UNIVERSITI
TEKNOLOGI
PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**PCM5164 – PRODUCTION ENGINEERING**
DATE	**:**	**31 JULY 2024 (WEDNESDAY)**
TIME	**:**	**2:30 PM – 5:30 PM (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **ELEVEN (11)** printed pages in this **double-sided** Question Booklet including the cover page and appendices.

1. a. A well is located at the center of a radial under-saturated reservoir. The well and reservoir data are listed in **TABLE Q1**.

TABLE Q1: Well and Reservoir Data

Parameter	Value
Reservoir permeability, k	100 md
Reservoir thickness, h	20 ft
Oil viscosity, μ_o	0.5 cP
Formation Volume Factor, β_o	1.1 rb/stb
Well radius, r_w	4-inch
Reservoir radius, r_e	1500 ft
Reservoir pressure, P_r	5,000 psia
Skin factor, s	0
Flow regime	Semi-Steady state

i. Draw a schematic diagram showing the variation of pressure of this reservoir with radial distance (from the well to reservoir boundary) at different times.

[3 marks]

ii. Calculate the productivity index of this reservoir.

[4 marks]

iii. Generate the inflow performance relationship (IPR) curve.

[6 marks]

b. A well is located in an undersaturated reservoir with an average pressure of 3,800 psia. The bubble point is 2,500 psia and a measured flow rate is found to be 400 stb/d at the well flowing pressure of 3,000 psia. Develop the IPR for this reservoir using VOGEL equation.

[8 marks]

c. A well is drilled in a loose sandstone reservoir where sand production is expected. Explain **TWO (2)** options for completing this well.

[4 marks]

2. a. NODAL analysis is a technique used to perform production optimization.

i. Describe schematically the typical production system and label **TWO (2)** locations which can be selected as nodes.

[4 marks]

ii. Draw the inflow and outflow curves and state the inflow and outflow expressions for a production system starting from the reservoir and ending at the wellhead considering a node at the bottomhole and single-phase flow in both the reservoir and tubing. And then show the effect of the change of fluid viscosity and permeability on the inflow and outflow curves.

[9 marks]

iii. Tubing diameter cannot be used to analyze the outflow of the above production system. Justify.

[2 marks]

b. 53.04 lbs/ft^3 oil is being produced and flowing at a velocity of 2.33 ft/s through a 2.259-in, 1,000 ft vertical tubing. If Reynolds number at the flow conditions is found to be 28,858, calculate the friction and hydrostatic pressure losses.

[6 marks]

c. Sketch a diagram to explain the effect of the gas lift on the pressure gradient above and below the gas injection point. Consider a well with two unloading valves and one injection valve.

[4 marks]

3. a. Onshore wells are likely to perform poorly or lower than expected due to low reservoir permeability and wellbore restriction because of formation damage or incomplete perforation. However, a well stimulation could improve its productivity.

i. An acid response curve is an important indicator in matrix acidizing. Schematically explain the effect of hydrofluoric acid on rock permeability.

[4 marks]

ii. Discuss at least **TWO (2)** factors needed to securely perform carbonate acidizing with a proper growth of wormhole.

[6 marks]

b. A 20-ft-thick deposit of sandstone with a 30% porosity and 10% (by volume) calcite ($CaCO_3$) is to be acidified with a solution of HF/HCl. To dissolve the carbonate minerals and create a low pH environment, a preflush of 15 wt% HCl solution must be injected prior to the main acid flooding. Before the HF/HCl stage penetrates the formation, HCl preflush is intended to eliminate all carbonates in an area within 1.24 ft of a wellbore with a radius of 0.428 ft. Recommend a detailed design of an acid pre-flush treatment for sandstone reservoir. Show clearly all calculation steps and used equations.

[10 marks]

c. Propped hydraulic fracturing is applicable to both sandstone and carbonate formations. Describe the main procedures required to do a propped hydraulic fracturing.

[5 marks]

4. a. Numerous strategies and additivities have been used to address issues related to acid injection.

   i. Analyze the possible problems associated with acid injection during production and explain how to manage those problems.

   [5 marks]

   ii. Explain the criteria used to evaluate the quality of stimulation candidates for matrix acidizing and fracturing.

   [5 marks]

b. Consider the reservoir and pipeline data given below:

Reservoir pressure	=	78 bar
Reservoir temperature	=	80°C
Molecular weight of Air	=	28.96 g/mol
Pipeline temperature	=	4°C
Pipeline pressure	=	78 bar

The gas composition is shown in **TABLE Q4**.

