UNIVERSITI
TEKNOLOGI
PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**PCM5123 – RESERVOIR ENGINEERING**
DATE	**:**	**11 AUGUST 2024 (SUNDAY)**
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 **TEN (10)** printed pages in this **double-sided** Question Booklet including the cover page and appendices.

1. a. Explain the steps required to find a flow equation for any flow geometry starting from differential of Darcy's law.

[5 marks]

b. Starting from the correct differential form of Darcy's Law, formulate an equation for the flow through a system whose surface area through which the flow is taking place is a right circular cylinder of radius r and length h.

[8 marks]

c. Explain interfacial tension, the reason for its existence, and its impact on oil recovery.

[5 marks]

d. Explain wettability and describe its influence on at least **TWO (2)** important rock/fluid properties.

[5 marks]

2. The coefficient of isothermal compressibility (c) is a measure of the relative change in volume of a fluid or gas with respect to pressure at a constant temperature. It is an important parameter in reservoir engineering, particularly for understanding the behaviour of gases under varying pressure conditions.

a. The coefficient of isothermal compressibility of a real gas can be expressed as:

$$c_g = \frac{1}{P} - \frac{1}{z}\left(\frac{dz}{dP}\right)_T$$

Given that the compressibility of a gas mixture is:

$$c_g = \frac{c_{pr}}{P_{pc}}$$

Show that the isothermal compressibility of a gas mixture can be expressed as:

$$c_g = \frac{1}{P_{pr}P_{pc}} - \frac{1}{z}\left(\frac{1}{P_{pc}}\frac{dz}{dP_{pr}}\right)$$

[15 marks]

b. Estimate the coefficient of isothermal compressibility for a dry gas at the following conditions.

- Temperature: 220°F
- Pressure: 2100 psig
- Specific gravity of the dry gas: 0.818

[10 marks]

3. a. An oil well is producing at a constant flow rate of 300 STB/day under either unsteady-state flow conditions or quasi-steady state flow conditions. The reservoir has the following rock and fluid properties:

- Formation Volume Factor (B_o) = 1.25 bbl/STB
- Viscosity of Oil (μ_o) = 1.5 cp
- Total Compressibility (c_t) = 12 × 10^{-6} psi^{-1}
- Permeability of Reservoir (k_o) = 60 mD
- Reservoir Thickness (h) = 15 ft
- Initial Reservoir Pressure (p_i) = 4000 psia
- Porosity (ϕ) = 15%
- Wellbore Radius (r_w) = 0.25 ft
- Outer boundary from the centre of the well (r_e) = 1500 ft

Evaluate whether the flow after 48 hours is quasi-steady state flow or transient state flow. Justification required.

[15 marks]

b. Differentiate between compressible, slightly compressible and incompressible fluids. Include the mathematical expressions used to describe each type and provide examples of each fluid type in reservoir engineering.

[10 marks]

4. The relative permeability data of a reservoir under consideration for Waterflooding is given in **TABLE Q4a**. The viscosity of reservoir brine is 1.1 cP, the viscosity of reservoir oil is 2.2 cp, and the initial/connate water saturation (S_{wi}) is 0.2.

TABLE Q4a: The relative permeability data of the reservoir

S_w	k_o/k_w
0.2	∞
0.26	35
0.32	13.48
0.38	6.77
0.42	4.28
0.48	2.15
0.52	1.36
0.56	0.86
0.62	0.43
0.68	0.22
0.74	0.11
0.87	0

a. Create a fractional flow curve for this reservoir.

[8 marks]

b. Determine the following at the time of water breakthrough:

i. The cumulative volume of water injected in reservoir pore volume.

[3 marks]

ii. The fractional flow (f_{wf}) and the saturation of water at the front (S_{wf}).

[3 marks]

iii. Average water saturation behind the front (S_{wavg})

[2 marks]

c. Determine the oil recovery factor (RF) at the time of breakthrough

[3 marks]

d. Using the Adalasani Screening Criteria provided in **FIGURE Q4** in the **APPENDIX 4**, select the most appropriate EOR process(es) for the reservoir whose production is declining after secondary recovery and whose properties are given in **TABLE Q4b**. Also, describe which process(es) you will completely reject. Justify.

