{1}{2} \ln \frac{4A}{e^{\gamma} C_A r_w^2} + S \right)$$ (SI units; field units: 18.66 → 141.2)

$$e^{\gamma} = e^{0.57721\mathrm{K}} = 1.781\mathrm{K}$$

Gas tests:

$$q_{sc} = C(\overline{p}^2 - p_{wf}^2)^n$$ (simplified deliverability, p^2 formulation)

$$\overline{p}^2 - p_{wf}^2 = a q_{sc} + b q_{sc}^2$$ (LIT based deliverability, p^2 formulation)

$$\mathrm{AOF} = \frac{1}{2b} \left(-a + \sqrt{a^2 + 4b\overline{p}^2} \right)$$ (LIT based AOF, p^2 formulation)

18. How does the deepest formation interval stand out from the rest in terms of log readings? *(2 p.)*
Provide a possible explanation of this "anomaly". *(3 p.)*

To answer Questions 19 and 20, interpret the pressure log shown in Fig. 3.
Make necessary marks directly on the figure sheet
and hand in this sheet together with the rest of your answers.

19. Indicate the intervals with constant pressure gradient and calculate the pressure gradient in each. Label the intervals A, B, ... from top to bottom. *(2 p.)*
Calculate the fluid density in the different intervals and identify the fluids in each interval. *(2 p.)*
Indicate which intervals are connected and where (at which depths) there are dis-connections. *(1 p.)*

20. Are any intervals overpressurized? *(1 p.)*
Fluid samples show an OWC at 624 m. What is the threshold pressure? *(2 p.)*
The permeability at this interval is 5 mD. If instead the permeability was 500 mD, where would the OWC be located (assuming the same FWL, i. e. the same pressure data)? *(2 p.)*

8. Name the two main applications of the neutron log. *(1 p.)*
Which two processes in the formation determine the response produced in the neutron log? *(2 p.)*
Explain how shale and cloride affect these processes and accordingly the neutron log. *(2 p.)*

9. Explain two possible implications of the presence of diagenetic chlorite clay in sandstone reservoirs. *(2 p.)*
Under what geological conditions is it reasonable for chlorite to form? *(1 p.)*
What is transit time in the context of sonic log? *(1 p.)*
Why is the number of transmitters and receivers important for the quality of the sonic log? *(1 p.)*

10. Formulate Archies 1st and 2nd laws mathematically, with the definition of all the symbols. *(2 p.)*
In a hydrocarbon reservoir zone: what important formation properties can you calculate from the shallow resistivity log and from the deep resistivity log, respectively? What are the main input and assumptions in those calculations? *(3 p.)*

To answer Questions 11-18, interpret the well logs shown in Fig. 1.
You will also use the crossplot in Fig. 2 for Question 16.
Make necessary marks directly on the figure sheets
and hand in these sheets together with the rest of your answers.

The following measurements from SCAL are given.
$R_w = 0.0025\,\text{Ohm·m}$ (formation brinc)
$m = 2$
$n = 3$

11. Mark the sand line and the shale line on the total GR log. *(2 p.)*
What are the corresponding values GR_{sh} and GR_{sand} in API units? *(2 p.)*
Use GR log to estimate the shale volume, V_{sh}, at depth around 2155 m. *(1 p.)*

12. Identify the lithologies in the well and draw them in the Depth track. *(5 p.)*

13. Find the hydrocarbon-saturated and water-saturated zones and show them in the resistivity log. Explain how you arrive at the conclusions. *(5 p.)*.

14. Are there any fluid contacts present? If yes, indicate them. If no, explain precisely what your conclusion is based on. *(5 p.)*

15. Select an interval with clean sand and water and calculate porosity from the resistivity log. Indicate clearly where the measurements are taken from. *(5 p.)*

16. Use the crossplot in Fig. 2 to estimate the porosity of the uppermost HC-containing zone and identify its lithology. *(3 p.)*
In addition to the crossplot and resistivity, state two other ways to estimate porosity from the available logs. What information would you require in each case? *(2 p.)*

17. Calculate the formation factor, resistivity index, and water saturation in the uppermost HC-containing zone. Specify all the assumptions made and indicate clearly where the measurements / values are taken from. *(5 p.)*