National Examinations May 2019

17-Pet-A2, Petroleum Reservoir Fluids

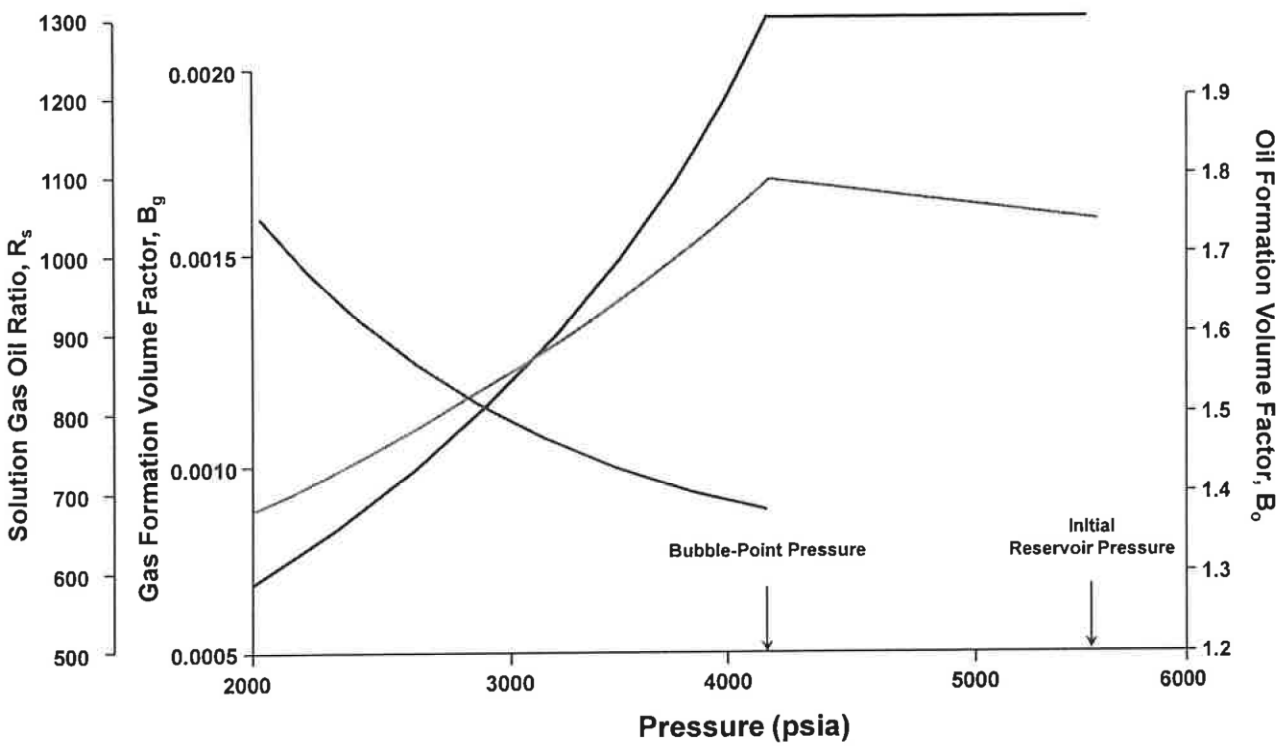
Duration of Examination: 3 hours

Important Notes, General Instructions and Guidelines for Examinees:

1. *Please check you have all pages of this question paper, which ends with a declaration:* **"The End of the Question Paper"**.
2. *It is a* **"CLOSED BOOK"** *examination. No books and/or materials sourced through internet or any communicating device (such as smart watch, cell phone, phablet, tablet and computers) are allowed in the examination hall.*
3. *Please answer any* **FIVE (5) questions** *in the question paper as five questions constitute a* **COMPLETE ANSWER PAPER.**
4. *All five questions are of equal value, and each question has multiple parts. Therefore, be sure to read the question paper carefully to avoid missing answers to certain parts.*
5. *Clarity and organization of your answers are important with regard to the methodology and sequential indication of each step in your calculations.*
6. *Conventional oilfield notations and symbols have been used in this question paper. Pay close attention to units when answering a question. The question that is set in a particular unit should be answered in the same unit.*
7. ***A formula sheet is provided at the end of the question paper.***
8. ***No further explanation or clarification on questions will be provided during the examination. If you suspect errors/omissions in any of the questions, please feel free to mention it accordingly on your answer script, and it will be taken into account during the grading.***
9. *Use of your personal scientific calculator, without any external communication link whatsoever, is permitted.*
10. *You must* **provide your answers on the question paper** *itself within the designated space for the question. This space should be adequate to fully answer your question. However, in case you run out of space, please use the blank space overleaf to complete your answer. In so doing, make sure that you identify your answer with the corresponding question number in the top-left corner.*
11. *If you still have to use extra paper, you must clearly write your name in full and ID# in the top left-hand corner of each sheet used.*
12. *Please* **write legibly** *with a darker imprint.*

