National Exams December 2019

17-Pet-A2, Petroleum Reservoir Fluids
3 hours duration

NOTES:

1. *Please check you have all pages of this question paper, which ends with a declaration* "**The End of the Question Paper**".
2. *This is a* **CLOSED BOOK** *exam. No books and/or materials sources through internet or any communicating device (such as smart watch, cell phone, phablet, tablet and computers) are allowed.*
3. *Ruler and approved Casio or Sharp calculator are permitted.*
4. **FIVE (5)** *questions constitute a complete exam paper.*
5. *The* **first five questions** *as they appear in the exam paper will be marked.*
6. *All questions are of equal value, and each question may have multiple parts. Therefore, be sure to read the question paper carefully to avoid missing answers to certain parts.*
7. *A* **formula sheet** *is provided at the end of the question paper.*
8. *Include all steps and units in calculations. Full credits are given only if intermediate steps are clearly indicated.*
9. *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.*
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. In case you run out of space, please use the blank space overleaf. In so doing, make sure that you identify your answer with the corresponding question number in the top-left corner. If you still have to use extra sheets, you must clearly write your name in full and ID# in the top-left corner of each sheet used.*
11. 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 considered during the grading.

Question 1 (20 marks)

(a) True(T) or False(F) (Marks =1×6 =6)

i. If the critical temperature of a fluid mixture is the same as its cricondentherm, retrograde condensation cannot occur. ____________

ii. 3-methylpentane has a higher normal boiling point than n-hexane.________

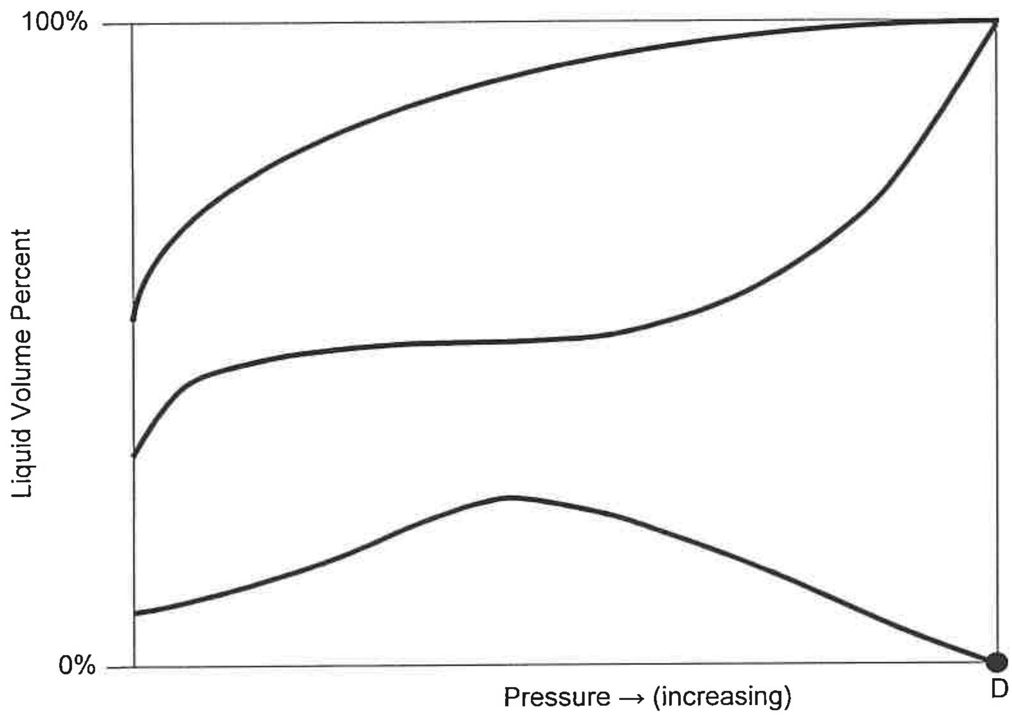
iii. A more volatile component is going to vaporize at a lower temperature than a less volatile component at the same pressure. __________

iv. Increasing the temperature of a gas at low pressure makes it more difficult for the molecules to move in a cohesive manner.__________

v. The oil firnation volume factor at pressures above the bubble-point pressure is less than the formation volume factor at bubble-point pressure. ________

vi. Small quantities of larger hydrocarbon mixed with methane can cause large reductions in the pressure and temperature requried to initiate hydrate formation when compared with pure methane. ___________

(b) The following graph gives liquid volume percent vs. pressure for three types of hydrocarbons produced at constant temperature. The three hydrocarbon types include retrograde gas, volatile crude oil and ordinary black oil. Label the following curves, i.e., write on each curve what it represents. (**Marks =2×3 =6**)



(c) For the pressure Point D in the figure above, does Point D have same definition for the three types of hydrocarbons? State the reason for your answer. **(Marks =2)**

Define the following terms concisely.