TABLE Q4b: The reservoir properties of the EOR candidate reservoir

Properties	Values
Reservoir Type	Carbonate
Depth	5000 ft
Temperature	110° F
Start oil saturation	52%
Permeability	80 md
Porosity	25%
Viscosity @ Reservoir Temp.	16 cp
Oil Gravity	25° API

[8 marks]

-END OF PAPER-

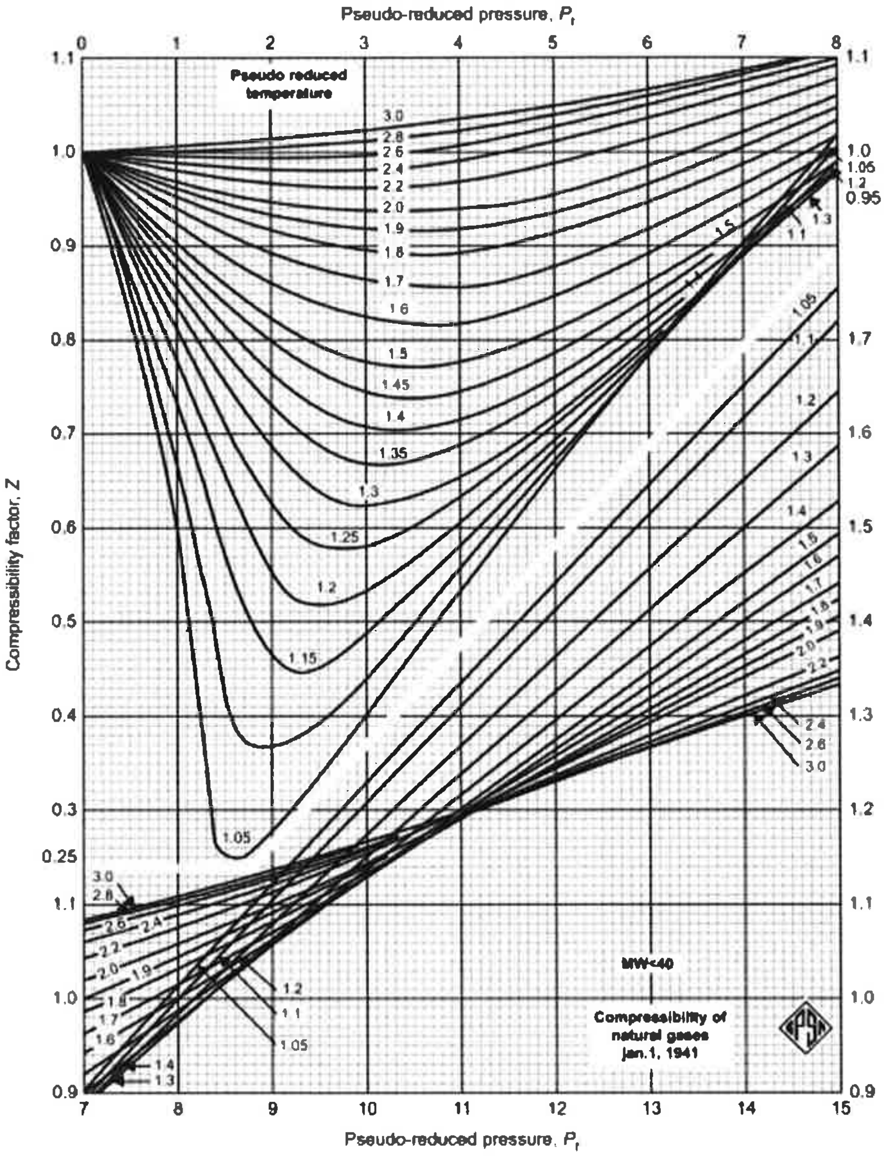
APPENDIX 1

$$p(r,t) = p_{\mathrm{i}} + \left[\frac{70.6Q_{\mathrm{o}}\mu_{\mathrm{o}}B_{\mathrm{o}}}{kh}\right] E_i\left[-\frac{948\phi\mu_{\mathrm{o}}c_{\mathrm{t}}r^2}{kt}\right]$$

