UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**PEB1043/PFB1043 - RESERVOIR ROCK PROPERTIES**
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 **NINE (9)** pages in this Question Booklet including the cover page and the Appendix.

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

1. Field Alpha is a sandstone reservoir discovered in 1998. A field development study has been conducted to assess the hydrocarbon potential of this field. Core plug samples were extracted, and wettability measurements were performed in the laboratory to characterize the reservoir rock samples.

   a. Discuss the conditions which indicate whether the reservoir rock is water – wet or oil – wet. Illustrate your discussion with necessary equations or sketches to show the difference between oil – wet and water – wet system.

   [12 marks]

   b. The results of the spontaneous and forced displacement tests on a set of core plug sample extracted from a well in Field Alpha are shown in **TABLE Q1**.

TABLE Q1 : Results of spontaneous and forced displacement tests.

Sample	A	B	C
Depth (ft)	3777.3	3640.7	3908
Spontaneous displacement of oil (mL)	0.20	0.30	0.30
Forced displacement of oil (mL)	0.80	0.50	2.50
Spontaneous displacement of water (mL)	0.20	0.20	0.30
Forced displacement of water (mL)	0.30	0.10	3.00

Determine the Amott – Harvey wettability index and evaluate the wettability of each rock sample.

[14 marks]

2. Permeability is a measure of the ability of rocks to transmit fluids. In the laboratory, permeability can be measured by using water or gas as the fluid phase.

a. Discuss permeability measurement using gas. Provide advantage or disadvantage of measuring permeability using this method. Using suitable sketches, explain the reason correction needs to be done for gas permeability measurement and steps required to perform the correction.

[12 marks]

b. **FIGURE Q2** is a plot showing the injected flow rate and corresponding pressure during a brine permeability experiment. A total of five different flow rates were injected during the experiment and the stabilized pressure after each rate was observed. The core plug sample measured 6 – inch length with diameter of 1.5 inch. The brine viscosity was 0.00105 Pa.s.

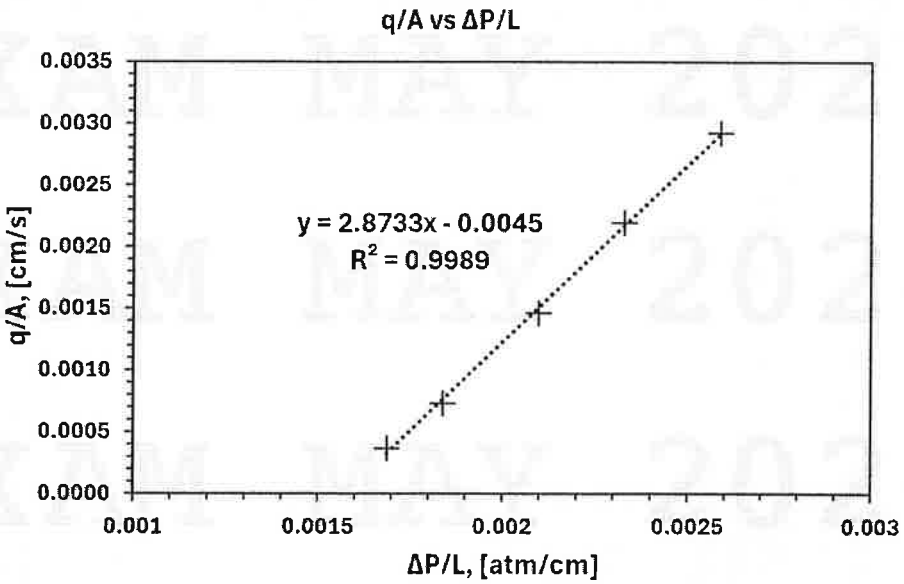

FIGURE Q2 : Plot of flow rates and corresponding pressures in a brine permeability experiment.

i. Estimate the final flow rate q (in cc/min) with the corresponding pressure difference, Δp (in psi) that were observed during this experiment.

[4 marks]

ii. Predict the pressure response, Δp (in psi) when the brine injection rate is increased to 5.0 cc/min.

[5 marks]

iii. Determine the permeability of the core plug sample in m^2.

[5 marks]

3. Capillary pressure measurements were performed in the laboratory for core plug sample from Field Alpha. The results are plotted in **FIGURE Q3**. Additional experimental parameters are given in **TABLE Q3**.