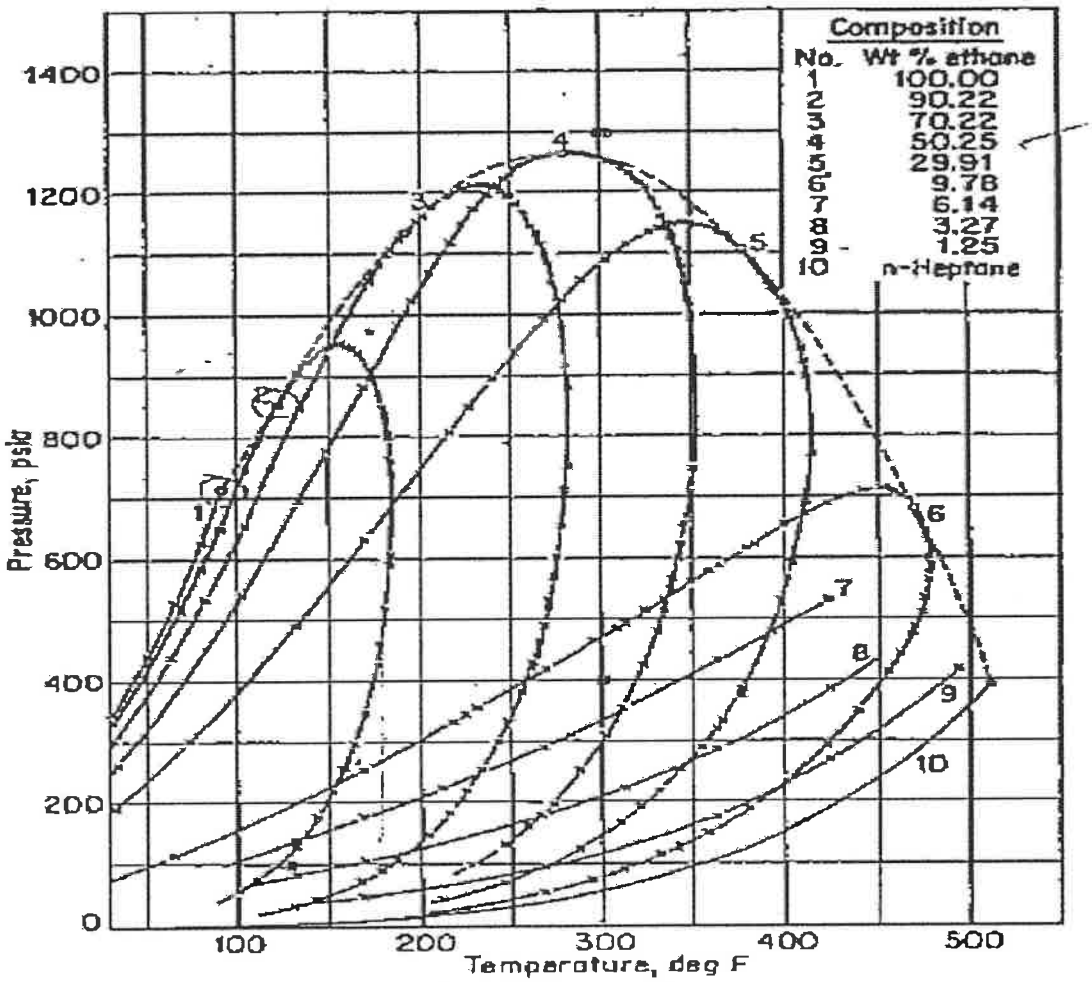
(d) Saturated oil and Undersaturated oil (**Marks = 2**)

(e) Wet Gases (**Marks = 2**)

(f) Differential Liberation Test (**Marks = 2**)

Question 2 (20 marks)

The following ethane and n-heptane mixture systems represent reservoir fluids.



Source: Industrial and Engineering Chemistry 30, 461.