Question 1 (Marks = 20)

a) Identify and label the following graphs as appropriate (i.e, write on each graph what it represents corresponding to Y-axis.) *(Marks = 3 x 2 = 6)*



b) On the figure above in Part (a), draw freehand the typical trend one should expect in the oil-viscosity versus the reservoir pressure relationship, when the pressure depletes from its initial pressure of 5500 psia to 2000 psia during production. *(Marks = 4)*

c) Using the basis of your answer to Part (b) question above, state the pressure at which the reservoir oil should theoretically be most mobile. State the reason for your answer. (Marks = 2 + 3 = 5)

d) **Strikeout the incorrect underlined-words presented in bold face** in the following statements concerning the use of reservoir fluid properties in the estimation of oil-in-place.

(Marks = 1 x 5 =5)

"Using the usual notations, the oil volume-in-place in a reservoir is given by the following equation:

$$\text{Oil Volume-in-place in a Reservoir} = A\,h\,\phi\,(1 - S_w - S_g)$$

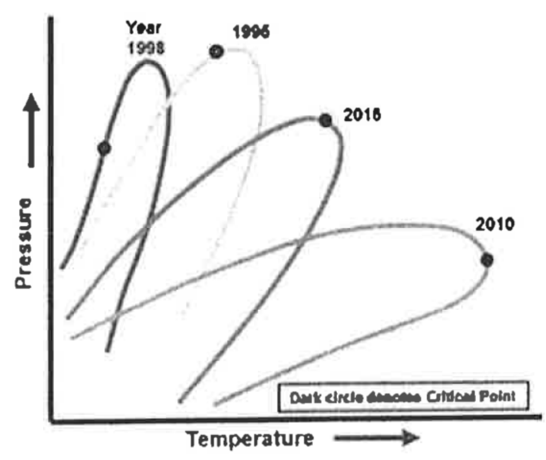
where, A = formation area, h = net formation thickness, ϕ = rock porosity, S_w = water saturation and S_g = gas saturation.

To convert this reservoir volume to stock-tank conditions (i.e., surface conditions), we need to ***divide / multiply*** *the reservoir oil volume by* ***B_g / B_o / c_o / S_o***. *Formation volume Factors for water, oil and gas are expressed in term of ratio of* ***reservoir / stock tank*** *to* ***reservoir / stock tank*** *volume conditions, and it always* ***greater / less*** *than unity for liquid phases (oil and water)."*

Question 2 (Marks = 20)

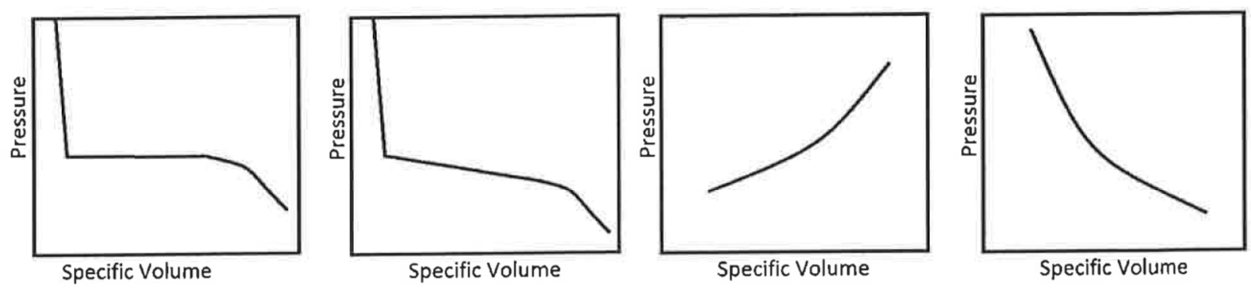
a) The following composite Pressure –Temperature (P-T) diagram was received from the reservoir management group with a note as indicated in the top. The composite P-T diagram shows a comparison of the changing P-T characteristics for reservoir fluids during 1995-2016. It is obvious that labels identifying the years are in wrong places! Reorganize these labels to indicate the respective year correctly in the figure, and then, state the reason why you needed to make those corrections. ***(Marks for correcting year-labels = 1 x 4 =4 and marks for stating the reason = 2)***

