DATE: 2nd of December 2021

FACULTY OF SCIENCE AND TECHNOLOGY

SUBJECT: PET-500 PVT of Petroleum Reservoirs and Fluids

TIME: 4 hours

AID: All aids are permitted.

THE EXAM CONSISTS OF 2 PARTS ON 14 PAGES.

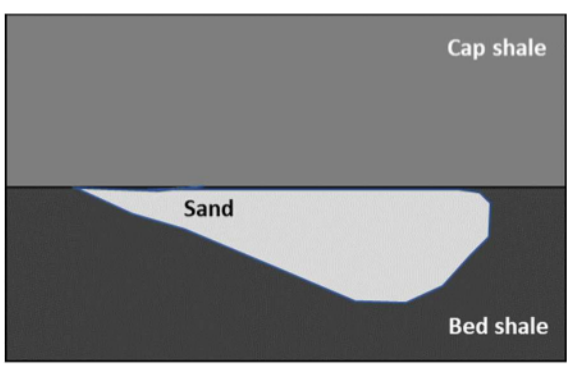
Part 1 is given equal weight as Part 2.

REMARKS: All answers in English.

Part 1
Reservoir Geology; 5 Questions (50*% of exam):*

1) Seismic Impedance.

Consider the following reservoir model that consists of three lithological units: cap shale, sand, and bed shale. All units are assumed to have constant seismic properties:



Calculate the P-wave impedance in the cap-shale layer employing the mudrock-equation:

$$V_P = 1360 + 1.16V_S \qquad \text{(units of m/s)}$$

and the assumption:

$$\frac{Z_P}{Z_s} = 2.15$$

where Z_P and Z_S are the P-wave and S-wave impedances, respectively. The density of the cap-shale layer is set to 2.45 g/cm³.

2) AVO Analysis.

Consider a shale layer overlying a clean sandstone layer that is fully saturated with brine. The seismic properties of these two lithologies are given in the table below:

Lithology	V_p (m/s)	V_s (m/s)	ρ (g/cm³)
Shale	2200	800	2.4
Sandstone	2400	1000	2.1

a) Calculate the effective bulk modulus (K) and shear modulus (μ) for these two lithologies. Give your answers in GPa ($1\text{x}10^9$ Pa = 1 GPa; 1 Pa = 1 N/m2). If the density of the sand (quartz) grains is ρ_{ma} = 2.65 g/cm³ and the density of the brine is 1.02 g/cm³, calculate the porosity of the sandstone.

b) Substitute water (brine) with gas in the sand layer, and compute the effective bulk modulus for the gas-saturated sand (K^*_g). Use the following equation (Gassmann):

$$\frac{K_W^*}{K_S - K_W^*} - \frac{K_W}{\emptyset(K_S - K_W)} = \frac{K_g^*}{K_S - K_g^*} - \frac{K_g}{\emptyset(K_S - K_g)}$$

where K_S is the bulk modulus of the sand grains (40 GPa), K_w is a constant bulk modulus of the water (2.5 GPa), K^*_W is the effective bulk modulus of the brine-saturated sandstone, $\emptyset$ is the porosity of the sandstone, and Kg is a constant bulk modulus of the gas. For simplicity in the calculations assume bulk of the gas to be equivalent to vacuum (K_g and $\rho_{gas} \approx 0$). At the end, calculate the effective density of the gas-saturated sandstone (ρ^*_{gas}) using:

$$\rho_{gas}^* = \rho_{gas}\emptyset + \rho_{ma}(1 - \emptyset)$$

c) Calculate the seismic AVO response [$R_{PP}(\theta)$] for the interface shale – gas-sand reflector. Remember to use your results of part (b), and that the effective shear modulus of the gas-saturated sand is equal to that of the brine-saturated sand. Comment briefly your results in terms of near versus far offset response (up to 30˚) and AVO class.

$$R_{PP}(\theta) \approx R_P(\theta) + G * \sin^2\theta$$

$$R_P = \frac{1}{2}\left(\frac{\Delta Vp}{Vp} + \frac{\Delta\rho}{\rho}\right)$$

$$G = R_P - 2R_S$$

$$R_S = \frac{1}{2}\left(\frac{\Delta Vs}{Vs} + \frac{\Delta\rho}{\rho}\right)$$

$$\Delta Vp = V_{P2} - V_{P1}$$

$$Vp = (V_{P2} + V_{P1})/2$$

$$\Delta Vs = V_{S2} - V_{S1}$$

$$Vs = (V_{S2} + V_{S1})/2$$

$$\Delta\rho = \rho_2 - \rho_1$$

$$\rho = (\rho_2 + \rho_1)/2$$

3) Compaction and diagenetic studies.

a) Sketch in one graph the mechanical compaction trend curves (porosity vs depth) of a (i) dry, pure smectite clay, (ii) oil-saturated pure smectite, (iii) brine-saturated pure kaolinite.

b) Sketch in one graph the mechanical compaction trend curves (porosity vs depth) of a (i) brine-saturated quartz-rich coarse-grained sand, (ii) brine-saturated fine-grained sand, (iii) dry fine sand.

c) Briefly discuss the effects in reservoir and cap rock properties due to the chemical transformation of smectite/kaolinite into illite. Assist your answers with simple sketches/drawings.