(a) Determine the following temperatures and pressures for the 70.22wt% ethane mixture:

(Marks =1×8 =8)

i. Bubble-point pressure at 150°F ____________________

ii. Critical temperature ______________________

iii. Dew-point temperature at 450psia ______________________

iv. Critical pressure ____________________

v. Bubble-point temperature at 700psia ____________________

vi. Cricondenbar ______________________

vii. Dew-point pressure at 200°F ____________________

viii. Cricondentherm ______________________

(b) Estimate the following temperatures and pressures:

i. Critical temperature ____________and critical pressure ___________for a mixture of 40wt% ethane and 60 wt% n-heptane. **(Marks =2×1 =2)**

ii. For a mixture of 50.25wt% ethane and 49.75wt% n-heptane, retrograde condensation will occur at the temperature range ____________________ and the corresponding pressures ______________________ .**(Marks =2×2 =4)**

(c) The initial reservoir pressure is 1500 psia and the temperature is constant at 210°F. The surface separator is operating at 280 psia and 40°F. Among the mixtures labeled "No.2", "No.3", "No.4", and "No.5" (upper right corner in the figure), label each of the mixtures as one of the five reservoir fluids, i.e. black oil, retrograde gas, volatile oil, wet gas and dry gas. **(Marks =1×4 =4)**

(d) The mixture of ethane (70.22wt%) and n-heptane (29.78%) is the reservoir fluid. During production the reservoir pressure keeps reducing from the initial reservoir pressure 1500psia to 300psia. The reservoir temperature is assumed to be constant at 180°F. Draw a schematic of oil viscosity and coefficient of oil isothermal compressibility as a function of pressure during the production. **(Marks =1×2 =2)**

Question 3 (20 marks)

(a) A rock sample with a bulk volume of 1 cm^3 is placed in a 8 cm^3-cell at a temperature of 25°C. The pressure inside the cell is recorded at 760mmHg. The cell is subsequently opened to another empty cell with an identical volume, and the final pressure reading is 360mmHg. Calculate the pore volume of the rock sample. Assume the temperature remains constant throughout this experiment. **(Marks =10)**

(b) A black oil reservoir is discovered. Reservoir temperature is approximately 250 °F and the bubble point pressure is estimated at about 1800 psia. At reservoir conditions of 2800 psia, 100 barrels of liquid is produced per day. The stock tank accumulates 65 barrels per day. The combined production of separator and stock tank gas is 50,000 scf/d, and the gas specific gravity is 0.7. Calculate oil formation volume factor B_o, solution-gas-oil ratio R_s and gas formation volume factor B_g at reservoir conditions.

(Marks =10)

Question 4 (20 marks)

Wells are drilled on 700-acres spacing and produce gas. The gas composition is given in the table below. The average formation thickness is 21feet. The average formation porosity is 0.18. The average water saturation is 0.33. The initial reservoir pressure is 3810 psia and temperature is 194°F.

Component	Composition, mole percent	Critical temperature, °R	Critical pressure, psia	Viscosity at atmospheric pressure, cp
Methane	97.12	343.33	666.4	0.0128
Ethane	2.42	549.92	706.5	0.011
Propane	0.31	666.06	616.0	0.0098
i-Butane	0.05	734.46	527.9	0.0091
n-Butane	0.02	765.60	550.6	0.0094
i-Pentane	trace			0.0080
n-Pentane	trace			0.0082
Hexanes	0.02	913.60	436.9	0.0078
Heptanes plus	0.06	1082	372	0.0068
	100			

Properties of Heptanes plus
Specific gravity 0.0758
Molecular weight 128 lb/lb mole

i. Determine the gas z-factor at initial reservoir condition. **(Marks = 5)**

ii. Determine the original amount, ft^3, of gas stored in a single well's drainage area.