Following is a composite depiction of some intermediate P-T diagrams obtained from equation of state studies conducted for a reservoir under primary depletion during the period, 1993-2017. While all P-T diagrams have been plotted correctly in the composite compartative diagram, the corresponding label denoting the particular year that a P-T curve represents is not! Please correct the "Year" label for each P-T diagram.



The reason(s) why needed to make correction in the P-T diagrams:

b) Which among the four diagrams below is the correct Pressure-Volume phase diagram for a pure substance at a temperature above its critical temperature? ***Circle the correct one.*** ***(Mark =1)***

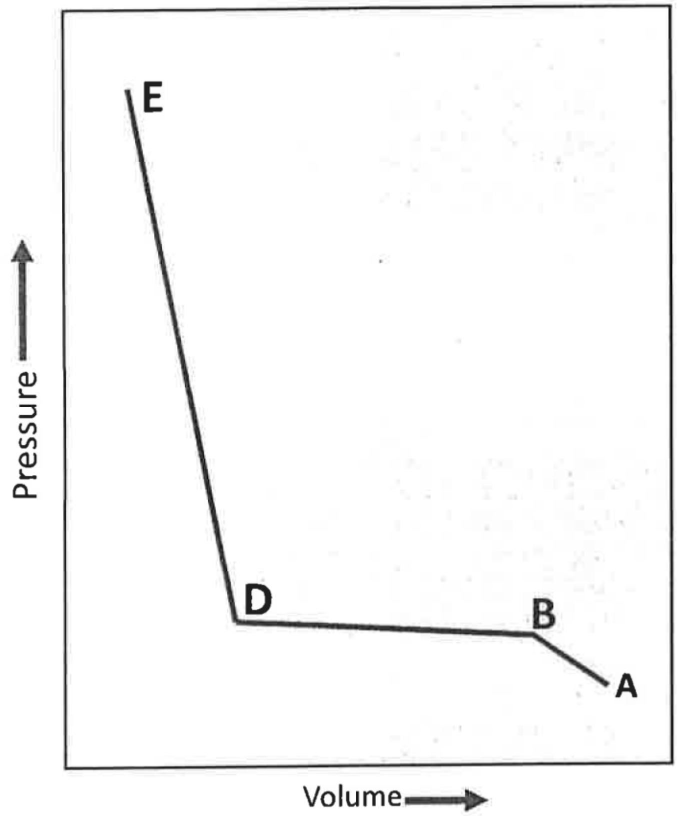


a. **b.** c. **d.**

ii) Draw a freehand sketch of a typical ternary diagram for a reservoir-fluid system that contains hydrocarbon (HC) components as well as non-hydrocarbon components, notably N_2 and CO_2 and H_2S. Also, show a representative two-phase envelope within the ternary diagram. *(Assume the HC components consist of methane (CH_4) and intermediates (i.e., C_2-C_6) in gaseous state and C_{7+} in liquid state. (Be sure to show where you would indicate the non-HC components.)* ***(Marks = 5+1 =6)***

iii) State what will be happen to the size of the two-phase envelope in your ternary diagram if the temperature of the system were lowered isobarically. ***(Mark = 1)***

iv) If the following diagram is a pressure-volume isotherm (**ABDE**) obtained for a constant–composition expansion test for an oil, identify following on and along **ABDE**: **(Marks = 6)**



