UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**PEB2023/PFB2033 - RESERVOIR ENGINEERING I**
DATE	**:**	**1 AUGUST 2024 (THURSDAY)**
TIME	**:**	**9:00 AM - 12:00 NOON (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 **THIRTEEN (13)** pages in this Question Booklet including the cover page and appendices.

ii. **DOUBLE-SIDED** Question Booklet.

1. a. The following parameters are given for Zeta field in **TABLE Q1a**.

TABLE Q1a: Properties of Zeta field.

Parameters	Variables
Field area, acres	a
Total thickness, feet	b
Formation volume factor, bbl/STB	c
Porosity, fraction	d
Net-to-gross, fraction	e
Connate water saturation, fraction	f
Recovery factor, fraction	g
Conversion factors	1 acre = 43560 ft^2 1 barrel (bbl) = 5.615 ft^3

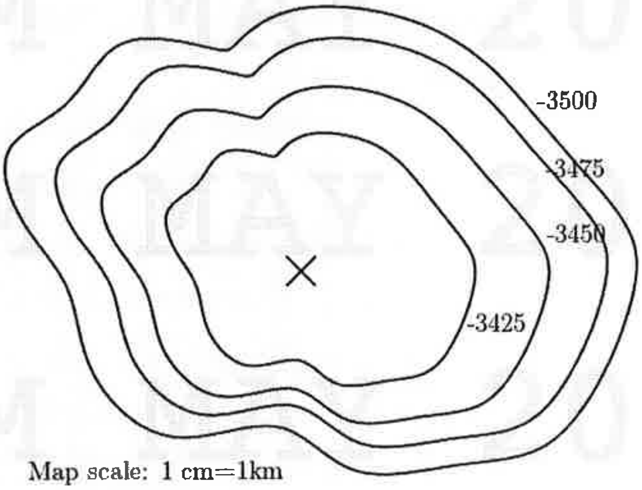
Write the equation, using the variables in **TABLE Q1a**, to express the reserve remaining in this field (in STB) after 50% from the initial reserve has been produced.

[6 marks]

b. Differentiate proved and unproved reserves and their related categories.

[6 marks]

c. The structure map for field Zeta is given in **FIGURE Q1**. The top structure is at -3417 m. The planimeter measurements of the contours are given in **TABLE Q1c(i)**. Additional parameters are shown in **TABLE Q1c(ii)**.



4.5 cm^2=12.5 p.u.

FIGURE Q1: Structure map of Zeta field.

TABLE Q1c(i): Planimeter measurements of contours.

Contour (m)	Area (p.u.)
3425	19.5
3450	24.7
3475	35.2
3500	42.6

TABLE Q1c(ii): Additional parameters.

Properties	Values
Oil formation volume factor, B_{oi} (bbl/STB)	1.35
Porosity, ϕ (%)	20
Net-to-gross (%)	75
Initial water saturation, S_{wi} (%)	25
Recovery factor (%)	37

Determine the gross rock volume for Zeta field in ft^3 and calculate the reserve in STB.

[12 marks]

2. a. Reservoir simulation study indicates the presence of strong aquifer underneath Alpha field. The following parameters for Alpha field are given:

TABLE Q2a: The properties of Alpha field.

Parameters	Values
Average permeability, k (m^2)	8.389 x 10^{-14}
Radius of external boundary, r_e (m)	914.4
Radius of wellbore, r_w (m)	0.2286
Reservoir thickness, h (m)	25.908
Formation volume factor, B_o (bbl/STB)	1.35
Oil viscosity, μ_o (Pa.s)	0.0017
Pressure at the external boundary, p_e (MPa)	17.23689

The field is producing at a stabilized rate of 1000 STB/day. Determine the bottom hole flowing pressure for the well in psi.

[10 marks]

b. The pressure response as function of distance for steady-state liquid flow in radial system of a reservoir can be represented by the semilog plot in **FIGURE Q2b**.