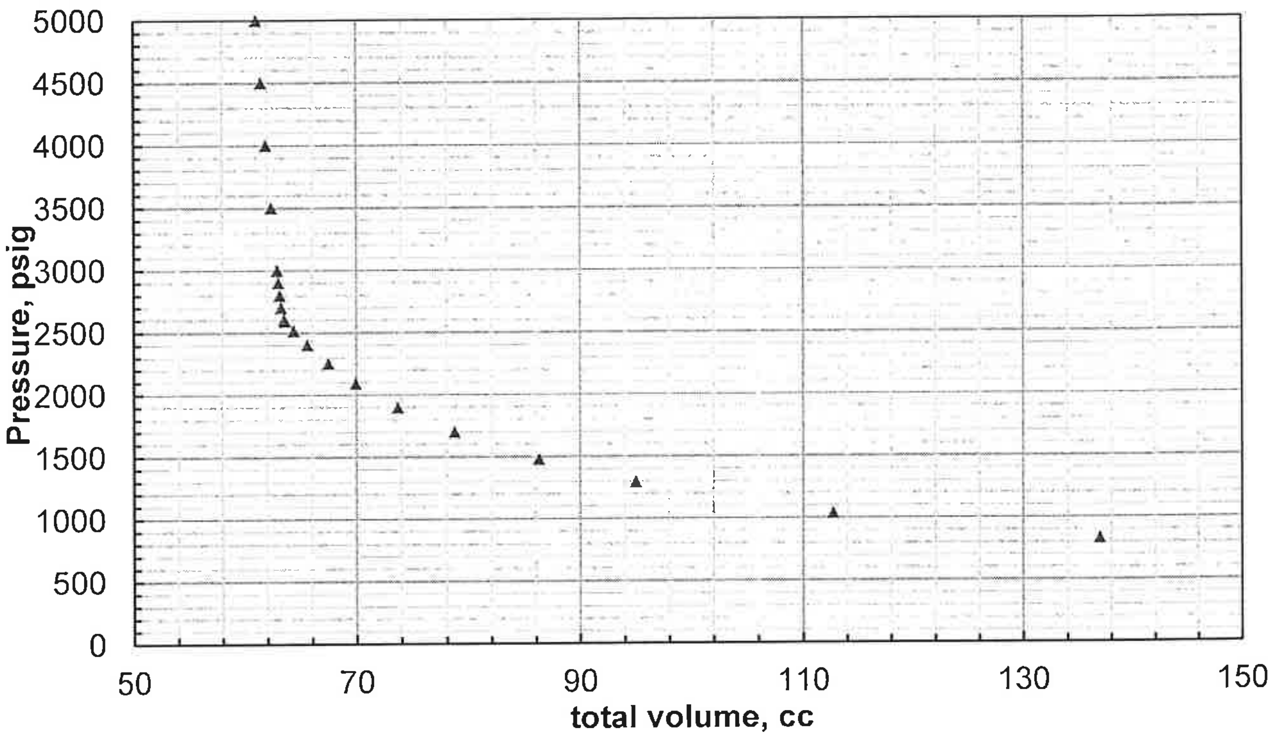
(Marks = 5)

iii. Calculate the viscosity at one atmosphere of the dry gas at temperature 194°F.

(Marks = 10)

Question 5 (20 marks)

(a) The following figure is from a flash vaporization on a black oil sample at 220°F. Determine the relative volume of the reservoir fluid at 4000psig. **(Marks =5)**

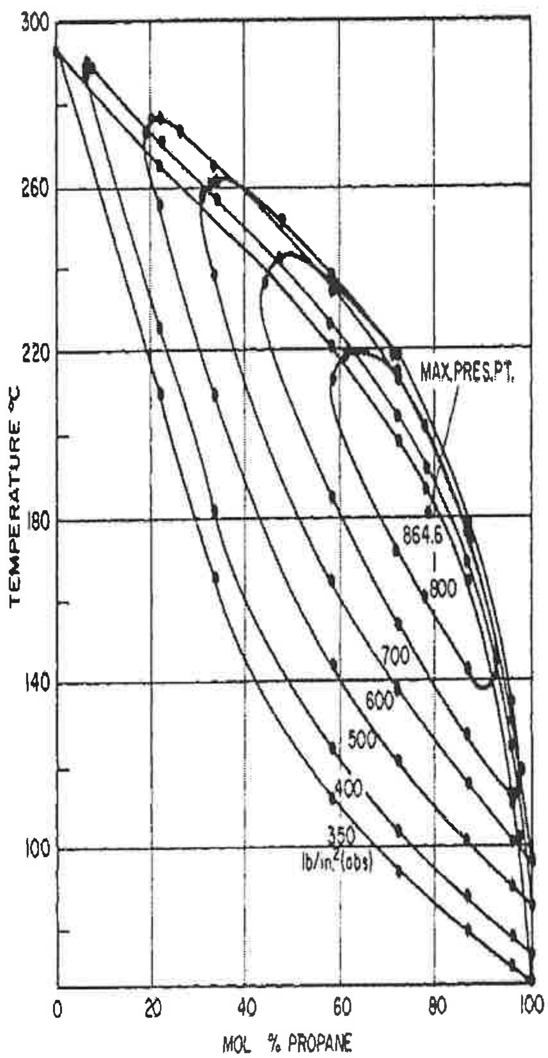


(b) The following table is from a differential vaporization on a black oil sample at 220°F. Calculate the solution-gas-oil ratio, relative total volume, z-factor and formation volume factor of gas at 1100psig. **(Marks =15)**

