RESERVOIR ENGINEERING FUNDAMENTALS

MFKOT720024

Olaj- és gázmérnöki mesterszak
Angol Olaj

English – MSc. of Petroleum Engineering

Nappali munkarend
Daily work schedule

TANTÁRGYI KOMMUNIKÁCIÓS DOSSZIÉ
CURRICULUM COMMUNICATION FILE

Miskolci Egyetem
Műszaki Földtudományi Kar
Kőolaj és Földgáz Intézet

Miskolc University
Faculty of Earth Science and Engineering
Institute of Petroleum and Natural Gas

Miskolc, 2023/2024 II. félév/semester
A tantárgy adatlapja / Course data sheet

Course Title: Reservoir Engineering Fundamentals **Instructor:** Dr. Dmour Hazim Nayel AB., Associates Professor **Instructor Assistant:** Dócs Roland, teaching assistant	**Code:** MFKOT720024 **Responsible department/institute:** GMTSZ/KFGI **Course element:** Compulsory
Position in curriculum* (Which semester): 2 (1)	**Pre-requisites (if any):** no
No. of contact hours per week (lecture + seminar): 2+2	**Type of Assessment (examination / practical mark / other):** examination
Credits: 6	**Course:** full time

Task and purpose of the subject:
To provide the students with a solid understanding of the basic principles of fluid flow in porous media, including Darcy's law, reservoir fluid properties and the fundamentals of oil reservoir engineering; reservoirs classification, oil in place, recovery factor, performance prediction, and water influx calculations, laboratory measurements and calculation methods determination, as well as volumetric and statistical determination of hydrocarbon in place (reserves).
Competencies to evolve:
Knowledge: T1, T6, T7, T8, T11
Ability: K1, K6, K7, K8, K11
Attitude:
Autonomy and responsibility: F1, F4, F6, F7

Assessment and grading:
Students will be assessed with using the following elements.
Attendance: 5 %
Homework 10 %
Midterm exam 40 %
Final exam 45 %
Total 100%
It is possible to make up for an unsuccessful or unwritten midterm exams in the last class of the semester.
Grading scale:

% value	Grade
90 -100%	5 (excellent)
80 – 89%	4 (good)
70 - 79%	3 (satisfactory)
60 - 69%	2 (pass)
0 - 59%	1 (failed

Compulsory or recommended literature resources:

Craft and Hawkins: Applied Petroleum Reservoir Engineering, Prentice Hall, 1991, ISBN 0-13-039884-5
Towler: Fundamental Principles of Reservoir Engineering, SPE Textbook Series, Vol.8., 2002, ISBN 1-55563-092-8
T. Ahmed: Advanced Reservoir Engineering, Gulf Publishing Co. 2005, ISBN-13: 978-0-7506-7733-2
T. Ahmed: Reservoir Engineering Handbook, Gulf Publishing Co., 2001, ISBN 0-88415-770-9
L. P. Dake: Fundamentals of Reservoir Engineering, Elsevier, 1978, ISBN 0-444-41830-X
János Török, Lipót Fürcht, Tibor Bódi: PVT Properties of Reservoir Fluids. (Book). University of Miskolc Miskolc, Hungary 2012. ISBN 978-963-661-988-5 p. 1-192

Féléves ütemterv / Course schedule

Dátum, date	**Hét, week**	**Téma, subject**
2024.02.16.	1.	Fundamental properties of porous media.
2024.02.23.	2.	Porosity, Compressibility, Specific surface area
2024.03.01.	3.	Saturation, Wettability and determination of capillary pressure
2024.03.08.	4.	Determination of the permeability of a porous media
2024.03.15	5.	Determination of the two-phase and relative permeability
2024.03.22	6.	Exam no.1
2024.03.29.	7.	Electric properties and the tortuosity of a porous rock
2024.04.05.	8.	Equations of state
2024.04.12.	9.	PVT correlation for natural gases
2024.04.19.	10.	PVT correlation for saturated black oils. PVT correlation for under saturated black oils
2024.04.26.	11.	Equilibrium calculation of two phase hydrocarbon systems. PVT correlations for water
2024.05.03.	12.	Exam no.2
2024.05.10.	13.	Viscosity correlations for petroleum reservoir fluids
2024.05.17.	14.	End of semester, writing supplementary tests