4) Petroleum systems.

a) Appendix 1a shows an exploration scenario in the subsurface. Following that figure, your task is to identify the trap class (Sales' Trap Classes) for the traps (a), (b), (c), and (d).
b) In the same area, source rock (Rock-Eval) data has been collected and are displayed in the chart below:

Sample name	TOC (%wt)	HI (mg HC/mg TOC)	Tmax (˚C)
A	7.7	400	436
B	4.8	640	422
C	10.7	700	419
D	5.1	280	448
E	6.2	500	440
F	4.4	230	452

Your task is then to: (i) interpret the depositional environment for each source rock/sample; (ii) which hydrocarbon product(s) will be expelled for each sample; and (iii) which sample(s) is(are) likely sourcing the exploration scenario in part (a). Support your observations using the HI vs Tmax plot in Appendix 1b.

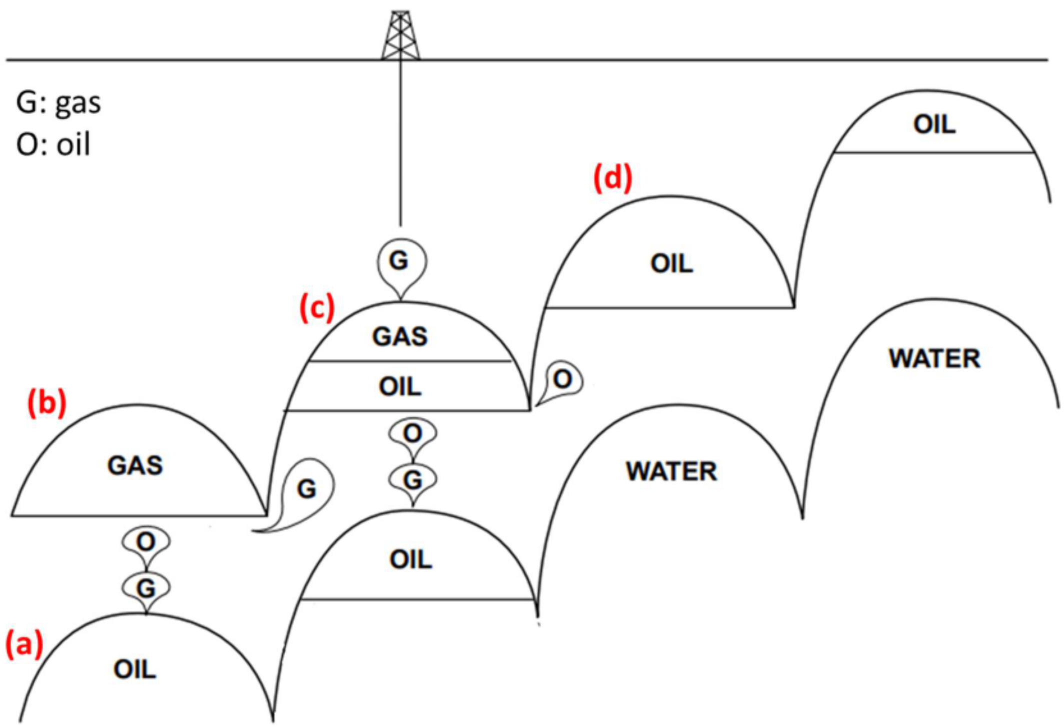
5) Seismic interpretation.

a) Appendix 2 shows an interpreted, depth-converted, seismic section within the Colorado rifted margin, offshore Argentina. The red lines (FS1) are major fault segments, and the black vertical line (Pe) is a drilled well. TC, BU, and TP refer just to the name of mapped horizons. Your task is to identify the different rift stages (pre-, post-, and syn-rift) within the section, including a brief reason of your choices.
b) Appendix 3 shows a seismic section (in TWT) of graben and half-graben basins, offshore Tunisia. Your task is to interpret main faults, and to correlate at least two (2) reflectors across fault planes. Speculate based on your results (briefly) about a possible hydrocarbon target for drilling.