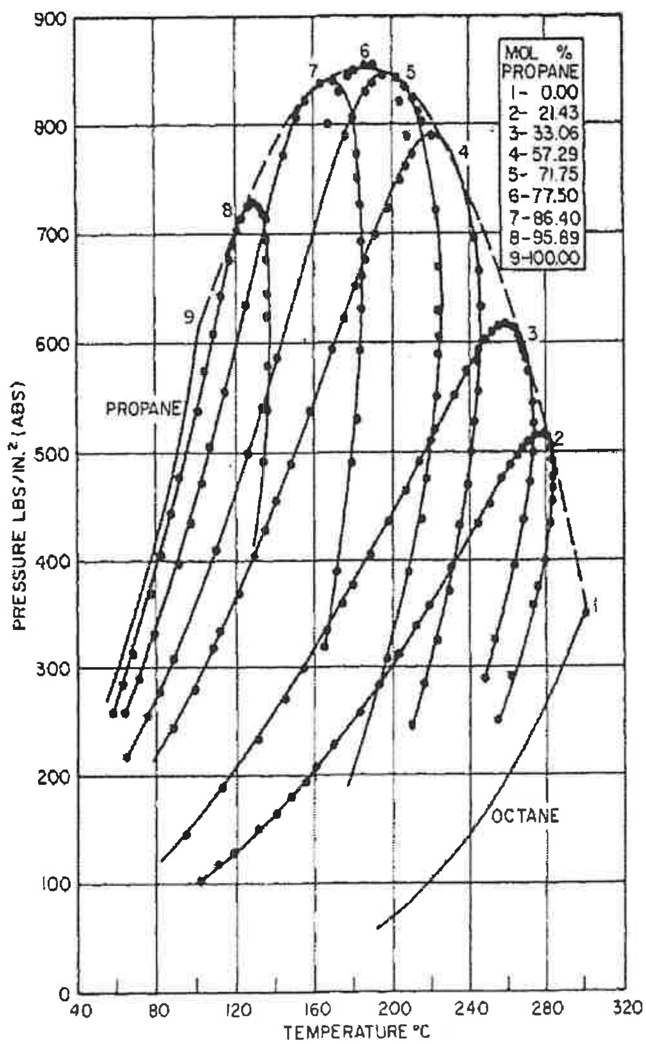
Pressure, psig	Gas removed at 220°F and cell pressure, cc	Gas removed at 60°F and 14.65psia, scf	Oil volume, cc	Incremental gas gravity
2620	—	—	63.316	—
2350	4.396	0.02265	61.496	0.825
2100	4.292	0.01966	59.952	0.818
1850	4.478	0.01792	58.528	0.797
1600	4.960	0.01693	57.182	0.791
1350	5.705	0.01618	55.876	0.794
1100	6.891	0.01568	54.689	0.809
850	8.925	0.01543	53.462	0.831
600	12.814	0.01543	52.236	0.881
350	24.646	0.01717	50.771	0.988
159	50.492	0.01643	49.228	1.213
0		0.03908	42.540	2.039
0		0.21256	39.572	

Question 6 (20 marks)

The phase diagrams for the binary system of propane (C_3) and n-octane ($n\text{-}C_8$) are given below:



Isobaric temperature-composition diagram of propane-n-octane system.



Pressure-temperature diagram of propane-n-octane system

Source: Journal of Chemical and Engineering Data 19 (3), 275-280.

(a) If 0.5 mole of C_3 is mixed with 0.5 mole of n-C_8 at 500 psia and 220°C, determine the compositions and vapor-to-liquid ratio of the equilibrium fluids. **(Marks =10)**

(b) How many moles of C_3 should be added to the system in part (a) in order to obtain a vapor-to-liquid ratio of 3? **(Marks =10)**

Vapor-to-liquid ratio= (number of moles of vapor)/ (number of moles of liquid)

Question 7 (20 marks)

(a) A separator test is completed on a black oil. The volume of oil at bubble-point pressure and reservoir temperature is 201.156cc. The volume of separator liquid at 200psig and 75°F is 150.833cc. The volume of stock-tank oil at 0psig and 75°F is 136.591 cc. The volume of stock-tank oil at 0psig and 60°F is 135.641cc. The volume of gas removed from separator is 0.51383 scf. The volume of gas removed from stock tank is 0.15186 scf. The specific gravity of stock-tank oil is 0.823. The specific gravity of separator gas is 0.732. The specific gravity of stock-tank gas is 1.329. Calculate the following **(Marks =15)**

i. formation volume factor of oil at the separator pressure (res bbl/STB);

ii. total gas-oil ratio at the separator pressure (scf/STB);

iii. separator gas-oil ratio (scf/SP bbl);

iv. Stock-tank gas-oil ratio (scf/ST bbl).