Values of the $-E_i(-x)$ as a function of x

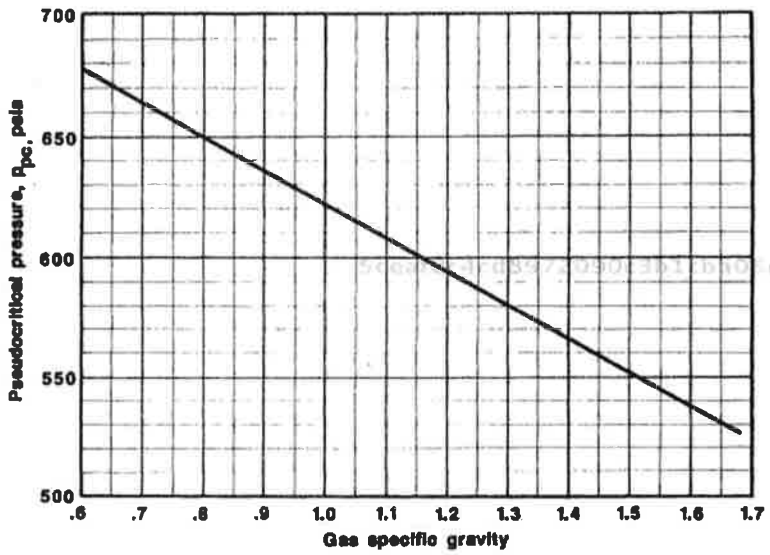
$2.0 < x < 10.9$, interval = 0.1										
x	0	1	2	3	4	5	6	7	8	9
2	4.89×10^{-2}	4.26×10^{-2}	3.72×10^{-2}	3.25×10^{-2}	2.84×10^{-2}	2.49×10^{-2}	2.19×10^{-2}	1.92×10^{-2}	1.69×10^{-2}	1.48×10^{-2}
3	1.30×10^{-2}	1.15×10^{-2}	1.01×10^{-2}	8.94×10^{-3}	7.89×10^{-3}	6.87×10^{-3}	6.16×10^{-3}	5.45×10^{-3}	4.82×10^{-3}	4.27×10^{-3}
4	3.78×10^{-3}	3.35×10^{-3}	2.97×10^{-3}	2.64×10^{-3}	2.34×10^{-3}	2.07×10^{-3}	1.84×10^{-3}	1.64×10^{-3}	1.45×10^{-3}	1.29×10^{-3}
5	1.15×10^{-3}	1.02×10^{-3}	9.08×10^{-4}	8.09×10^{-4}	7.19×10^{-4}	6.41×10^{-4}	5.71×10^{-4}	5.09×10^{-4}	4.53×10^{-4}	4.04×10^{-4}
6	3.60×10^{-4}	3.21×10^{-4}	2.86×10^{-4}	2.55×10^{-4}	2.28×10^{-4}	2.03×10^{-4}	1.82×10^{-4}	1.62×10^{-4}	1.45×10^{-4}	1.29×10^{-4}
7	1.15×10^{-4}	1.03×10^{-4}	9.22×10^{-5}	8.24×10^{-5}	7.36×10^{-5}	6.58×10^{-5}	5.89×10^{-5}	5.26×10^{-5}	4.71×10^{-5}	4.21×10^{-5}
8	3.77×10^{-5}	3.37×10^{-5}	3.02×10^{-5}	2.70×10^{-5}	2.42×10^{-5}	2.16×10^{-5}	1.94×10^{-5}	1.73×10^{-5}	1.55×10^{-5}	1.39×10^{-5}
9	1.24×10^{-5}	1.11×10^{-5}	9.99×10^{-6}	8.95×10^{-6}	8.02×10^{-6}	7.18×10^{-6}	6.44×10^{-6}	5.77×10^{-6}	5.17×10^{-6}	4.64×10^{-6}
10	4.15×10^{-6}	3.73×10^{-6}	3.34×10^{-6}	3.00×10^{-6}	2.68×10^{-6}	2.41×10^{-6}	2.16×10^{-6}	1.94×10^{-6}	1.74×10^{-6}	1.56×10^{-6}