<u>**Sample of Midterm Exam no.1:**</u>

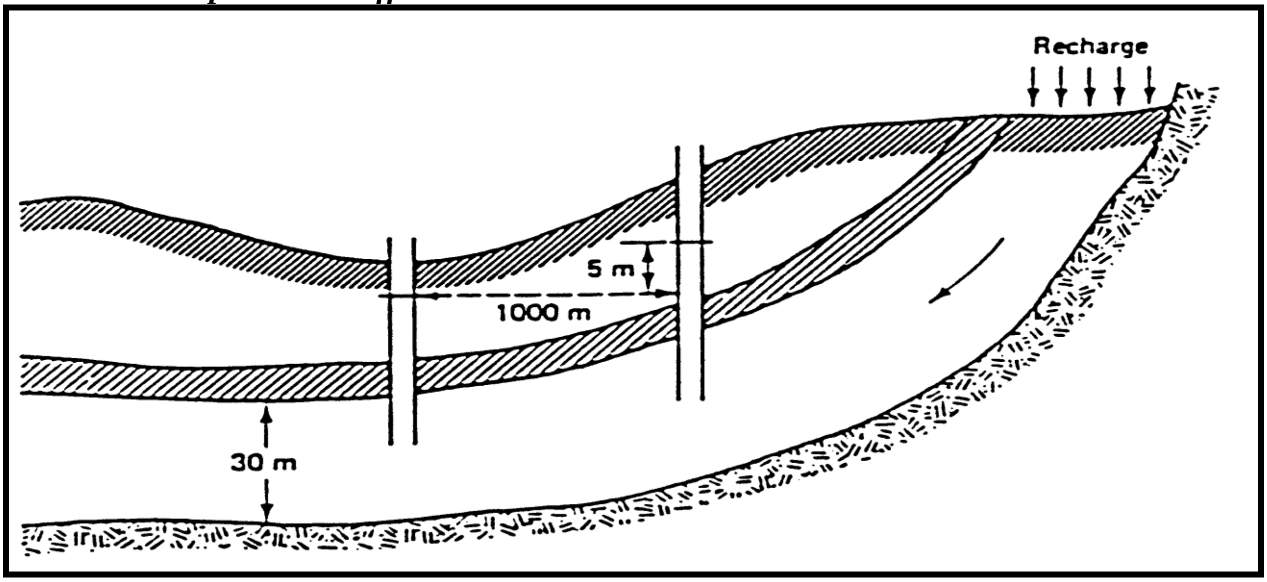
Darcy's Law

- **A confined aquifer has a source of recharge, figure below.**
- **K for the aquifer is 50 m/day, and n is 0.2.**
- **The piezometric head in two wells 1000 m apart is 55 m and 50 m respectively, from a common datum.**
- **The average thickness of the aquifer is 30 m, and the average width is 5 km.**

Calculate:

- **The rate of flow through the aquifer**
- **The time of travel from the head of the aquifer to a point 4 km downstream**

****Assume no dispersion or diffusion***



The solution

GIVEN EQUATIONS

- $V = -K(\Delta h/\Delta L)$
- $Q = VA$
- $Q = -KA(dh/dL)$
- $V = Q/A$, $v \propto -\Delta h$, and $v \propto 1/\Delta L$
- $Q = A\, v_D = A_V\, V_s$
- $V_S = V_D\,(A/A_V)$
- $V_S = V_D\,(AL / A_V L) = V_D\,(V_T / V_V)$
- $V_v / V_T = n$ *the soil porosity*
- $V_S = V_D / n$

Where:

Q = flow rate A = cross-sectional area of material A_V= area of voids V_s = seepage velocity v_D= Darcy velocity V_T = total volume V_V = void volume

