

**Petroleum Engineering 310
Reservoir Fluid Properties
Study Guide
Fall, 2009**

A quote on Beginnings

"Before you begin a thing, remind yourself that difficulties and delays quite impossible to foresee are ahead. If you could see them clearly, naturally you could do a great deal to get rid of them but you can't. You can only see one thing clearly and that is your goal. Form a mental vision of that and cling to it through thick and thin"

-Kathleen Norris

Chapter 1: Components of Naturally Occurring Petroleum Fluids (p.1-45)

1. *Why would petroleum engineers need to learn about organic chemistry? How do you think you will use the information from Chapter 1 in your future job as a petroleum engineer?*
2. *What is the difference between organic and inorganic chemistry? Why is the study of carbon so important?*
3. *Define structural theory and homologous series. Name two types of chemical bonds and explain why molecules tend to bond together to form compounds.*
4. *What is Figure 1-1 showing us? Explain the process of ionic bonding using this figure. How does an ionic bond stay together?*
5. *Explain the process of covalent bonding. Why do covalent bonds stay together? Explain the difference between single, double and triple bonds.*
6. *What is a valence angle? What is the typical valence angle for carbon atoms?*
7. *What conventions do we use to name organic compounds?*
8. *Give an example of an alkane and describe the distinguishing features of molecules of the family, other names for the family, and the general formula of alkanes. What is the structural formula for the alkane you have used as your example? How was it named?*
9. *What are structural isomers? Explain using hexane as an example.*
10. *Is there a relationship between the size of the alkane molecule and its physical or chemical properties. Do all alkanes have similar physical and chemical properties? Is this what you would expect?*
11. *Give an example of an alkene and describe the distinguishing features of molecules of the family, other names for the family, and the general formula of alkenes. What*

is the structural formula for the alkene you have used as your example? How was it named?

12. *Do alkenes have structural isomers? Explain using hexene as an example. Are there any other types of isomers formed by alkenes? Why are these isomers not formed by alkanes?*
13. *Describe the relationship between the size of the alkane molecule and its physical or chemical properties. What are typical properties of alkenes? Are they related to alkanes?*
14. *Give an example of an alkyne and describe the distinguishing features of molecules of the family, other names for the family, and the general formula of alkynes. What is the structural formula for the alkyne you have used as your example? How was it named?*
15. *What are the differences between alkynes and dienes?*
16. *What are the difference between the chemical and physical properties of alkynes and those of alkanes or alkenes?*
17. *What is the difference between the homologous series alkanes, alkenes and alkynes and the cyclic compounds?*
18. *Give an example of a common cycloalkane and describe the distinguishing features of molecules of the family, other names for the family, and the general formula of cycloalkanes. What is the structural formula for the cycloalkane you have used as your example? How was it named?*
19. *Again, the physical properties of this family exhibit a trend with the size of the molecule. What about the chemical properties? Why is cyclohexane the least reactive of the cycloalkanes? What are the most reactive cycloalkanes and why?*
20. *Do cycloalkanes have structural isomers? What about geometric isomers? Give an example of isomerism in cycloalkanes.*
21. *What are condensed rings? Give an example.*
22. *Show with examples the differences between cycloalkanes, cycloalkenes, and cycloalkadienes.*
23. *Which cyclic compounds are most commonly found in petroleum?*
24. *What do the names aromatic and aliphatic mean? What are the differences between these two types of compound?*
25. *Describe the structure of benzene and explain why it is not considered a cycloalkatriene.*

26. *What bonds are present in the benzene ring? Draw the benzene ring as it is usually represented. Why does this not accurately represent the true bonding structure of benzene? Can we represent it differently, and perhaps more accurately?*
27. *Is there a systematic method of naming aromatic hydrocarbons? If so, describe it step-by-step. If not, give guidelines which can be used to name the compounds which contain a benzene ring.*
28. *Go through the procedure of naming aromatics for at least one example which includes an alkyl group bonding with the benzene ring.*
29. *Give examples of typical physical properties of aromatic hydrocarbons. Do these physical properties correlate with molecule size as with other homologous series?*
30. *What about chemical properties? Are aromatics very reactive? Why or why not.*
31. *What are cycloalkanoaromatics? Give an example.*
32. *Explain the classification of organic compounds other than hydrocarbons, based on their "functional group". What is the functional group for ketones? Amines? Aldehydes? Alcohols?*
33. *Give an example of a polyfunctional group.*
34. *What are the most common non-organic constituents of petroleum?*
35. *What are resins and asphaltenes? Are they important in the study of petroleum?*
36. *In which sulfur compounds are we most interested? Give examples of each, state their general formula and draw the structure of your example. Explain the importance of each sulfur compound.*
37. *Which oxygen compounds are most commonly found in crude oils? Give an example of an oxygen compound in crude and explain its importance.*
38. *Give an example of a nitrogen compound found in crude oils.*
39. *What are porphyrins? Why are they important?*
40. *What are the differences between resins and asphaltenes? Explain these in terms of chemical reactions and structure.*
41. *How do we classify crude oils? Name the physical characteristics we use to determine the value of petroleum liquid. Find out desirable values for each physical characteristic listed.*

42. *Describe different methods to classify petroleum using chemical properties. Are there standards set for chemical classification similar to those for physical classification?*

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A quote on Confidence

"There are admirable potentialities in every human being. Believe in your strength and your youth. Learn to repeat endlessly to yourself: It all depends on me."