TABLE Q4: Composition of the natural gas fluid

Component	Volume fraction	MW (g/mol)
Methane	0.800	16.04
Ethane	0.060	30.07
Propane	0.030	44.10
Carbon dioxide	0.006	44.01
Nitrogen	0.104	28.01

Using Mcketta and Wehe Chart and other standard design criteria, suggest hydrate inhibitor design treatment for produced gas stream to prevent hydrate formation.

[15 marks]

----------- END OF PAPER -----------

APPENDIX

CONVERSION FACTORS

1 m^3 = 6.29 bbl.
1 bbl = 5.615 ft^3.
1 bar = 14.7 psia=10^5 Pascal.

PHYSICAL CONSTANTS:

1 degree F	=	(1.8 °C) + 32
Molecular weight of methanol	=	32 g/mol
Molecular weight of water	=	18 g/mol
1 lb/MMSCF	=	0.01602 g/Sm^3

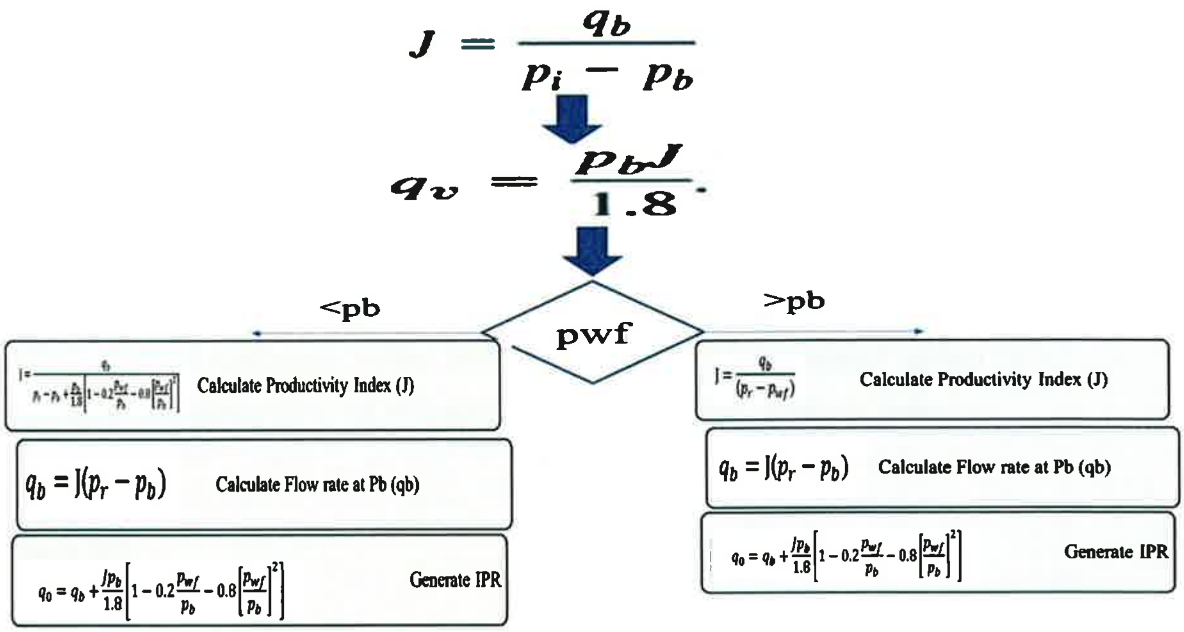
Darcy equation for radial pseudo-steady state reservoirs

$$q = \frac{7.08 \times 10^{-3}\, k\, h \left(P_e - P_{wf}\right)}{\mu_o\, B_o \left(\ln\left(\frac{r_e}{r_w}\right) - \frac{3}{4} + S\right)}$$

Friction factor and friction pressure

$$f_m = 0.0056 + 0.5\, N_{Re}^{-0.32}$$

$$\Delta P_f = f \frac{h \rho V^2}{2dg}$$



Gravimetric dissolving power $\beta = \frac{\nu_{\text{mineral}} \text{MW}_{\text{mineral}}}{\nu_{\text{acid}} \text{MW}_{\text{acid}}}$

Volumetric dissolving power $X = \beta \frac{\rho_{\text{acid solution}}}{\rho_{\text{mineral}}}$