- Cross-Sectional area= 30(5)(1000) = 15 x 10^4 m^2
- Hydraulic gradient = (55-50)/1000 = 5 x 10^{-3}
- Rate of Flow for K = 50 m/day Q = (50 m/day) (75 x 10^1 m^2) = 37,500 m^3/day
- Darcy Velocity and Seepage Velocity: V = Q/A = (37,500m^3/day) / (15 x 10^4 m^2) = 0.25m/day

  V_s = V/n = (0.25) / (0.2) = 1.25 m/day (about 4.1 ft/day)
- Time to travel 4 km downstream:

  T = 4(1000m) / (1.25m/day) = 3200 days or 8.77 years
- *This shows that water moves very slowly underground.*

Sample of Midterm Exam no.2:

Question no.1

An incompressible fluid flows in linear porous media with the following properties:

$L = 2000$ ft, $h = 20$ ft, width $= 300$ ft
$k = 100$ md, $\phi = 15\%$, $\mu = 2$ cp
$p_1 = 2000$ psi, $p_2 = 1990$ psi

Calculate:

(a) flow rate in bbl/day;
(b) apparent fluid velocity in ft/day;
(c) actual fluid velocity in ft/day.

Solution Calculate the cross-sectional area A:

$$A = (h)(\text{width}) = (20)(100) = 6000 \text{ ft}^2$$

(a) Calculate the flow rate from Equation 1.2.2:

$$q = \frac{0.001127 kA(p_1 - p_2)}{\mu L} = \frac{(0.001127)(100)(6000)(2000 - 1990)}{(2)(2000)} = 1.6905 \text{ bbl/day}$$

(b) Calculate the apparent velocity:

$$v = \frac{q}{A} = \frac{(1.6905)(5.615)}{6000} = 0.0016 \text{ ft/day}$$

(c) Calculate the actual fluid velocity:

$$v = \frac{q}{\phi A} = \frac{(1.6905)(5.615)}{(0.15)(6000)} = 0.0105 \text{ ft/day}$$

Question no. 2

Calculate the pressure difference, i.e., capillary pressure, and capillary rise in an oil-water system from the following reservoir data:

$\theta = 30°$ $\quad \rho_w = 1.0\ gm/cm^3$ $\quad \rho_o = 0.75\ gm/cm^3$

$r = 10^{-4}\ cm$ $\quad \sigma_{ow} = 25\ dynes/cm$

- **Gas-liquid system**

Solution

Step 1. Apply Equation 4-32 to give

$$p_c = \frac{(2)\,(25)\,(\cos\ 30°)}{0.0001} = 4.33 \times 10^5\ dynes/cm^2$$

Since 1 dyne/cm^2 = 1.45 × 10^{B5} psi, then

$p_c = 6.28$ psi

This result indicates that the oil-phase pressure is 6.28 psi higher than the water-phase pressure.

Step 2. Calculate the capillary rise by applying Equation 4-33.

$$h = \frac{(2)\,(25)\,(\cos\ 30°)}{(0.0001)\,(980.7)\,(1.0 - 0.75)} = 1766\ cm = 75.9\ ft$$

- **Gas-liquid system**

$$P_c = \frac{2\,\sigma_{gw}\,(\cos\theta)}{r}$$

and

$$h = \frac{2\,\sigma_{gw}\,(\cos\ \theta)}{r\,g\,(\rho_w - \rho_{gas})}$$

where ρ_w = water density, gm/cm^3

σ_{gw} = gas-water surface tension, dynes/cm

r = capillary radius, cm

θ = contact angle

h = capillary rise, cm

g = acceleration due to gravity, cm/sec^2

p_c = capillary pressure, dynes/cm^2

- **Oil-water system**

$$p_c = \frac{2\,\sigma_{ow}\,(\cos\theta)}{r}$$

and

$$h = \frac{2\,\sigma_{wo}\,(\cos\ \theta)}{r\,g\,(\rho_w - \rho_o)}$$

where σ_{wo} is the water-oil interfacial tension.