(b) For the black oil sample in part (a), tables below give part of the sample fluid analysis results. Compute the oil formation volume factor and solution-gas-oil ratio at 4500psig and 1600psig for the black oil sample. **(Marks =5)**

Pressure, psig	**Relative volume@220°F**
5000	0.9639
4500	0.9703
4000	0.9771
3500	0.9846
3000	0.9929
2900	0.9946
2800	0.9964
2700	0.9983
2620	1.0000
2605	1.0022
2519	1.0041
2516	1.0154
2401	1.0350
2253	1.0645
2090	1.1040
1897	1.1633
1698	1.2426
1477	1.3618
1292	1.5012
1040	1.7802
830	2.1623
640	2.7513
472	3.7226

Relative volume: V/Vsat is barrels at indicated pressure per barrel at saturation pressure.

Pressure, psig	**Solution gas/oil ratio**	**Relative oil volume**
2620	854	1.600
2350	765	1.554
2100	684	1.515
1850	612	1.479
1600	544	1.445
1350	479	1.412
1100	416	1.382
850	354	1.351
600	292	1.320
350	223	1.283
159	157	1.244
0	0	1.075

Solution gas/oil ratio: cubic feet of gas at 14.65 psia and 60°F per barrel of residual oil at 60°F.
Relative oil volume: barrels of oil at indicated pressure and temperature 220°F per barrel of residual oil at 60°F.

Formula Sheet

Real gas law

$pV = ZnRT$

where p in psia, T in °R, V in ft³, R=10.732 psi-ft³/(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$_{mass}$/ft³, p in psia, T in R, M is molecular weight in lb$_{mass}$/lb$_{mole}$ (MW of Ai =28.97), R=10.732 psi-ft³/(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: $c_g = \frac{1}{p} - \frac{1}{Z}\left(\frac{dZ}{dP}\right)_T = \frac{1}{p} - \frac{1}{Z}\left(\frac{1}{p_c}\frac{dZ}{d\,\text{Pr}}\right)_T$