Hydrochloric acid density	66.77 b/ft^3
Rock density	169 b/ft^3

Skin factor

$$S = \left(\frac{k}{k_s} - 1\right) \ln \frac{r_s}{r_w}$$

Perforation skin

$$S_p = S_H + S_V + S_{wb}$$

$$S_H = \ln\left(\frac{r_w}{r_w'(\theta)}\right) \qquad r_w'(\theta) = \frac{L_{perf}}{4} \; for\, \theta = 0$$

$$S_V = 10^a \times h_D^{b-1} \times r_D^b$$

$$a = a_1 \times \log r_D + a_2 \qquad b = b_1 \times r_D + b_2$$

$$r_{wD} = \frac{r_w}{L_{perf} + r_w}$$

$$S_{wb} = C_1 \times e^{C_2 r_{wD}}$$

$S_{C+\theta}$ is the skin due to partial completion and slant.

Dimensionless reservoir thickness, $h_D = \frac{h}{r_w}$

Elevation Ratio $= \frac{z_w}{h}$

Completion Ratio $= \frac{h_w}{h}$

$$V_m = \pi \left(r_{HCl}^2 - r_w^2\right)(1 - \phi)\, x_{CaCO_3}$$

$$V_p = \pi \left(r_{HCl}^2 - r_w^2\right) \phi$$

$$V_d = \frac{V_m}{X}$$

$$V_{acid} = V_p + V_d + V_m$$

Acid Injection Rate

$$q_{i,max} = \frac{4.917 \times 10^{-6} kh \left(P_{bd} - P_e - \Delta P_{sf}\right)}{\mu_a \left(ln\left(\frac{0.472 re}{r_w}\right) + S\right)}$$

$$P_{bd} = G_f \times L$$

$$\Delta P_f = \frac{518 \times \gamma^{0.79} q^{1.79} \mu^{0.207} \times L}{1000 \times D^{4.79}}$$

$$P_{si} = P_{wf} - \Delta P_h + \Delta P_f$$

$$\Delta P_h = 0.433 \times \gamma L$$

$$P_{wf} = P_{bd} - \Delta P_f$$

$$T_f\,(\deg C) = -6.44 - \frac{3.79}{d^2} + 7.68 ln\left(P(bars)\right)$$

$$Specific\ Gravity = \frac{(MW)_{mixture}}{(MW)_{air}}$$

Nielson and Bucklin Equation:

$$\Delta T\,(\deg C) = -72\, ln(x_w)$$

$$w_{methanol} = \frac{x_{methanol} MW_{methanol}}{x_{methanol} MW_{methanol} + x_{water} MW_{water}}$$

Constants for Perforation Skin Effect Calculation[a]

Perforation Phasing	a_θ	a_1	a_2	b_1	b_2	c_1	c_2
0° (360°)	0.250	-2.091	0.0453	5.1313	1.8672	1.6E−1	2.675
180°	0.500	-2.025	0.0943	3.0373	1.8115	2.6E−2	4.532
120°	0.648	-2.018	0.0634	1.6136	1.7770	6.6E−3	5.320
90°	0.726	-1.905	0.1038	1.5674	1.6935	1.9E−3	6.155
60°	0.813	-1.898	0.1023	1.3654	1.6490	3.0E−4	7.509
45°	0.860	-1.788	0.2398	1.1915	1.6392	4.6E−5	8.791

[a]From Karakas and Tariq, 1988.