a) **Liquid Region:** ______________________

b) **Vapor Region:** ______________________

c) **Liquid + Vapor Region:** ______________________

d) **Dew-Point Pressure Point:** ______________________

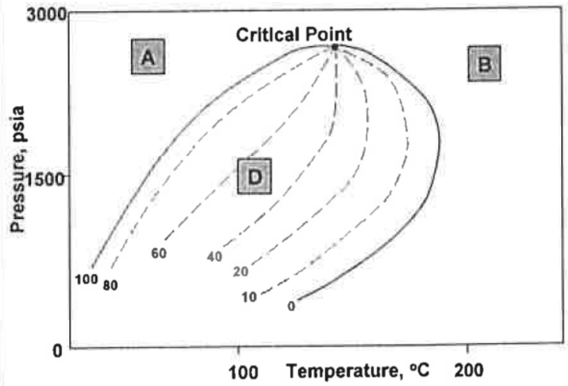
e) **Bubble-Point Pressure Point:** ______________________

If the temperature of the reservoir fluid system in the test were raised while keeping all other conditions the same, state whether the BD region will **shrink** or **expand:** ______________________

Question 3 (Marks =20)

i) The statements in column #2 of the following table have been made on the basis of the pressure-temperature (P-T) diagram shown in the third column. **Strikeout the incorrect underlined words in bold face** in these statements to provide the correct interpretations from this P-T diagram. *(Marks = 8)*

a	The single-phase oil reservoir is indicated by **A / B / D** in the P-T diagram and it is classified as **saturated / undersaturated** reservoir. The two-phase reservoir is denoted by **A / B / D** in the same P-T diagram and	

	it is represents a **saturated / undersaturated** reservoir.	
b	Any point on the red curve off the critical point represents the **Dew-point / Bubble-point** pressure. Likewise, any point on the blue curve emanating from the critical point represents the **Dew-Point / Bubble-point** pressure.	
c	The reservoir **A** can eventually reach the state of reservoir **D** due to: ______ ______ ______	
d	Which one of the three reservoirs represent by the reservoir pressure and temperature conditions at points **A, B** and **D,** can potentially deliver the oil of highest API gravity? ______	

ii) List the two major limitations of the ideal gas laws that render them impossible to use it to represent the real gases that are encountered in petroleum reservoirs. (Hint: van der Waals attempted to address these limitations circa 1873!) ***(Marks = 2)***

______

______

And how were the limitations overcame by van der Waals in his equation? ***(Marks = 5)*** *iii)* Determine the API gravity of an oil mixture made up of three crude oils in the following proportions: 52% of a 32°API oil, 45% of a 48°API oil, and the balance is a heavy oil of 10°API. *[Note: °API = (141.5/Specific Gravity - 131.5)]* ***(Marks = 5)***

Question 4 *(Marks = 20)*

A) If a 10-ft^3 cylindrical tank contains a gas of gravity 0.80 at 2500 psia and 100°F, calculate:

I. Number of gas moles in the tank if the gas deviation factor is 0.67 at 2500 psia and 100°F
II. Standard volume of gas in SCF
III. Final tank pressure if 1000 SCF of gas is bled off from the tank causing its temperature and gas deviation factor to drop to 60°F and 0.627, respectively.

(Marks for Part A = 15)

B) Using the following graphical correlations by Carr *et al.* and the methodology outlined, estimate the viscosity of a natural gas mixture of MW of 26.33 with a gas gravity of 0.908 at 3010 psia and 224°F. [Assume pseudo critical temperature and pressure of 454R and 657 psia, respectively.]

(Marks for Part B = 5)