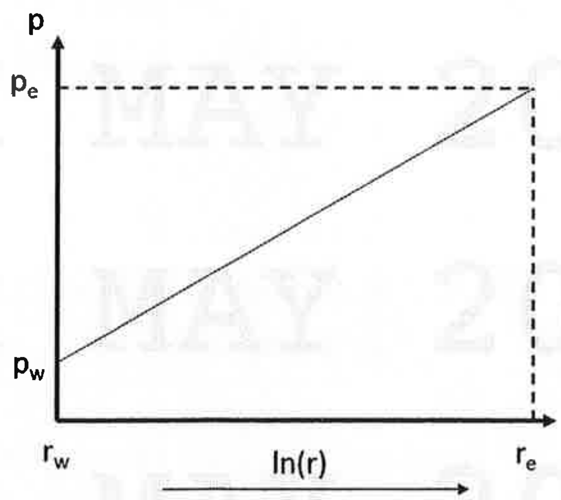


FIGURE Q2b: Semilog sketch of pressure as a function of distance for steady-state liquid flow in a radial system.

Based on **FIGURE Q2b**, write "T" for true statements and "F" for false statements.

i. The pressure p_e at the external boundary, r_e changes with respect to time.

ii. When producing at constant rate, the slope for the pressure profile at $t = 0$ is higher than the slope at $t = 100$ days.

iii. The pressure p_w at the wellbore is the same after $t = 100$ days.

iv. The flowrate at the external boundary, r_e is the same as the flowrate at wellbore.

[8 marks]

c. The relative permeability curve obtained from steady-state experiment of Alpha core plug sample is shown in **FIGURE Q2c**. The experimental data is given in **TABLE Q2c**.

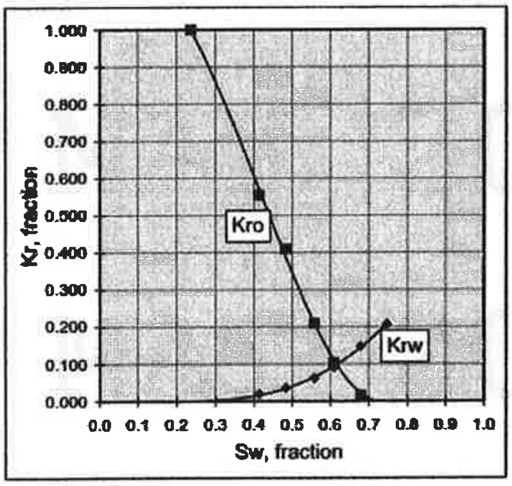


FIGURE Q2c: Relative permeability curve of core plug sample from Alpha field.

TABLE Q2b: Experimental properties of steady-state experiment.

Initial water saturation, S_{wi} (%)	24
Effective oil permeability at S_{wi}, k_{eo} (Darcy)	0.36
Oil viscosity, μ_o (cp)	0.80
Water viscosity, μ_w (cp)	1.03
Pressure difference, Δp (psi)	50
Core length, L (inch)	6
Core diameter, D (inch)	1.5

Design the oil and water flow rates required, in cc/min so that the oil saturation inside the core can be reduced to 40%.

[8 marks]

3. a. Assess a suitable primary drive mechanism for Delta field based on the forecast production profile shown in **FIGURE Q3a** and evaluate its production characteristics.

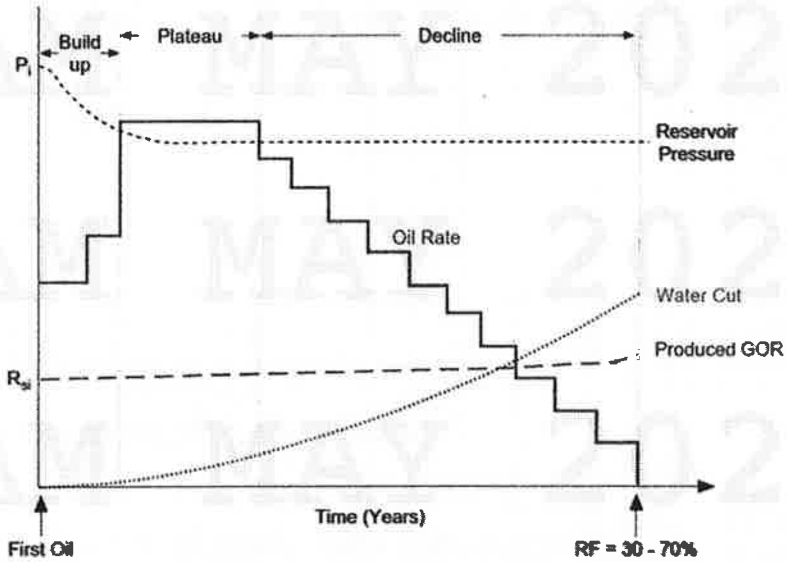


FIGURE Q3a: Forecast production profile of Field Delta.