Molecular Weights of Species in Acidizing

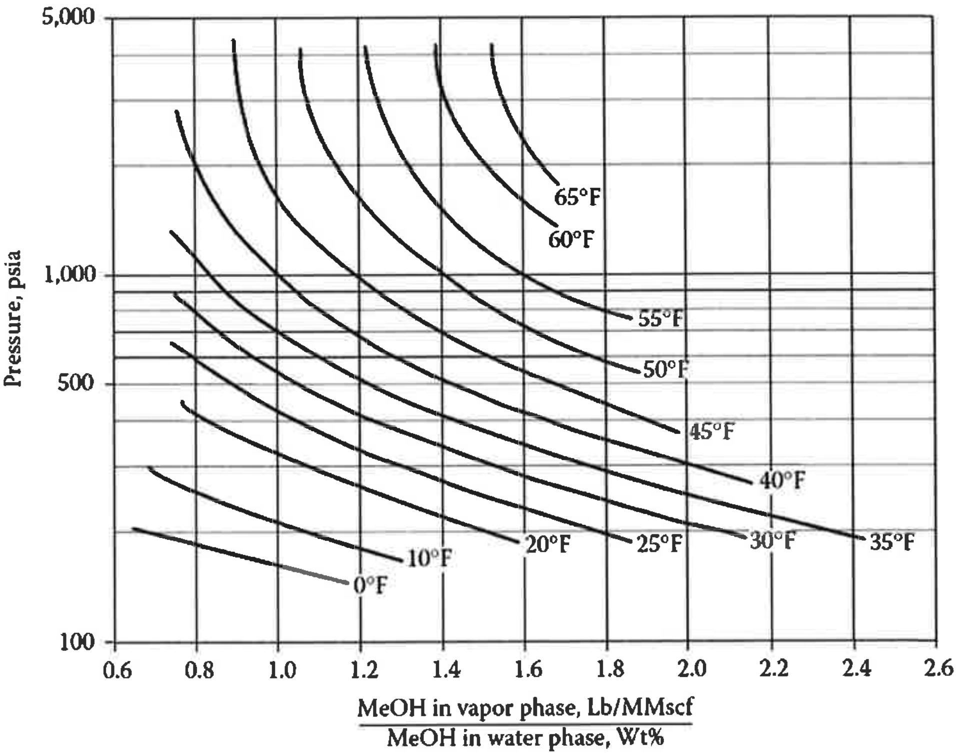
Species	Molecular Weight (mass/mole)
Elements	
Hydrogen, H	1
Carbon, C	12
Oxygen, O	16
Fluorine, F	19
Sodium, Na	23
Magnesium, Mg	24.3
Aluminum, Al	27
Silicon, Si	28.1
Chlorine, Cl	35.5
Potassium, K	39.1
Calcium, Ca	40.1
Iron, Fe	55.8
Molecules	
Hydrochloric acid, HCl	36.5
Hydrofluoric acid, HF	20
Calcite, $CaCO_3$	100.1
Dolomite, $CaMg(CO_3)_2$	184.4
Siderite, $FeCO_3$	115.8
Quartz, SiO_2	60.1
Albite (sodium feldspar), $NaAlSi_3O_8$	262.3
Orthoclase (potassium feldspar), $KAlSi_3O_8$	278.4
Kaolinite, $Al_4Si_4O_{10}(OH)_8$	516.4
Montmorillonite, $Al_4Si_8O_{20}(OH)_4$	720.8

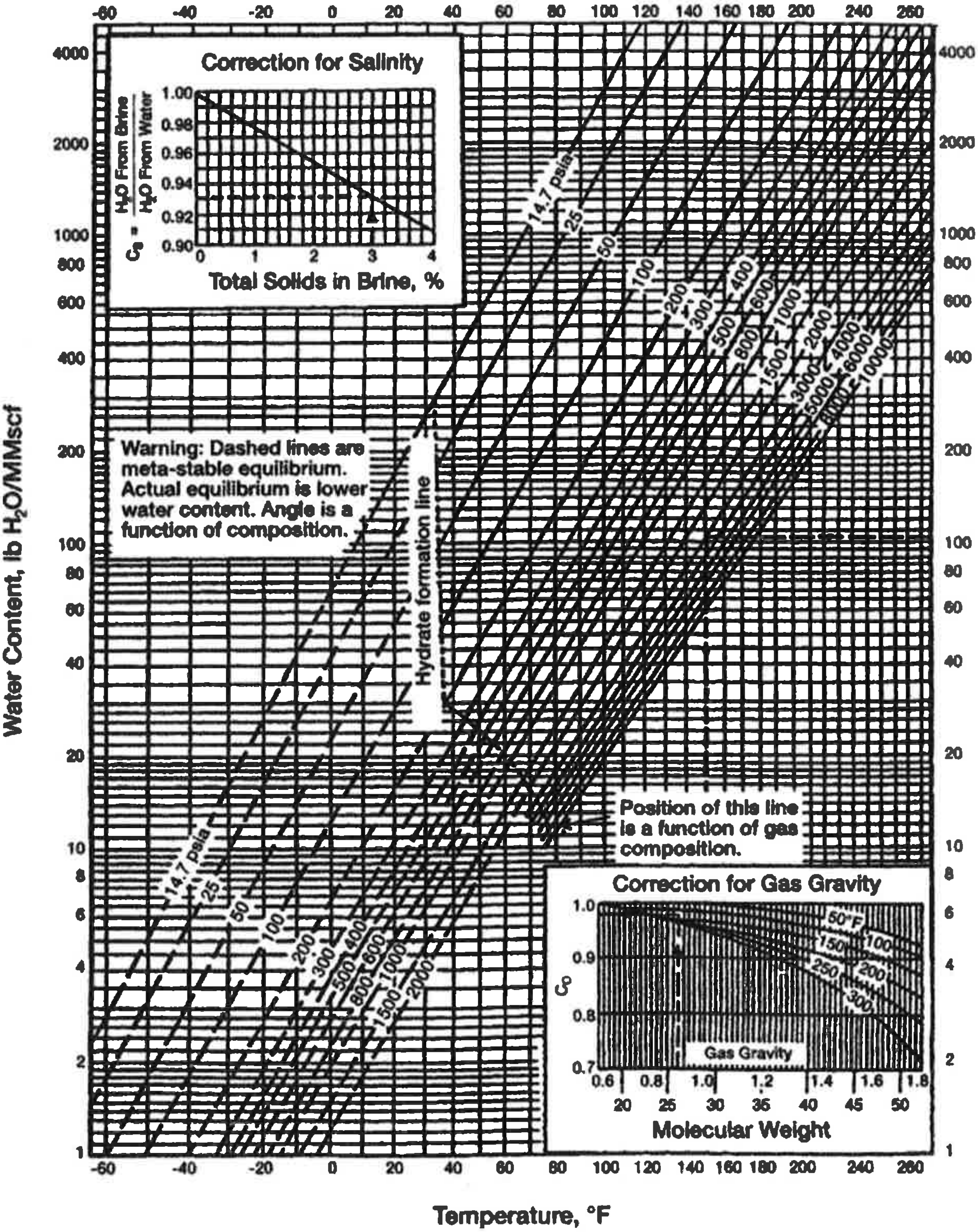
Table *Primary Chemical Reactions in Acid Treatments*