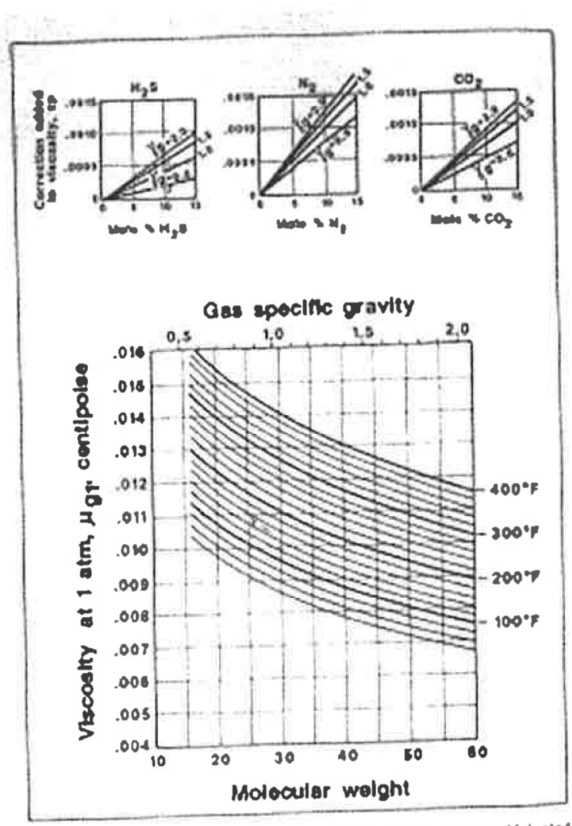


Fig. 6–8. Viscosities of natural gases at atmospheric pressure. (Adapted from Carr et al., *Trans.*, AIME, 201, 997.)

Viscosity of Gas Mixtures

$$\mu_g = \left[\frac{\mu_g}{\mu_{g1}}\right] \times \mu_{g1}$$

1. Table look-up for the specific gravity (γ_g) or molecular weight required ("apparent molecular weight")

2. Read the viscosity at 1 atm (μ_{g1}) as a function of T and γ_g. *(see figure on left)*

To obtain viscosity using the equation, read viscosity ratio (μ_g / μ_{g1}) as a function of pseudo-reduced properties from following figures (These figures have been lifted from *The Properties of Petroleum Fluids* (2nd Ed. 1990; by McCain)

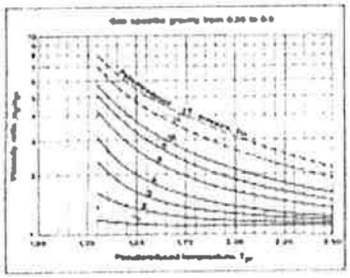


Fig. 6-9. Viscosity ratios for natural gases with specific gravities from 0.56 to 0.9

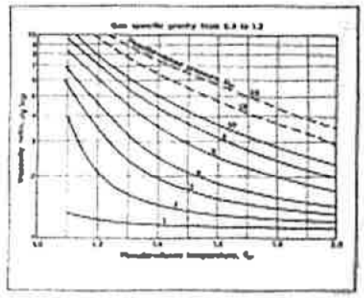


Fig. 6-10. Viscosity ratios for natural gases with specific gravities from 0.9 to 1.2

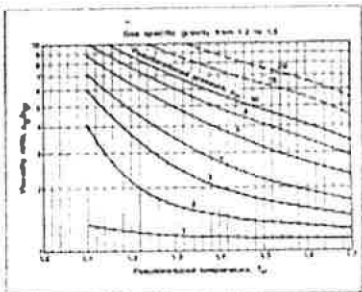


Fig. 6-11. Viscosity ratios for natural gases with specific gravities from 1.2 to 1.5

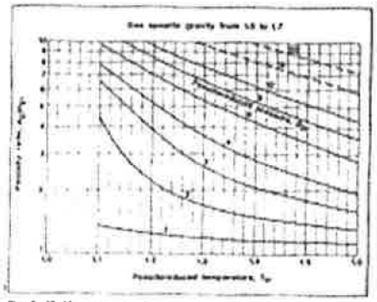


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Fig. 6-12. Viscosity ratios for natural gases with specific gravities from 1.5 to 1.7

Question 5 (Marks 20)

A well is producing 2000 STB/day of oil and 2 MMSCFD gas from a reservoir currently at 2375 psia and 185°F. Laboratory tests indicate the following properties of oil and gas:

Oil density at stock tank condition = 53 lb/ft^3
Specific Gravity of gas at standard conditions = 0.67
Air density at standard conditions = 0.076 lb/ft^3
B_o = 1.19 rb/STB @current reservoir pressure
B_g = 0.0012 rb/SCF @current reservoir pressure
R_s = 347 SCF/STB @current reservoir pressure

a) Calculate the oil and gas densities in the reservoir at the current pressure
b) Given that above flow rates are at stock tank conditions, what are the flow rates of oil and gas in the reservoir (i.e., in the vicinity of the well bottom)?
c) Indicate whether the reservoir is currently in two-phase (oil and gas) or single-phase (oil) state, and state whether it is a saturated or undersaturated.