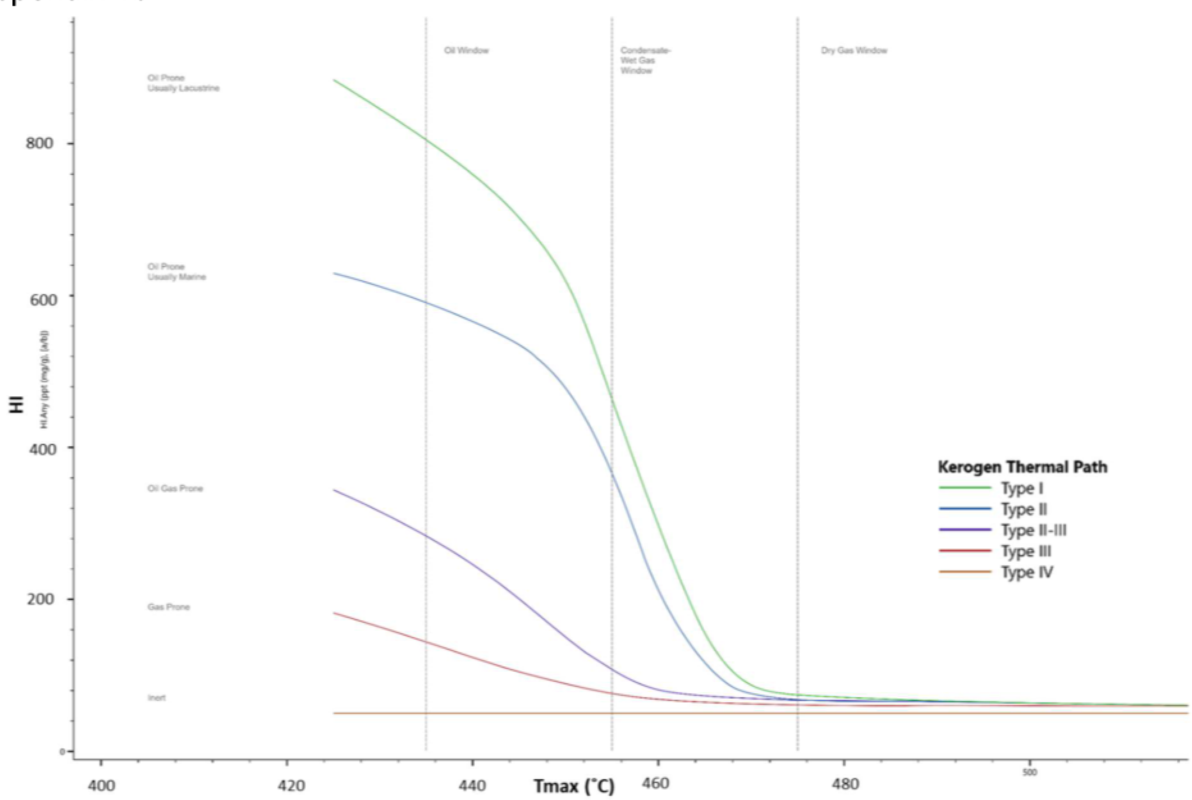
Appendixes on next pages

Good luck! – Lykke til!