[8 marks]

b. Discuss the effect of both fluid compressibility and pore compaction as the basis for drive energy which cause hydrocarbon production from a reservoir. Please illustrate your discussion with suitable sketches or equations.

[10 marks]

c. Field Omega is located northwest of Field Delta. Reservoir simulation study was conducted as part of the field development plan and the result is shown in **FIGURE Q3c**. The plot shows the average pressure and GOR as a function of oil recovery when the field started production.

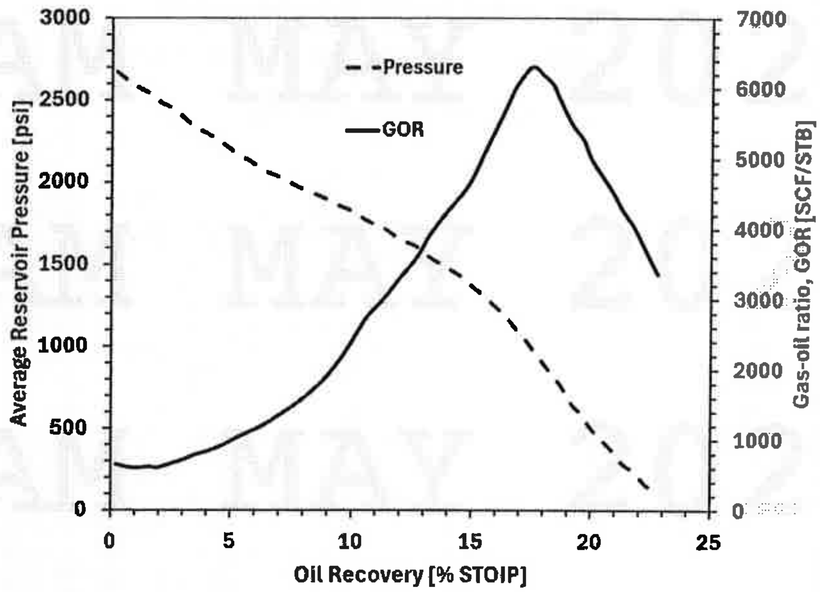


FIGURE Q3c: Production profile of Field Omega.

Identify the primary drive for Field Omega and discuss the effect on reservoir pressure and gas-oil ratio (at conditions above and below bubble point) when the drive mechanism is present in the reservoir.

[8 mark]

4. a. i. A laboratory cell with volume of 0.007063 ft^3 contains 0.03589 lb of ethane. Using Van der Waals equation of state (EOS), calculate the pressure to be expected when the temperature is raised to 180°F.

[8 marks]

ii. Experimental result indicates that the pressure calculated in **part (i)** differs by 10 – 20%. Justify your answer against conditions stated by Van der Waals EOS.

[4 marks]

b. A pure propane is held in a closed container at 120°F. Both gas and liquid are present. Using Redlich – Kwong (RK) EOS, calculate the density of each gas and liquid phase.

[12 marks]

- END OF PAPER –

APPENDIX

Length	**Area**
1 ft = 0.3048 m = 12 in	1 ft^2 = 0.092903 m^2 = 144 in^2
1 m = 3.281 ft = 39.37 in = 100 cm	1 m^2 = 10.7649 ft^2 = 10000 cm^2
Volume	**Force**
1 ft^3 = 0.02831 m^3 = 28.3168 L	1 lbf = 4.44822 N = 32.2 lbm.ft/s^2
1 m^3 = 35.29 ft^3 = 1000 L	1 N = 0.2248 lbf = 1kg.m/s^2
Interfacial Tension	**Permeability**
1 N/m = 1000 mN/m = 1000 dyne/cm	1 Darcy = 9.869233 x 10^{-13} m^2 1 Darcy = 1000 mD