Montmorillonite (Bentonite)-HF/HCl:	$Al_4Si_8O_{20}(OH)_4 + 40HF + 4H^+ \leftrightarrow 4AlF_2^+ + 8SiF_4 + 24H_2O$
Kaolinite-HF/HCl:	$Al_4Si_8O_{10}(OH)_8 + 40HF + 4H^+ \leftrightarrow 4AlF_2^+ + 8SiF_4 + 18H_2O$
Albite-HF/HCl:	$NaAlSi_3O_8 + 14HF + 2H^+ \leftrightarrow Na^+ + AlF_2^+ + 3SiF_4 + 8H_2O$
Orthoclase-HF/HCl:	$KAlSi_3O_8 + 14HF + 2H^+ \leftrightarrow K^+ + AlF_2^+ + 3SiF_4 + 8H_2O$
Quartz-HF/HCl:	$SiO_2 + 4HF \leftrightarrow SiF_4 + 2H_2O$
	$SiF_4 + 2HF \leftrightarrow H_2SiF_6$
Calcite-HCl:	$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$
Dolomite-HCl:	$CaMg(CO_3)_2 + 4HCl \rightarrow CaCl_2 + MgCl_2 + 2CO_2 + 2H_2O$
Siderite-HCl:	$FeCO_3 + 2HCl \rightarrow FeCl_2 + CO_2 + H_2O$

Dissolving Power of Various Acids

Formulation	Acid	β100	X			
			5%	10%	15%	30%
Limestone $CaCO_3$ ρ=2.71 g/cm³	HCl	1.37	0.026	0.053	0.082	0.175
	HCOOH	1.09	0.020	0.041	0.062	0.129
	CH3COOH	0.83	0.016	0.047	0.047	0.096
Dolomite $MgCa(CO_3)_2$ ρ=2.87 g/cm³	HCl	1.27	0.023	0.031	0.071	0.152
	HCOOH	1.00	0.018	0.036	0.054	0.112
	CH3COOH	0.77	0.014	0.027	0.041	0.083




Correction for Salinity
$C_s = \frac{H_2O \text{ From Brine}}{H_2O \text{ From Water}}$
Total Solids in Brine, %
Warning: Dashed lines are meta-stable equilibrium. Actual equilibrium is lower water content. Angle is a function of composition.
Hydrate formation line
Position of this line is a function of gas composition.
Correction for Gas Gravity
C_G
Gas Gravity
Molecular Weight
14.7 psia
Water Content, lb H_2O/MMscf
Temperature, °F