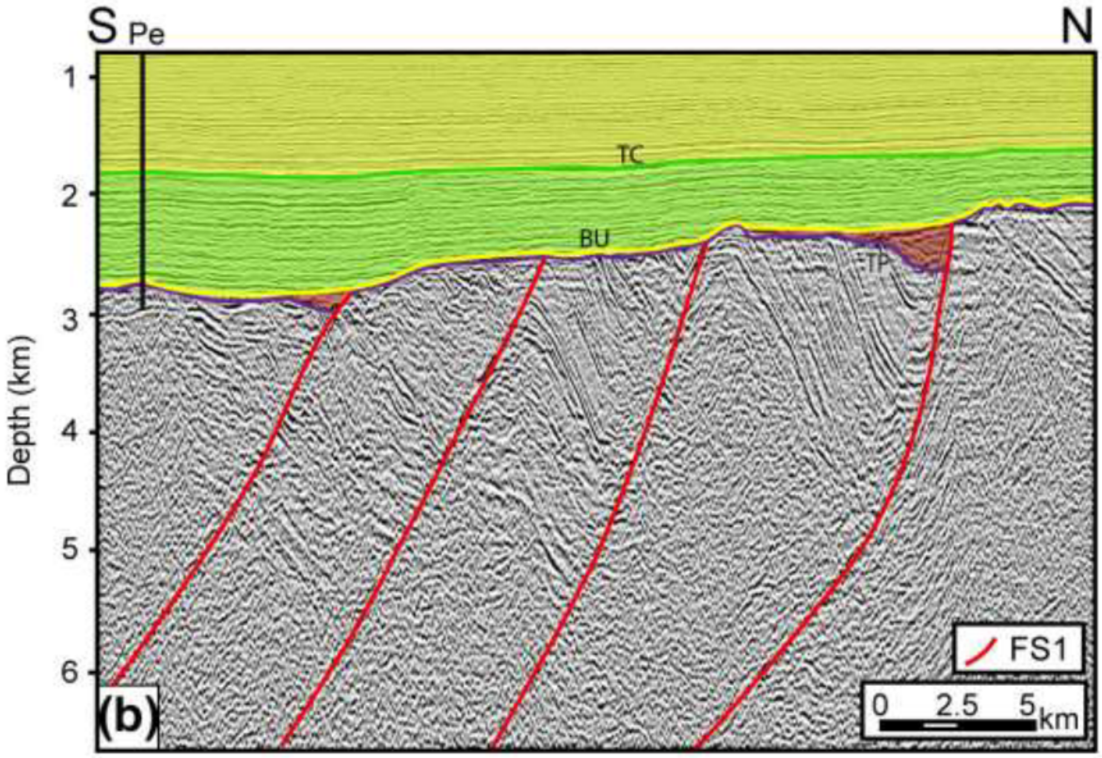
Appendix 1a



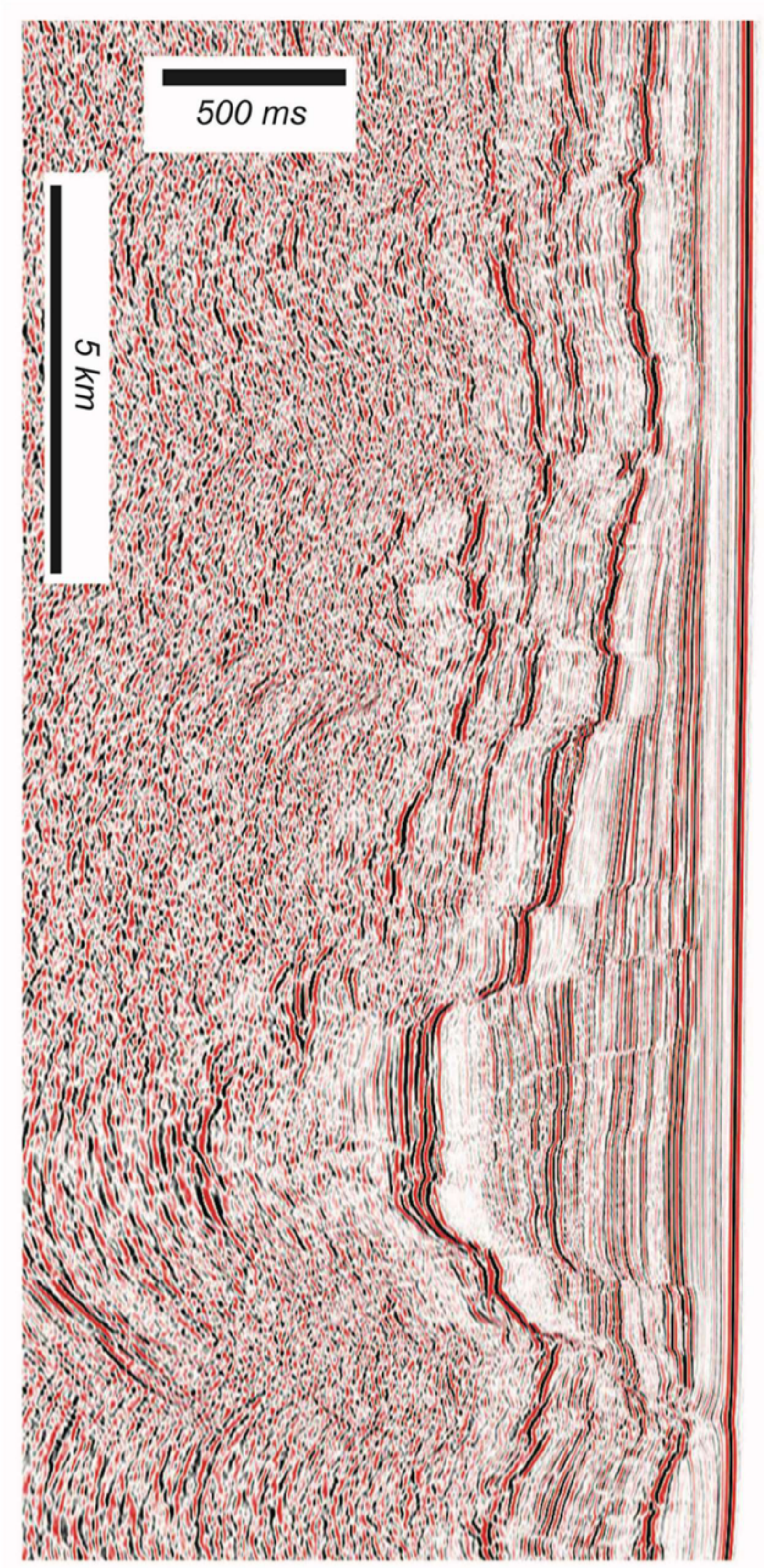
Appendix 1b



Appendix 2



Appendix 3



Part 2
PVT of Fluids; 6 Questions (50*% of exam):*

A representative hydrocarbon fluid sample are taken from a reservoir and brought to laboratory for analyses.

The following reservoir data are given:

Initial pressure:	P_i = 460 bar
Reservoir temperature:	T_{res} = 90 °C
Bulk reservoir volume:	$V_B = 10^6 m^3$
Reservoir Porosity:	Ø = 0.20
Residual water saturation:	S_{wi} = 0.15

A constant mass expansion and a separator test are performed. The results are reported in Table 1 and Table 2.

Table 1 CME data at T_{res} :

Pressure Bar	Cell volume cm^3	Rel Vol V/V_b	Compressibility 1/Bar
510	154.144	0.9634	
460	155.088	0.9693	
410	156.144	0.9759	
360	157.312	0.9832	
310	158.624	0.9914	
263		1.0000	
260	160.528	1.0033	
210	171.6	1.0725	
160	193.392	1.2087	
110	244.336	1.5271	
60	418.528	2.6158	

Table 2 Separator test:

Pressure Bara	Temp, °C	GOR Sm^3/Sm^3	Gravity Air =1	Oil Density g/cm^3	FVF* m^3/Sm^3
263	90.0			0.728	1.340
110.0	60.0	75	0.682	0.794	1.155
40.0	40.0	33	0.710	0.833	1.070
1.0	15.0	22	1.048	0.865	1.000

*FVF = formation volume factor

a.

1. Describe shortly how a constant mass expansion experiment is performed.
2. Describe how to calculate/find the bubble point (P_b).
3. What is the cell volume at P_b.
4. Calculate the compressibility factor for the single phase fluid between P_b and P_i.

b.

Describe how the chemical composition analyses is performed experimentally on a representative reservoir fluid sample.