Sample of Midterm Assignments

Assignment no.1

1. The table on page 2 provides core analysis data for a sandstone reservoir (Cardium Formation – Pembina ss) in Alberta. The well these cores were taken from is 00/05-17-049-8W5/0 (APF ET AL PEMBINA 5-17-49-8). *NOTE: These data are available in an Excel file on the Assignments page of our class website.*

(a) Using these data, plot the maximum permeability to air (KMax) against porosity (PHI). Use a log scale for the Y-axis (KMax).

Using Excel's built-in trendline feature, determine the empirical equation that best fits this dataset (i.e., find the trendline type that yields the highest value for the regression coefficient R^2). Print this plot, showing the trendline. **[1 mark]**

(b) Consider the following, slightly modified version of the Kozeny-Carmen equation:

$$k = A\frac{\phi^3}{(1-\phi)^2}$$

where:

k = intrinsic permeability (in mD, for this assignment)

A = constant that accounts for tortuosity, grain size, and conversion from SI units (m^2) to field units (mD)

Show a plot of k vs $\phi^3/(1-\phi)^2$, and determine the value of A. **[2 marks]**

(c) Which equation gives a better match to this dataset; your answer to part (a) or part (b)? Does there seem to be any advantage to using the Kozeny-Carmen relationship in this particular case? **[1 mark]**

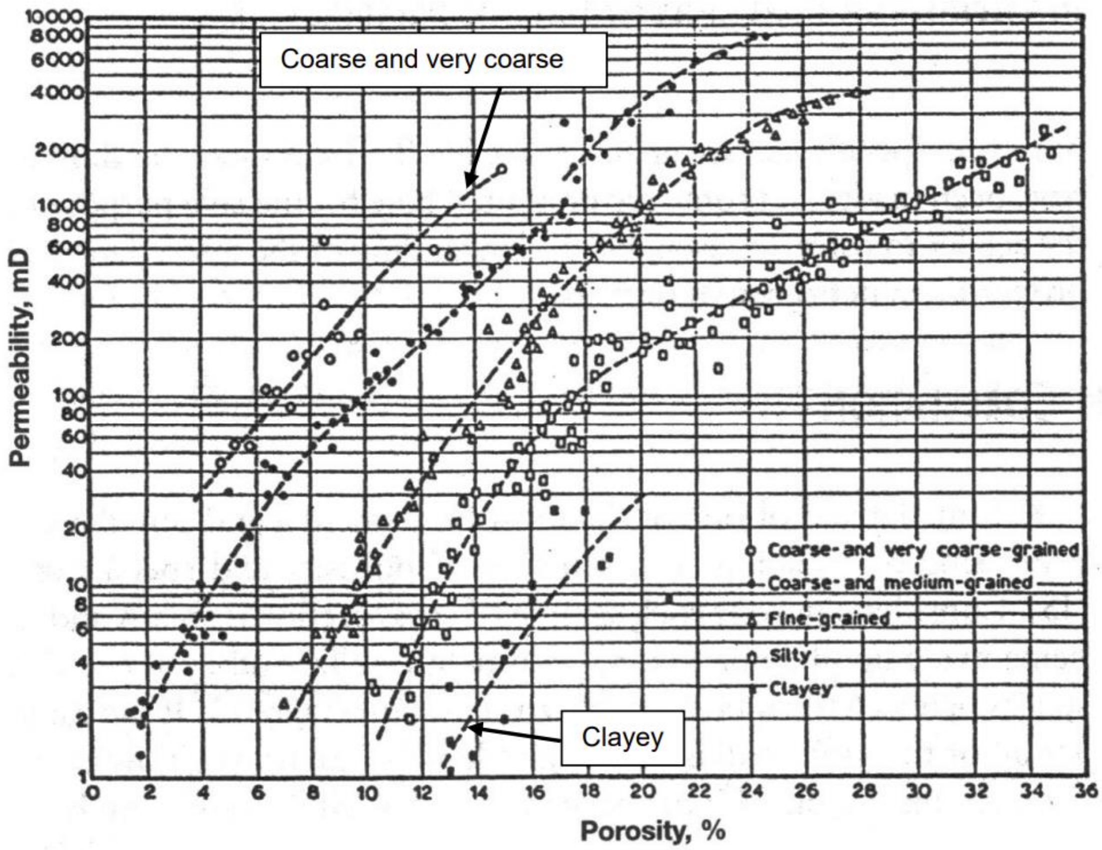
(d) The figure on page 2 shows a semi-log plot of Permeability vs Porosity for various sandstones ranging from very coarse-grained to very fine-grained (i.e., clayey). Based on the trendline drawn for coarse / very coarse-grained sandstones, what (approximately) is a representative permeability for these rocks at 14% porosity? Compare this to a representative permeability for clayey rocks at 14% porosity. Give two possible reasons why these rocks would have such different permeabilities, even though their porosities are the same. **[2 marks]**