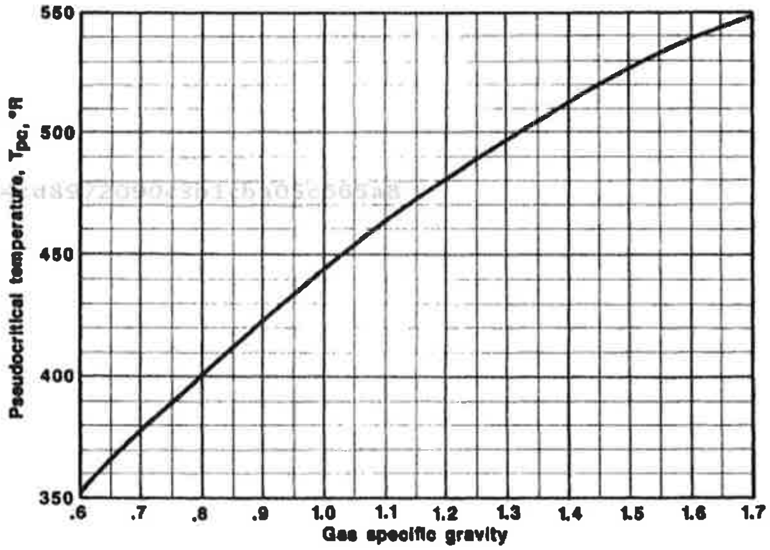
APPENDIX 2



Pseudo-reduced pressure, P_r
Pseudo reduced temperature
Compressibility factor, Z
MW<40
Compressibility of natural gases Jan. 1, 1941

APPENDIX 3


700
650
600
550
500
Pseudocritical pressure, p_{pc}, psia
.6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
Gas specific gravity


550
500
450
400
350
Pseudocritical temperature, T_{pc}, °R
.6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7
Gas specific gravity

APPENDIX 4

Adapted from Adalasani Screening Criteria (SPE 130726)

		Oil Properties		Reservoir characteristics						Score
EOR methods	Projects	Specific Gravity (API)	Viscosity (cp)	Porosity (%)	Oil satrn (% PV)	Formation type	Perm. (md)	Depth (ft)	Temp. (°F)	
Miscible Gas Injection (CO2)										
CO2	139	22-45	<10	3-37	15-89	Sandstone or Carbonate	1.5-4500	1500-13365	82-250	
Nitrogen	3	35-54	<3	7.5-14	40-80	Sandstone or Carbonate	0.2-35	6000-18500	190-325	
Thermal flooding										
Steam	271	Aug-30	<20000	Dec-65	35-90	Sandstone	>50	<115000	10-350	
In-Situ Combustion	27	Oct-38	<5000	14-35	50-94	Sandstone or Carbonate	>200	<4500	64.4-230	
Hot water	10	Dec-25	170-8000	25-37	15-85	Sandstone	900-6000	500-2950	75-135	
Chemical flooding										
Polymer	53	13-42.5	10-150	10.4-33	34-82	Sandstone	>10	700-9460	74-237.2	
Combination EOR										
ASP	13	20-35	<35	26-32	35-74.8	Sandstone	>10	2723-9000	80-200	
Surfactant + (Polymer or Alkanline)	3	22-39	3-15.6	16-16.8	43.5-53	Sandstone	50-60	625-5300	122-155	
WAG	3	35-54	0-0.2	7.5-14	40-80	Sandstone or Carbonate	0.2-35	6000-18500	190-325	
Microbial										
Microbial	4	Dec-33	1.7-8900	Dec-26	55-65	Sandstone	180-200	1572-3464	86-90	