Question 6 (Marks = 20)

A reservoir, which is at P_{res}=2400 psia and T_{res}=185°F, produces 1.5 MMSCFD gas with the oil. The produced gas has the following molar composition. The corresponding T_c, P_c and Molecular Weight

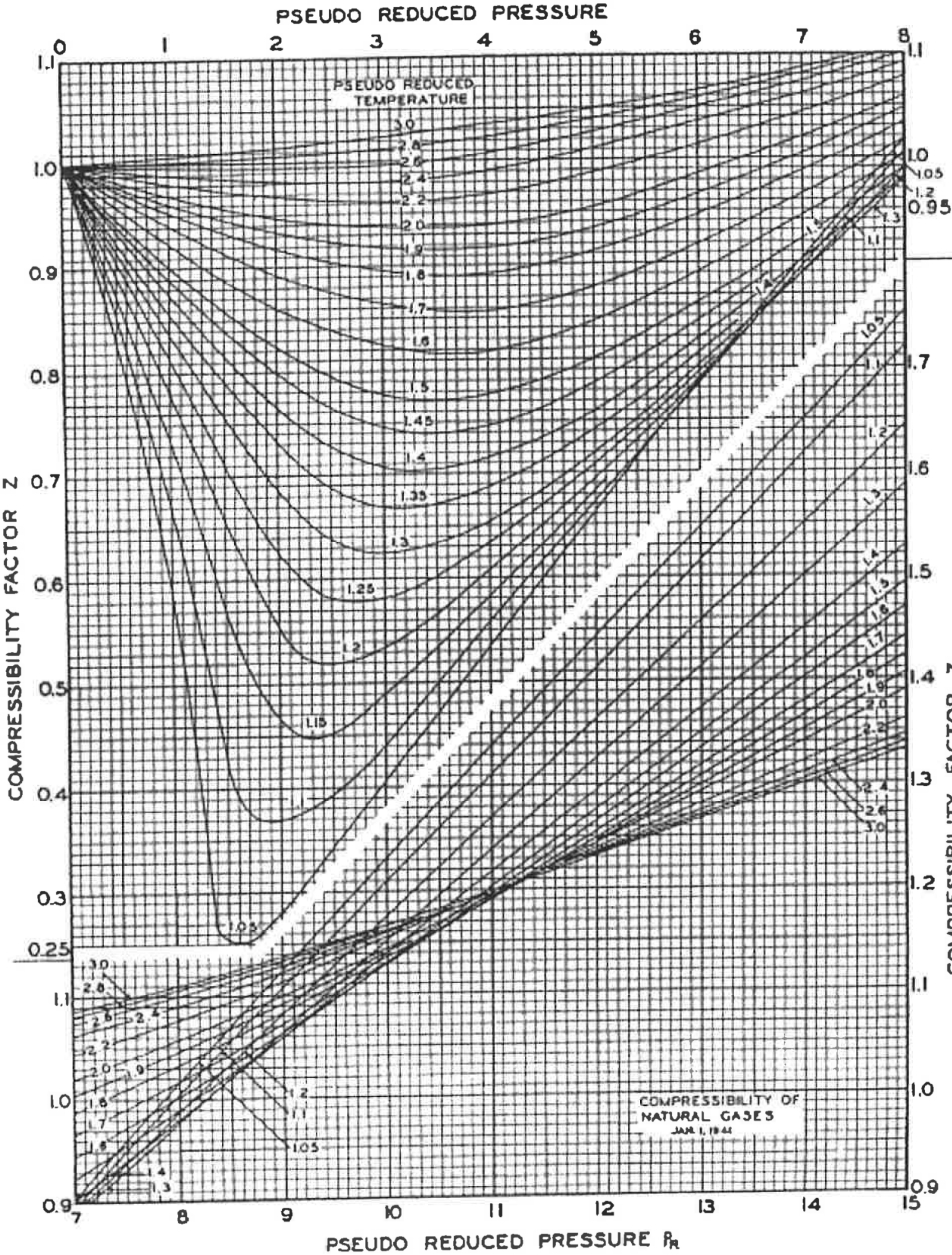
(MW) of components are provided, and it is also noted that the standard volume, V_{sc}, per lb-mol for any gas is 379.4 SCF.