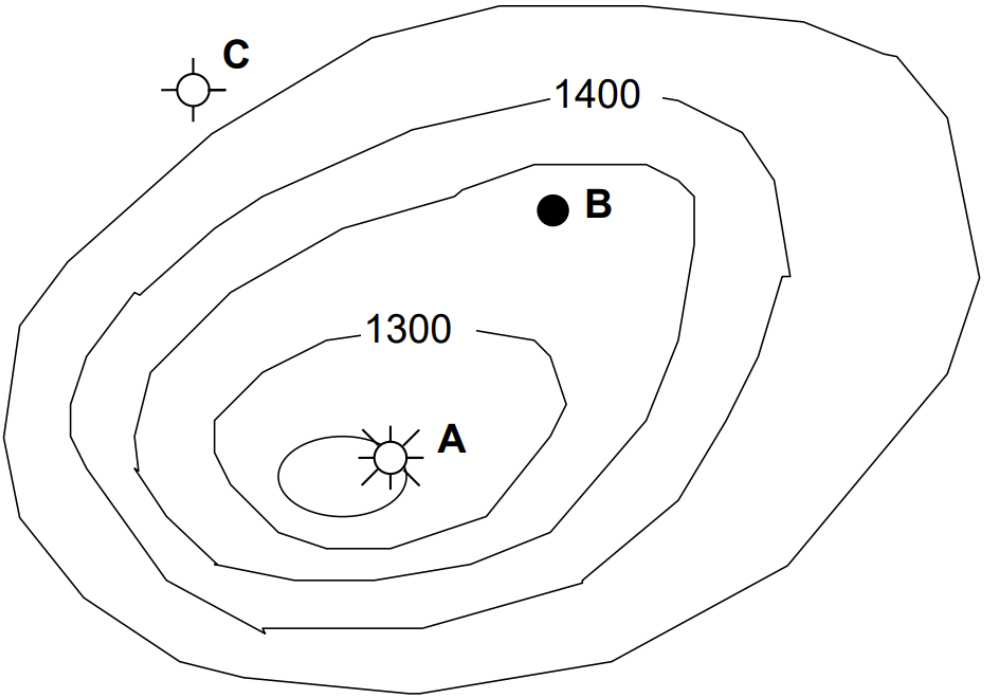
Core Analysis Report for 00/05-17-049-8W5/0 (APF ET AL PEMBINA 5-17-49-8) *Source: IHS Energy (Accumap)*

Core: 1 1504.00 to 1522.00; Length: 18.00 m; Recovered: 17.90 m = 99.4%; Type: Conventional; Test Date: 1993-06-04