Viscosity $\mu_g = \dfrac{\sum_j \mu_{gj} y_j M_j^{1/2}}{\sum_j y_j M_j^{1/2}}.$

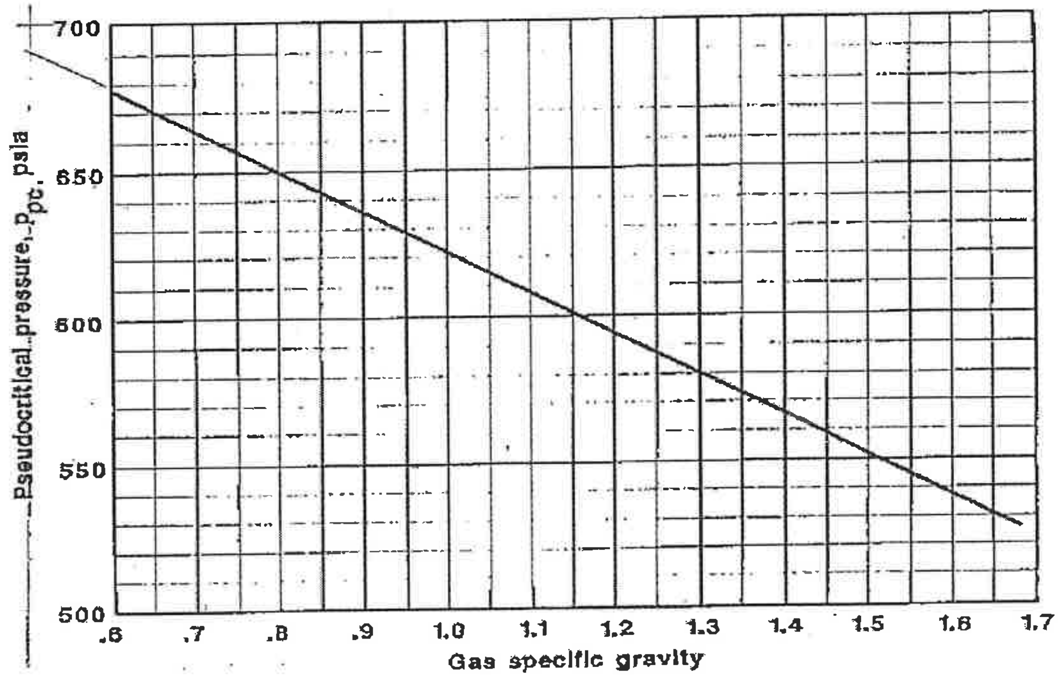
Conversion Factors

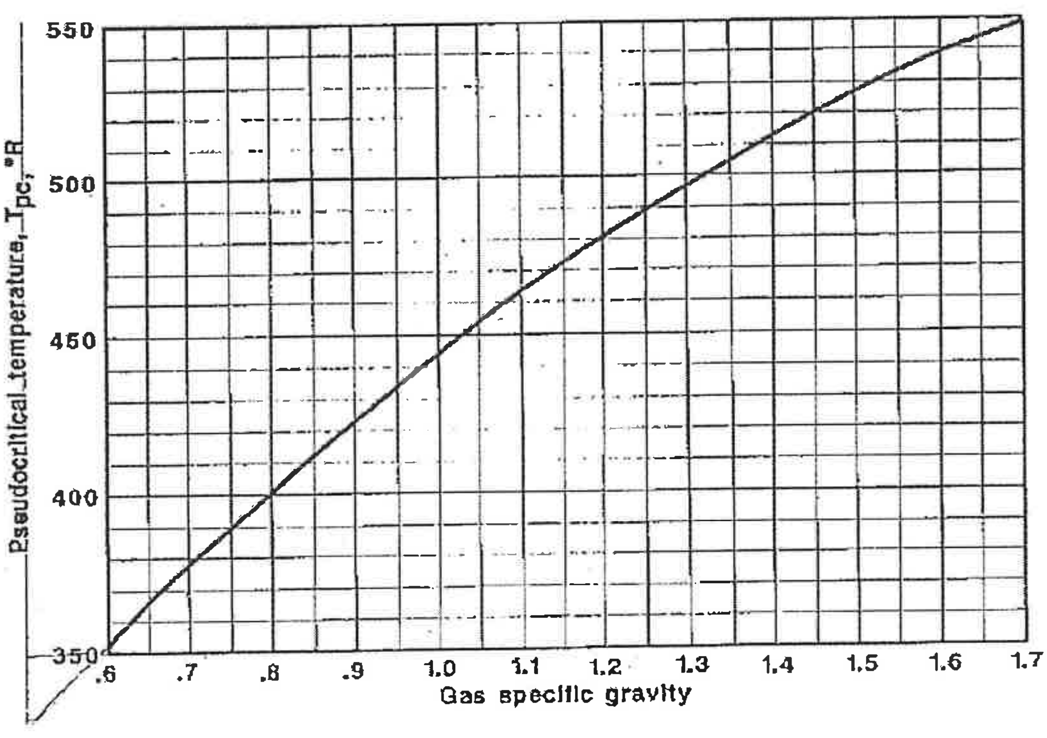
1 lb/in^2 = 1 psi
1acre =43560 ft^2
1 m^3 = 6.28981 bbl =35.3147 ft^3
1 atm =14.6959488 psi =101.32500 kPa=1.01325 bar
1 m = 3.28084 ft = 39.3701 inch
1kg = 2.20462 lb_{mass}