c.

Determine:

1. Initial oil formation factor, $(B_o)_i$.
2. Initial oil in place, IOIP, as Sm^3.
3. initial gas in place, IGIP, as Sm^3.

d.

1. Calculate the recovery of STO (Sm^3) and gas (Sm^3) during a pressure depletion from P_i to P_b . Suppose that the HCPV is constant during the production.
2. What is the recovery factor at P_b.

e.

1. Based on the given data, show that the average molecular weight of produced gas (M_g) = 21.75
2. According to the separator test, it is seen that $(\rho_o)_b$ = 0.728 g/cm^3 = 728 kg/m^3 .

   Calculate $(\rho_o)_b$ by using the added empirical correlations and actual values from the separator test.

   Compare the values and comment the results.

f.

1. Describe the reservoir fluid in a PT diagram.
2. Suppose that the reservoir fluid is produced by a pressure depletion from P_i to P_a=100 bar. Illustrate the following relations:
    a. GOR = f(P_{res})
    b. B_o = f(P_{res})
    c. ρ_o = f(P_{res})
    d. μ_o = f(P_{res})
    e. μ_g = f(P_{res})

Additions attached to the next pages

Good luck! – Lykke til!

Addition 1.

Important conversion factors, formula/correlations.

Temperature:

°K = 273.15 + °C
°F = 1.8 x °C + 32
°R =°F + 459.69

Pressure:

1atm = 1013.250 mBar = 1.013250 bar = 101.3250 kPa = 0.1013250 MPa = 14.69595 psia
psia = 14.69595 + psig
1 atm = 760.002 mmHg at 0 °C

Density:

1 g/cm³ = 62.43 lb/ft³ = 350.54 lb/bbl
1 lb/ft³ = 16.0185 kg/m³
ρ_w = 0.999015 g/cm³ (60 °F, 1 atm)
ρ_w = 0.9991 g/cm³ (15 °C, 1 atm)

Specific density:

For liquids: Determined relative to water at sc.
For gases: Determined relative to air at sc.

$$\gamma_o = \frac{\rho_o}{\rho_w} = \frac{141.5}{131.5 + {}^oAPI}$$

$${}^oAPI = \frac{141.5}{\gamma_o} - 131.5$$

$$\gamma_g = \frac{M_g}{M_{air}} = \frac{M_g}{28.96}$$

Cragoe`s formula (empirical formula giving molecular weight of hydrocarbons):

$$M_o = \frac{6084}{{}^oAPI - 5.9}$$

Volume:

1 bbl = 5.615 ft³ = 0.15898 m³
1 ft³ = 0.0283 m³
1 US Gallon = 3.785 litre
1 Imp. Gallon = 4.546 litre
Molar volume of gas at standard conditions:
V_m = 379.51 SCF/lb mole (60 °F and 14.69595 psia)
V_m = 23644.7 cm³/g mole = 23.6447 m³/kg mole (15 °C and 101.3250 kPa)

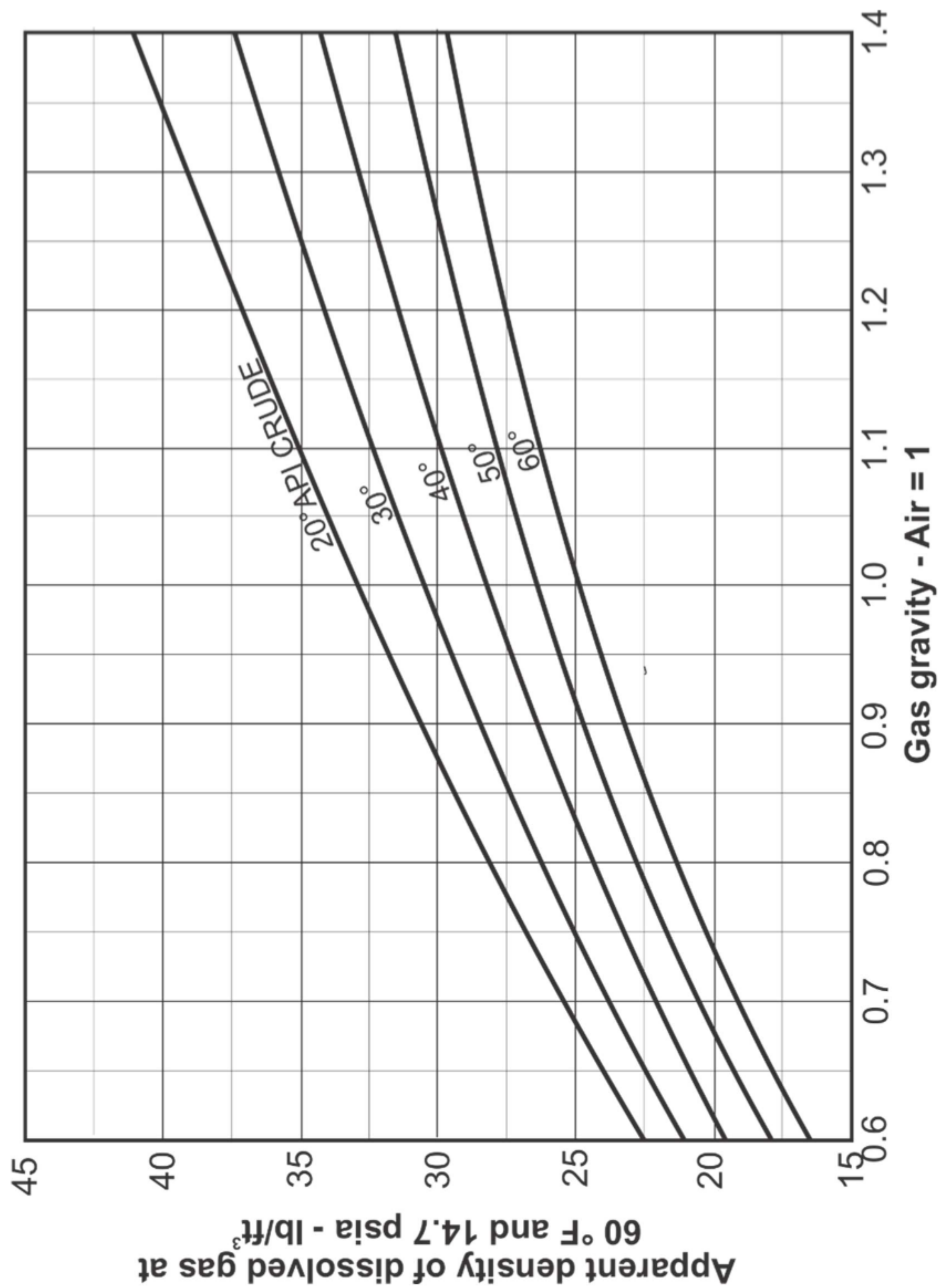
Air:

Z_{air} = 0.9959 (60 °F, 14.69595 psia)
M_{air} = 28.96

Gas constant:

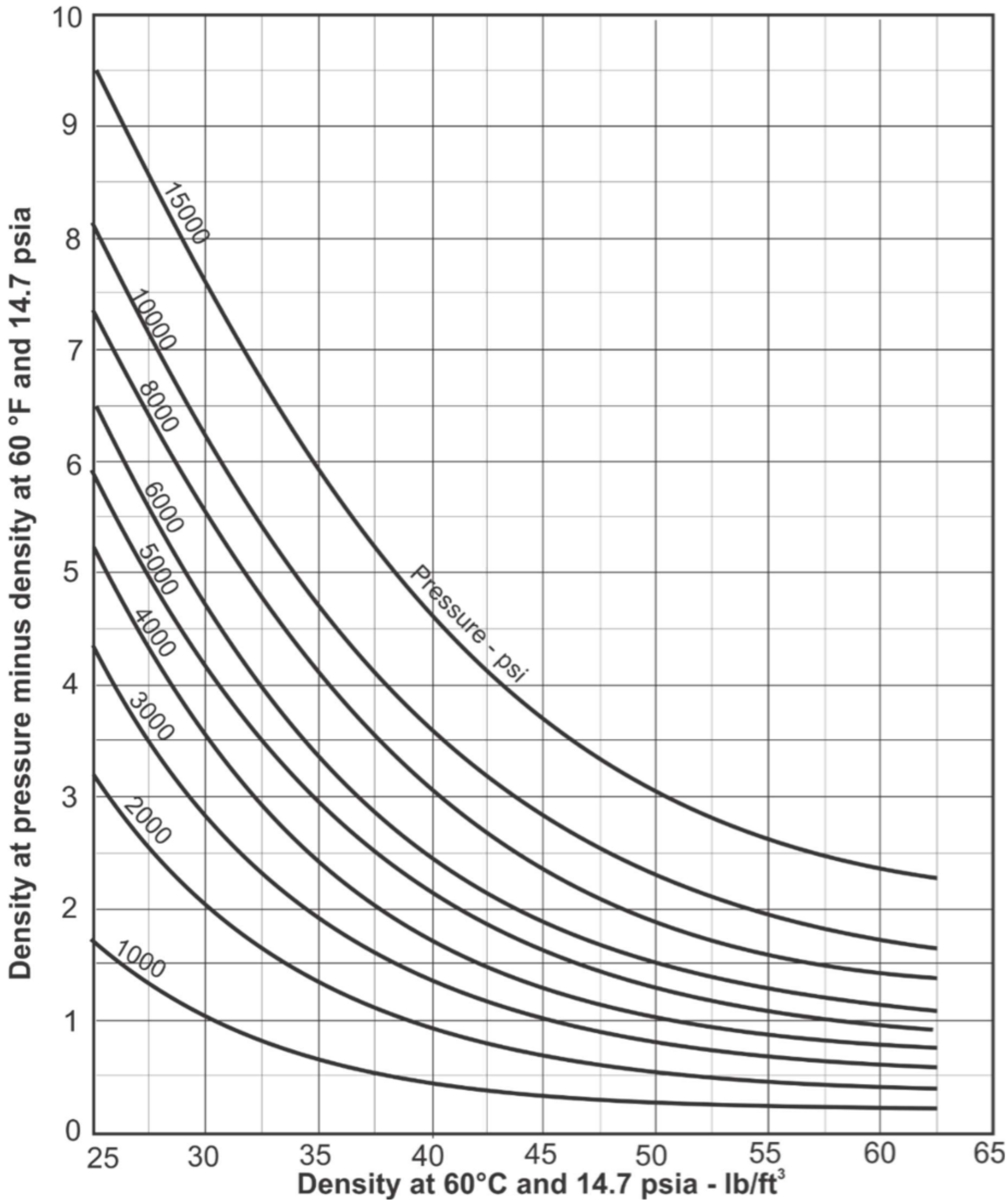
R = 10.732 (psia, ft³, °R, lb mole)
R = 0.082054 (atm, litre, °K, g mole)
R = 8.3145 (kPa, m³, °K, kg mole)

Addition 2.