Component	Mole Fraction	T_c (°F)	P_c (psia)	MW
Methane	0.82	-116.5	673.1	16.04
Ethane	0.05	90.09	708.3	30.07
Propane	0.04	206.26	617.4	44.10
n-butane	0.03	305.62	550.7	58.12
CO_2	0.03	88.0	1073	44.01
N_2	0.03	-232.8	492	28.01

Calculate, for the gas stream, the following:

a) z factor *(Using the Standing and Katz graphical correlation provided[1] and assuming corrections for CO2 and N2 are negligible)*
b) molecular weight
c) gas density in lb/ft³
d) daily number of lb-mole of gas produced
e) daily mass in lb of the gas produced.
f) specific volume of the gas; i.e., the volume of gas each lb of it occupies.
g) Using the definition of the formation volume factor for gas (B_g), which is the volume of gas at reservoir conditions required to produce one standard cubic foot of gas at the surface, write the expression for B_g based on gas laws and calculate B_g in Reservoir bbl/SCF.

[1] *M.B. Standing and D.L. Katz, "Density of Natural Gases", Trans. AIME (1942), Vol. 149, 144.*


PSEUDO REDUCED PRESSURE
PSEUDO REDUCED TEMPERATURE
COMPRESSIBILITY FACTOR Z
COMPRESSIBILITY FACTOR Z
COMPRESSIBILITY OF NATURAL GASES
JAN. 1, 1941
PSEUDO REDUCED PRESSURE P_R

Formula Sheet

Real gas law

$pV = ZnRT$

where p in psia, T in °R, V in ft^3, R=10.732 psi-ft^3/(lb$_{mol}$-°R)

Pseudo critical pressure and temperature

$T_{pc} = 168 + 325\gamma_g - 12.5\gamma_g^2$ in °R

$p_{pc} = 677 + 15.0\gamma_g - 37.5\gamma_g^2$ in $psia$

Reduced temperature: $T_r = \frac{T}{T_c}$

Reduced pressure: $p_r = \frac{p}{p_c}$

where γ_g is the gas specific gravity (Air=1)

Average molecular weight: $M_{av} = \sum y_i M_i$

Pseudo critical Temperature: $T_{pc} = \sum y_i T_{pc_i}$

Reduced temperature: $T_r = \frac{T}{T_c}$

Pseudo critical pressure: $p_{pc} = \sum y_i p_{pc_i}$

Reduced pressure: $p_r = \frac{p}{p_c}$

Gas density: $\rho = \frac{pM}{ZRT}$

where ρ is gas density in lb$_{mass}$/ft^3, p in psia, T in R, M is molecular weight in lb$_{mass}$/lb$_{mole}$ (MW of Air =28.97), R=10.732 psi-ft^3/(lb$_{mol}$-°R)

Gas formation volume factor, $B_g = 0.02827\frac{ZT}{p}$ in $\frac{\text{ft}^3}{\text{SCF}}$, where p in psia, T in °R.

Total or two-phase formation volume factor: $B_t = B_o + B_g(R_{sob} - R_{so})$

Coefficient of isothermal oil compressibility: $c = -\frac{1}{B_{ob}}\left(\frac{dB_o}{dP}\right)_T$

Flash calculations: $\sum_i \frac{z_i}{1+V(K_i-1)} = 1, \quad x_i = \frac{z_i}{1+V(K_i-1)}$

Isothermal gas compressibility: $c_g = \frac{1}{p} - \frac{1}{Z}\left(\frac{dZ}{dP}\right)_T = \frac{1}{p} - \frac{1}{Z}\left(\frac{1}{p_c}\frac{dZ}{d\,\text{Pr}}\right)_T$

Conversion Factors

1 m^3 = 6.28981 bbl =35.3147 ft^3

1 atm =14.6959488 psi =101.32500 kPa=1.01325 bar

1 m = 3.28084 ft = 39.3701 inch

1kg = 2.20462 lb$_{mass}$

The End of the Question Paper!

Scoring Rubric

Question # Answered	Q#__	Q#__	Q#__	Q#__	Q#__	Total Marks
Marks per Question	20	20	20	20	20	100
Marks earned per Question						