	-------Interval (m)-------			------Gas Perm (mD)------			Porosity	Grain	----Residual Sat----					
Sample	Top	Base	Len (m)	KMax	K90	KVert	PHI	Density (kg/m³)	Oil	Water	Formation	Lithology		
1	1504	1509.46	5.46	-	-	-	-	-	-	-	PEMBSS	SH		
2	1509.46	1509.58	0.12	-	-	-	-	-	-	-	PEMBSS	CGL	SHY	
3	1509.58	1509.61	0.03	-	-	-	-	-	-	-	PEMBSS	SH		
4	1509.61	1509.91	0.3	15.2	12.1	1.89	0.181	2660	0.213	0.276	PEMBSS	SS	VF	
5	1509.91	1510.17	0.26	72.7	72.4	44.5	0.231	2650	0.255	0.223	PEMBSS	SS	VF	
6	1510.17	1510.39	0.22	123	117	104	0.242	2650	0.203	0.261	PEMBSS	SS	VF	
7	1510.39	1510.61	0.22	37.8	36.9	4.25	0.203	2650	0.198	0.242	PEMBSS	SS	VF	
8	1510.61	1510.65	0.04	-	-	-	-	-	-	-	PEMBSS	SH		
9	1510.65	1510.91	0.26	3.22	2.66	0.27	0.141	2650	0.253	0.185	PEMBSS	SS	VF	
10	1510.91	1511.06	0.15	14.7	14.2	3.6	0.188	2650	0.297	0.145	PEMBSS	SS	VF	
11	1511.06	1511.23	0.17	0.06	0.06	0.01	0.051	2670	0.569	0.166	PEMBSS	SS	VF	PYR
12	1511.23	1511.29	0.06	0.01	-	-	0.005	2970	0.18	0.4	PEMBSS	SS	VF	FEST
13	1511.29	1511.49	0.2	78.9	78.5	63.6	0.251	2650	0.175	0.222	PEMBSS	SS	VF	
14	1511.49	1512.08	0.59	40	38.8	1.78	0.157	2650	0.328	0.211	PEMBSS	SS	VF	SHBK
15	1512.08	1512.45	0.37	0.6	0.55	0.01	0.141	2660	0.395	0.087	PEMBSS	SS	VF	
16	1512.45	1513	0.55	2.27	1.87	0.12	0.143	2650	0.335	0.121	PEMBSS	SS	VF	SHBK
17	1513	1513.07	0.07	-	-	-	-	-	-	-	PEMBSS	SH	SDY	
18	1513.07	1513.77	0.7	41	29.8	0.34	0.12	2650	0.409	0.134	PEMBSS	SS	VF	SHBK
19	1513.77	1514.58	0.81	2.32	0.36	0.01	0.082	2630	0.275	0.34	PEMBSS	SS	VF	SHBK
20	1514.58	1514.99	0.41	0.14	0.13	0.01	0.065	2650	0.352	0.308	PEMBSS	SS	VF	
21	1514.99	1515.22	0.23	3.45	3.29	1.28	0.146	2650	0.38	0.084	PEMBSS	SS	VF	
22	1515.22	1515.28	0.06	-	-	-	-	-	-	-	PEMBSS	SH		
23	1515.28	1515.76	0.48	15.9	-	-	0.183	2640	0.249	0.187	PEMBSS	SS	VF-F	
24	1515.76	1516.63	0.87	84.9	82.7	0.14	0.134	2670	0.239	0.163	PEMBSS	SS	VF	SHBK
25	1516.63	1517.48	0.85	0.58	0.53	0.01	0.086	2640	0.409	0.201	PEMBSS	SS	VF	
26	1517.48	1518.28	0.8	11.8	11.1	0.54	0.155	2650	0.303	0.186	PEMBSS	SS	VF	SHBK
27	1518.28	1518.36	0.08	4.77	-	-	0.148	2640	0.321	0.121	PEMBSS	SS	VF	
28	1518.36	1521.85	3.49	-	-	-	-	-	-	-	PEMBSS	SH	SDY	
29	1521.85	1522	0.15	-	-	-	-	-	-	-	xxx	LOST CORE		

LEGEND:
KMax = maximum permeability measured in the horizontal plane.
K90 = permeability measured in the horizontal direction rotated 90° from the direction of KMax.
KVert = permeability measured in the vertical direction.