Pressure
1 atm = 101.3 kPa = 1.013 bar = 14.696 lbf/in^2 (psia)
1 psia = 6.89 kPa = atm/14.696
1 bar = 14.504 psia
1 Pa = 1 N/m^2 = 1 kg/m.s^2 = 10^{-5} bar = 1.450 x 10^{-4} lbf/in^2 = 10 dyne/cm^2
psia = psig + 14.7
Density
1 g/cc = 1000 kg/m^3 = 62.427 lb/ft^3 = 8.345 lb/gal = 0.03361 lb/in^3
Viscosity
1 Pa.s = 1000 cp

Volumetrics formula

$$N = \frac{GRV \times NTG \times \phi \times (1 - S_w)}{FVF}$$

Trapezoid Rule: $V_B = \frac{h}{2}(A_0 + 2A_1 + 2A_2 + \cdots 2A_{n-1} + A_n) + \frac{h_n A_n}{2}$

Fluid flow in porous media formula

$$q = c_r \frac{kh}{B\mu} \frac{(p_e - p_w)}{\ln\left(\frac{r_e}{r_w}\right)} \; (all\ parameters\ in\ field\ units)$$

$c_r = 7.081 \times 10^{-3}$

APPENDIX

Permeability and relative permeability formula

$$q = \frac{kA}{\mu L}\Delta P \qquad q_w = \frac{k_w A}{\mu_w L}\Delta P \qquad q_o = \frac{k_o A}{\mu_o L}\Delta P$$

Equation of States (EOS) formula

Mass per mole, $n = \frac{m}{M} = \frac{\text{mass (in } g \text{ or } lb)}{\text{molecular weight}}$

Molar volume, $V_m = \frac{\text{volume of component}}{\text{mass per mole}} = \frac{V}{n}$

Van der Waals EOS

$$P = \frac{RT}{V_m - b} - \frac{a}{V_m^2} \qquad Z^3 - (1-B)Z^2 + AZ - AB = 0$$

where

P is pressure (psia)

R is the universal gas constant, 10.73 psia.ft^3 / lb.mol.°R

T is the temperature in Rankine $(°R = °F + 460)$

V_m is the molar volume of gas $(\text{ft}^3 / \text{lb.mol})$

a is the constant, $a = 0.421875\frac{R^2 T_c^2}{P_c}$

b is the constant, $b = 0.125\frac{RT_c}{P_c}$

$$A = \frac{aP}{R^2T^2} \qquad B = \frac{bP}{RT}$$

Redlich – Kwong EOS

$$P = \frac{RT}{V_m - b} - \frac{a}{V_m(V_m + b)\sqrt{T}} \qquad Z^3 - Z^2 + (A - B - B^2)Z - AB = 0$$