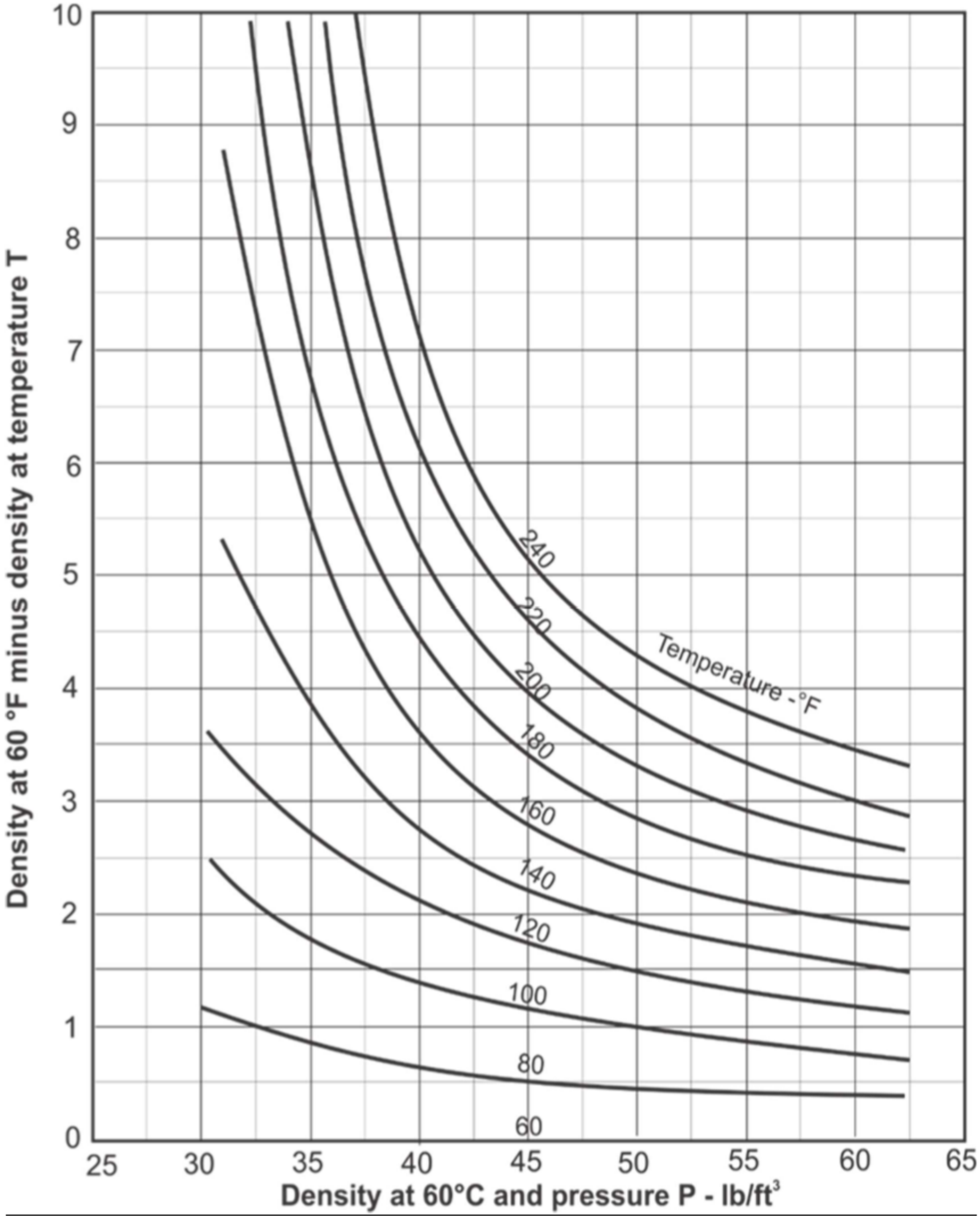
Apparent density of dissolved gas at 60 °F and 14.7 psia - lb/ft³
Gas gravity - Air = 1
20° API CRUDE
30°
40°
50°
60°
45
40
35
30
25
20
15
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4

Addition 3.



Density at pressure minus density at 60 °F and 14.7 psia
Density at 60°C and 14.7 psia - lb/ft³
Pressure - psi
15000
10000
8000
6000
5000
4000
3000
2000
1000
10
9
8
7
6
5
4
3
2
1
0
25
30
35
40
45
50
55
60
65

Addition 4.



Density at 60 °F minus density at temperature T
Density at 60°C and pressure P - lb/ft³
Temperature - °F
240
220
200
180
160
140
120
100
80
60
0
1
2
3
4
5
6
7
8
9
10
25
30
35
40
45
50
55
60
65