2. The map above shows the location of three wells, and 50 m interval depth contours on a structural closure with a high point at 1240 m GL. At A, the well tested gas with a pressure of 13,020 kPa and a gradient of 2 kPa/m at 1250 m GL. At B, the well tested 45°API oil at 1360 m GL and a pressure of 13,480 kPa. At C, the well tested 11.8 kPa/m brine with a pressure of 14,520 kPa at 1460 m GL.

(a) Find the oil-water contact (OWC) and gas-oil contact (GOC) and sketch these on the given map. **[3 marks]**

(b) Calculate the pressure kick (Δp) at the top of the structure assuming overlying formations are normally pressured with a gradient of 10.0 kPa/m and a surface pressure (i.e., D_w) of 100 kPa. **[1 mark]**

Assignment 2

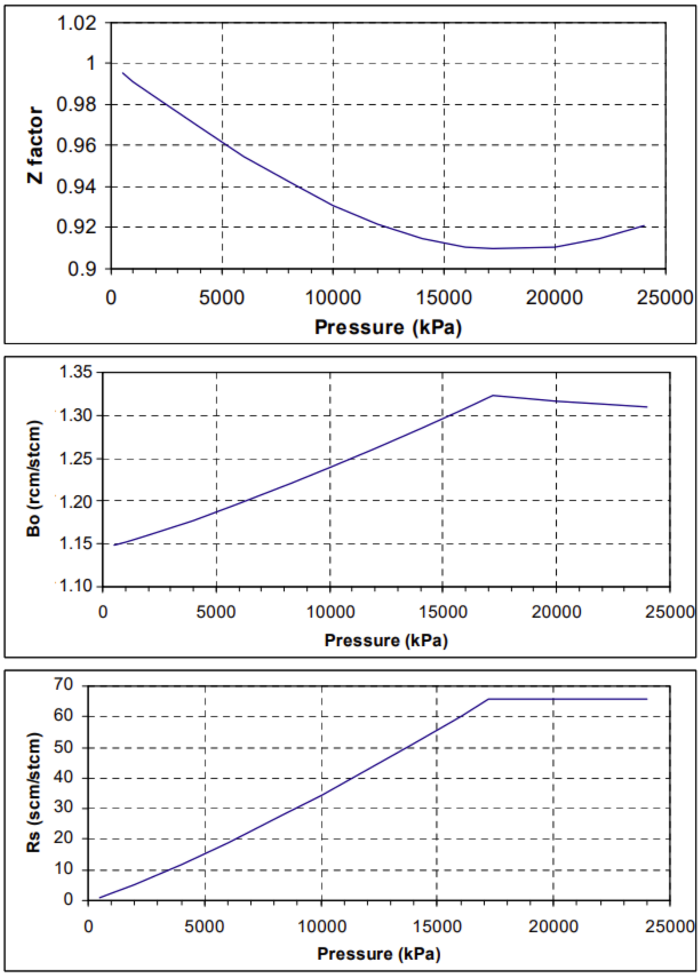
The graphs to the right show the properties of oil and gas present in an oil field that was initially under-saturated.

Below are some additional data that you will need for this assignment:

Initial res. pressure:	24,000 kPa
Res. temperature:	90 °C
Initial R_s:	66 scm/stcm

The separator and stock tank are at standard temperature and pressure.

The producing gas-oil-ratio remains constant at 66 scm/stcm for the entire life of the reservoir (this is after all an example problem).



(a) Based on these graphs, what is the bubble-point pressure of this reservoir (to the nearest 1000 kPa)?

Consider 50 m^3 of oil in the stock tank at three different times: (t_1) when the reservoir pressure was 24,000 kPa; (t_2) when it was 17,000 kPa; and (t_3) when it was 10,000 kPa.

(b) For the 50 m^3 of stock tank oil at each of these times, compute the volume of solution gas and free gas produced at standard conditions.

(c) At each of these times, compute the volume that the produced fluids occupied in the reservoir.