where

a is the constant, $a = 0.42747\frac{R^2 T_c^{2.5}}{P_c}$

b is the constant, $b = 0.08664\frac{RT_c}{P_c}$

For liquid phase mixture

$$a_m = \left[\sum_{i=1}^{n} x_i \sqrt{a_i}\right]^2$$

$$b_m = \sum_{i=1}^{n} [x_i b_i]$$

For gas phase mixture

$$a_m = \left[\sum_{i=1}^{n} y_i \sqrt{a_i}\right]^2$$

$$b_m = \sum_{i=1}^{n} [y_i b_i]$$

$$\rho = \frac{PM_a}{ZRT}$$

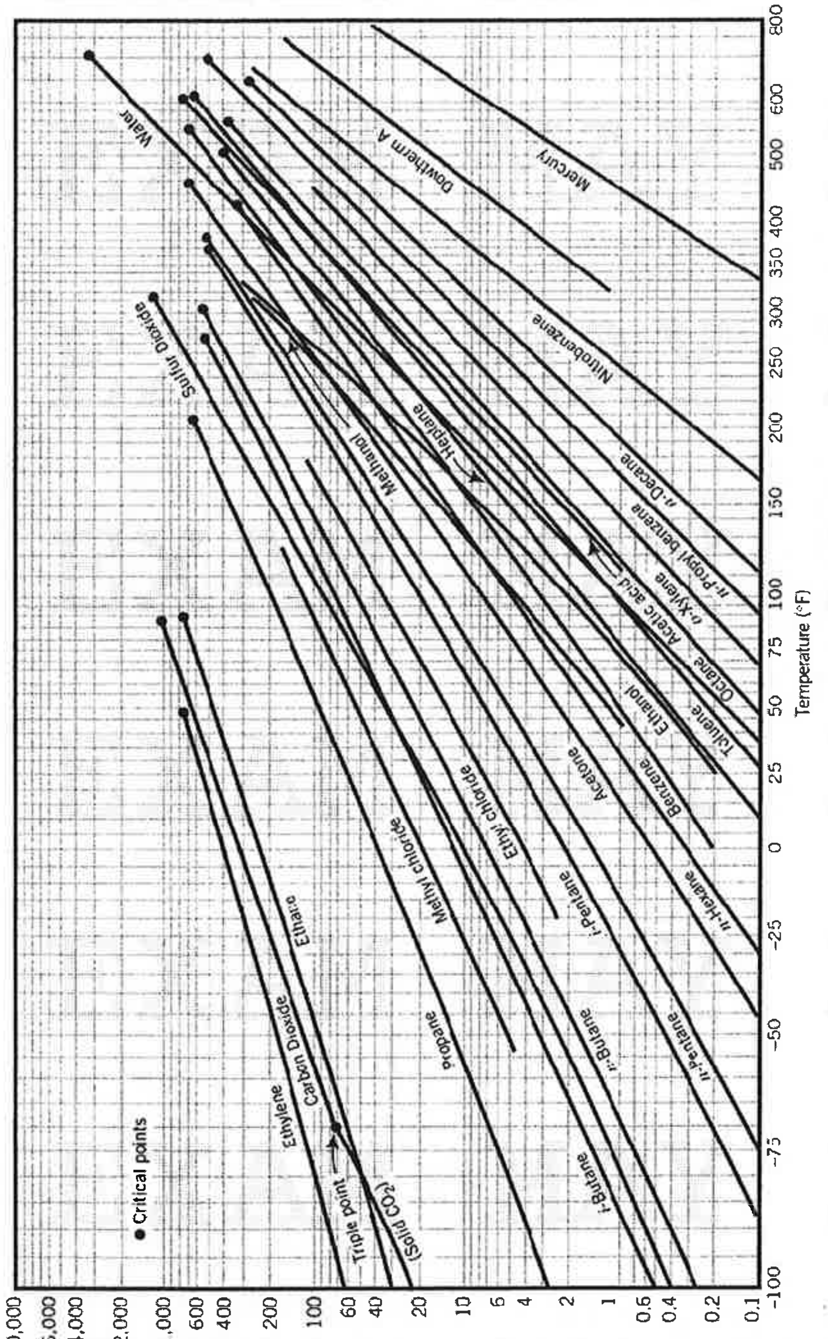
$M_a = \sum x_i M_i$ (liquid) or $M_a = \sum y_i M_i$ (gas)

$$°R = °F + 460 = K \times 1.8$$

Critical Pressure and Temperature of Gas

Compound	**Formula**	**Molecular weight (g/mol)**	**Critical constants**	
			Pressure, psia	Temperature, °F
Methane	CH_4	16.043	666.4	-116.67
Ethane	C_2H_6	30.07	706.5	89.92
Propane	C_3H_8	44.097	616	206.06
Isobutane	C_4H_{10}	58.124	527.9	274.46
n-Butane	C_4H_{10}	58.124	550.6	305.62
Isopentane	C_5H_{12}	72.151	490.4	369.1

APPENDIX


Critical points
Triple point
(Solid CO_2)
Water
Mercury
Dowtherm A
Nitrobenzene
n-Decane
n-Propyl benzene
o-Xylene
Acetic acid
Octane
Toluene
Ethanol
Benzene
Acetone
Heptane
Methanol
n-Hexane
i-Pentane
n-Pentane
n-Butane
i-Butane
Ethyl chloride
Methyl chloride
Sulfur Dioxide
Propane
Ethane
Carbon Dioxide
Ethylene
Vapor pressure, p^* ($lb_f/in.^2$)
Temperature (°F)
10,000
6,000
4,000
2,000
1,000
600
400
200
100
60
40
20
10
6
4
2
1
0.6
0.4
0.2
0.1
−100
−75
−50
−25
0
25
50
75
100
150
200
250
300
350
400
500
600
800