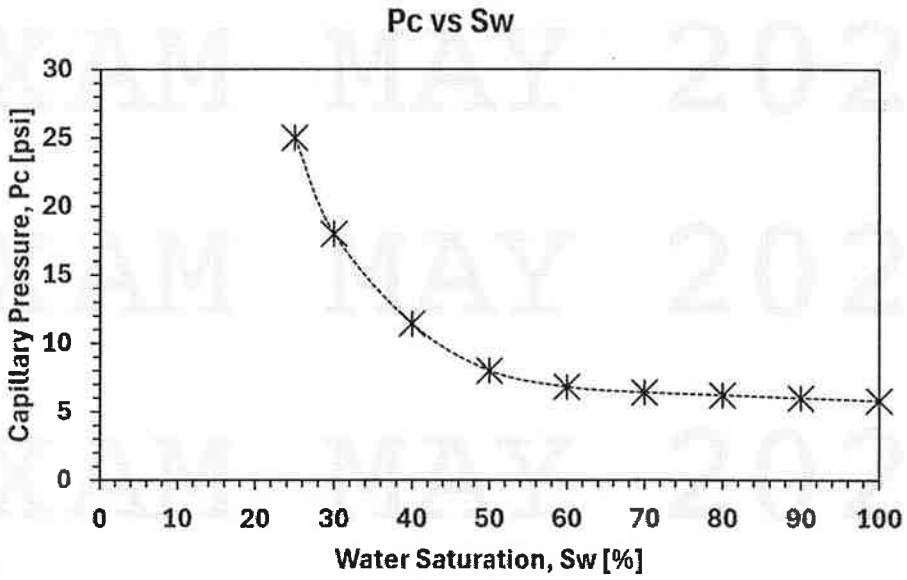

FIGURE Q3 : Results of laboratory capillary pressure measurements

TABLE Q3 : Additional experimental parameters

Laboratory conditions	
$\sigma_{a/w}$ (dynes/cm)	72
$\theta_{a/w}$	0°
Reservoir conditions	
$\sigma_{o/w}$ (dynes/cm)	26
$\theta_{o/w}$	20°
ρ_o (g/cm^3)	0.8
ρ_w (g/cm^3)	1.0
Conversion 1 g/cm^3	62.4 lb/ft^3

a. The oil – water contact for this field was found at a depth of 2000 ft below sea level.

i. Determine the irreducible water saturation and threshold capillary pressure for this core plug sample and explain whether the capillary pressure curve represents drainage or imbibition capillary pressure and provide your justification.

[4 marks]

ii. Estimate the free – water level (FWL) for this field and the estimated depth where water saturation is 40%.

[6 marks]

iii. Predict the suitable depth to complete a well, if the field will be developed to produce the oil. Provide justification for the calculated depth.

[5 marks]

b. Discuss the effect of wettability on the imbibition capillary pressure curve and how wettability can be determined using the Amott method from the capillary pressure curve. Illustrate your answer with suitable sketch.

[9 marks]

4. a. Differentiate the coring methods available to retrieve the rock sample from the reservoir and describe the challenges to obtain a representative sample.

[13 marks]

b. Choose any **TWO (2)** clays typical in a sandstone and discuss the morphologies of these clays. Then, describe the mechanism by which the chosen clays can cause formation damage or permeability reduction in a reservoir.

[7 marks]

c. Discuss the mechanism of pore volume reduction due to rock compressibility.

[4 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 D = 1000 mD = 9.869233 x 10^{-13} m^2
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	

Porosity formula	
$\phi = \frac{V_p}{V_b} = \frac{V_b - V_m}{V_b}$	$\bar{\phi} = \sum \frac{\phi_i}{n}$
$V_p = \frac{W_s - W_d}{\rho}$	$\bar{\phi} = \frac{\sum \phi_i h_i}{\sum h_i}$
$W_{displ\ fluid} = W_{dry} - W_{apparent}$	$\bar{\phi} = \frac{\sum \phi_i A_i}{\sum A_i}$
$V_b = \frac{W_{displ\ fluid}}{\rho} - V_{coat}$	$\bar{\phi} = \frac{\sum \phi_i A_i h_i}{\sum A_i h_i}$
$P_1 V_1 = P_2 (V_1 + V_2 - V_m)$	

Saturation, permeability, and relative permeability formula

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

$$\bar{k} = \sum_{i=1}^{n} \frac{k_i h_i}{h} \qquad \bar{k} = \frac{L}{\sum_{i=1}^{n} \frac{L_i}{k_i}} \qquad S_w = \frac{m_{wet} - m_{rock} - PV\rho_o}{PV(\rho_w - \rho_o)}$$

$$W_s = W_d + W_w + W_o$$
$$W_s = W_d + \rho_w V_w + \rho_o V_o \qquad S_o = \frac{W_s - W_d - \rho_w V_p}{V_p(\rho_o - \rho_w)}$$

Capillary pressure and wettability

$$P_c = \frac{2\sigma\cos\theta}{r} \qquad h = \frac{2\sigma\cos\theta}{rg\Delta\rho} \qquad P_c = \frac{h}{144}\Delta\rho,\ P_c \text{ in psi}$$

$$P_{c,res} = P_{c,lab}\frac{\sigma_{res}\cos\theta_{res}}{\sigma_{lab}\cos\theta_{lab}} \qquad FWL = WOC + \frac{144 p_d}{\Delta\rho}$$

$$\delta_w = \frac{V_{os}}{V_{ot}} \qquad V_{ot} = V_{os} + V_{of} \qquad \delta_o = \frac{V_{ws}}{V_{wt}} \qquad V_{wt} = V_{ws} + V_{wf}$$

$$I_w = \frac{S_w(B) - S_w(A)}{S_w(C) - S_w(A)} \qquad I_o = \frac{S_o(D) - S_o(C)}{S_o(E) - S_o(C)}$$