Temperature conversions

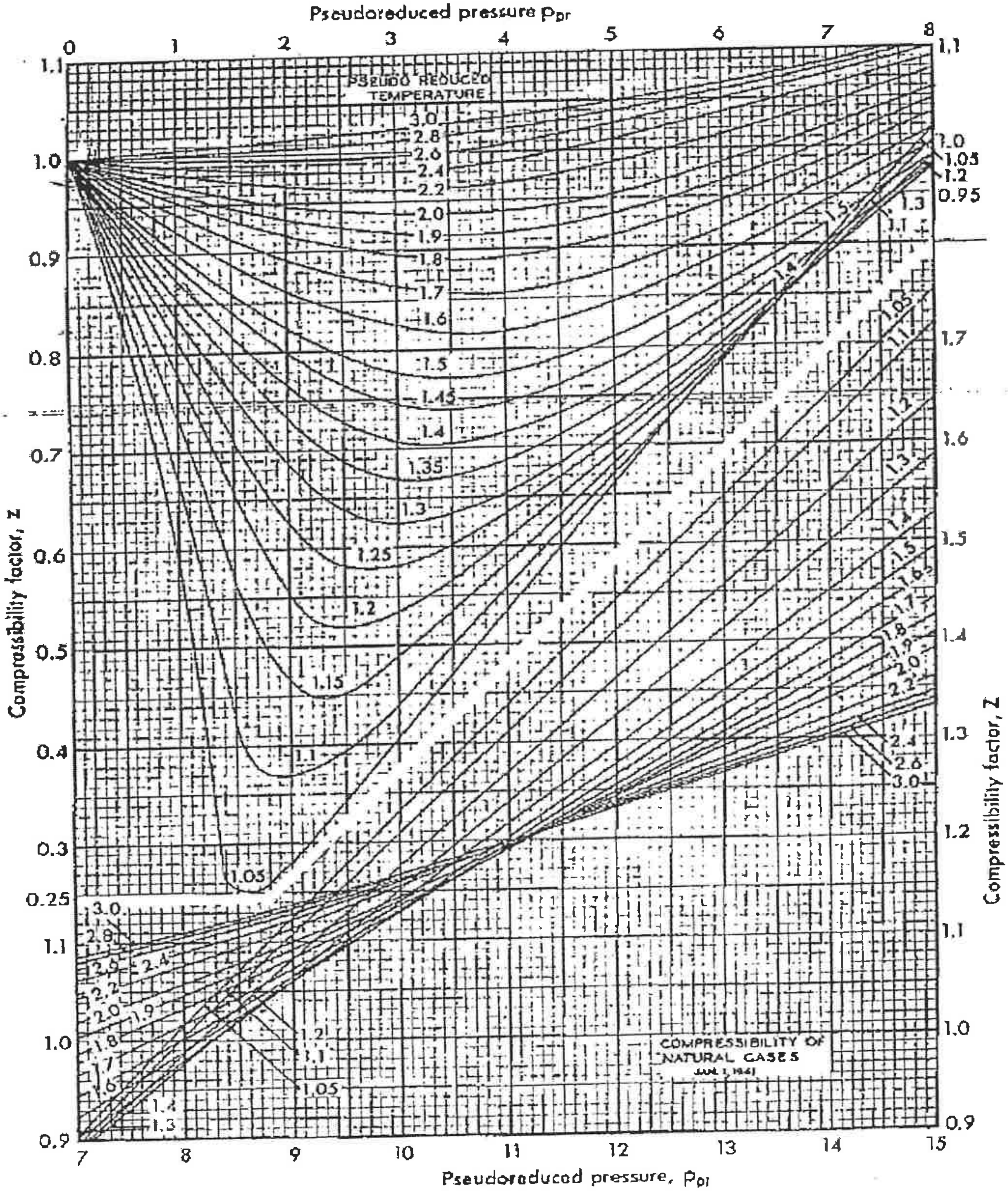
	from Celsius	to Celsius
Fahrenheit	[°F] = [°C] × 9⁄5 + 32	[°C] = ([°F] − 32) × 5⁄9
Kelvin	[K] = [°C] + 273.15	[°C] = [K] − 273.15
Rankine	[°R] = ([°C] + 273.15) × 9⁄5	[°C] = ([°R] − 491.67) × 5⁄9
Delisle	[°De] = (100 − [°C]) × 3⁄2	[°C] = 100 − [°De] × 2⁄3
Newton	[°N] = [°C] × 33⁄100	[°C] = [°N] × 100⁄33
Réaumur	[°Ré] = [°C] × 4⁄5	[°C] = [°Ré] × 5⁄4
Rømer	[°Rø] = [°C] × 21⁄40 + 7.5	[°C] = ([°Rø] − 7.5) × 40⁄21

(Source: Wikipedia)





Pseudocritical properties of natural gases. (*Source: Properties of Petroleum Fluids-Second Edition*)


Pseudoreduced pressure p_{pr}
0 1 2 3 4 5 6 7 8
PSEUDO REDUCED TEMPERATURE
3.0 2.8 2.6 2.4 2.2 2.0 1.9 1.8 1.7 1.6 1.5 1.45 1.4 1.35 1.3 1.25 1.2 1.15 1.1 1.05
1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.25
Compressibility factor, z
1.1 1.0 0.9 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9
Compressibility factor, Z
COMPRESSIBILITY OF NATURAL GASES
7 8 9 10 11 12 13 14 15
Pseudoreduced pressure, p_{pr}

The End of the Question Paper!

Question #	Q# 1	Q# 2	Q# 3	Q# 4	Q# 5	Q# 6	Q# 7	Total Marks
Marks per Question	20	20	20	20	20			100
Marks earned per Question								