-André Gide

Chapter 2: Phase Behavior: Pure Substances (p.46-61)

1. Give a thorough, but concise definition of a phase.
2. How are physical properties classified? What are the differences between the two types of physical properties and with which are petroleum engineers most concerned?
3. Which three factors are most important to the physical behavior of individual molecules? Describe the effects of these factors on different phases (solids, liquids, gases).
4. Why do we consider pure substances? Is crude oil a pure substance? What about natural gas?
5. Consider the typical phase diagram (PT , or pressure-temperature diagram) for a pure substance, Fig. 2-1. Explain the meaning of the vapor-pressure line. What is the significance of points C and T? Why, then, is the vapor pressure line shown as a dashed line below point "T"? What is the meaning of the melting point line?
6. What is Fig. 2-2 describing? Can this be illustrated by a phase diagram? Cite a figure that does so. What would happen if the experiment described by Fig. 2-2 was performed at a constant temperature above the critical temperature?
7. What is Fig. 2-5 describing? Can this be illustrated by a phase diagram? Cite a figure that does so. What would happen if the experiment described by Fig. 2-5 was performed at a constant pressure above the critical pressure?

8. *Can we express the vapor pressure line shown in Fig. 2-1 by an equation? How is this equation developed?*
9. *Work through Example 2-1. What is the purpose of this example?*
10. *What is a Cox Chart and how are Cox Charts useful? What are the limitations and assumptions of Cox Charts?*
11. *What does Fig. 2-9 illustrate? What is the difference between the process shown by line 123 and the process shown by line 45? Is this a better way to illustrate these processes than a PT diagram?*
12. *Give the explicit definitions of the bubble-point pressure, p_b , and the dew-point pressure, p_d .*
13. *What is a saturation envelope? Cite a figure to help your definition.*
14. *Work through Example 2-2. What is the purpose of this example?*
15. *What is the Law of Rectilinear Diameters? How is it illustrated?*

Chapter 2: Phase Behavior: 2 component systems (p.63-75)

1. *Why would petroleum engineers consider two component (binary) systems important?*
2. *A pure component pressure-temperature (PT) diagram has a single vapor pressure curve, but binary systems have a two phase (gas and liquid) envelope which is bounded by bubble-point and dew-point lines. Cite a figure which illustrates a typical binary system and indicate the bubble-point line, dew-point line, and the critical point.*
3. *Give the explicit definitions of the bubble-point pressure, p_b , and the dew-point pressure, p_d .*
4. *In Fig. 2-14 it is shown the liquid and gas phases can coexist, for a given mixture of components A and B, at conditions higher than the critical temperatures and pressures of the individual components A and B. This violates the definition of the critical point for a pure component which states that liquid and gas can not coexist above the critical point. What then, is the definition of the critical point of a 2 (or more) component system?*
5. *Fig. 2-14 also illustrates that the critical pressure for any binary mixture will be greater than the critical pressure of the pure components in that binary mixture. What relationship do the critical temperatures of pure components and binary mixtures exhibit? (Hint: See Figs. 2-15 and 2-16).*

6. Fig. 2-15 illustrates various binary mixtures of methane and ethane. Note the many different saturation envelopes for differing compositions. What does this suggest about the complexity of binary phase diagrams? Note also the line which connects the critical points of all of the mixtures. What is this line called and what is its significance?
7. Rework Example 2-3.
8. A very useful plot for binary *n*-paraffin mixtures is given by Fig. 2-16. This plot yields vapor pressures for the given pure components and the critical loci for given binary mixtures. The low molecular weight and high molecular weight binary mixtures (eg, C₁ and *n*-C₁₀ mixtures) exhibit very high critical pressures. Why?
9. We note (from Figs. 2-14, 2-15, and 2-17) that the critical pressure and temperature for a given mixture are not the highest pressure and temperature exhibited by the two-phase envelope. Why is this? (Hint: Consider the definition of the critical point for multicomponent mixtures.)
10. The highest pressure and temperature exhibited by the two-phase envelope are called the cricondenbar and cricondentherm, respectively. Using Fig. 2-17, illustrate the determination of the cricondenbar and cricondentherm for the given mixture. As an exercise, rework Example 2-4.
11. Note from Fig. 2-18 that an upper and lower dewpoint line exists for this particular binary mixture. This behavior is exhibited for practically all binary mixtures of hydrocarbons, as indicated by the methane-ethane mixtures shown in Fig. 2-15. What happens when the pressure is lowered into the two phase envelope through the upper dew point line? Through the lower dew-point line?
12. The region between the critical temperature and the cricondentherm is called the "retrograde condensation" region. What happens in this region when pressure is lowered (at a constant temperature) through the upper dew-point line? Sketch a curve from the critical temperature and the cricondentherm which encloses this "retrograde condensation" region on Fig. 2-18.
13. Rework Example 2-5 for the given mixture and for other mixtures as an exercise.
14. Cite pressure-volume diagrams for a pure component and for a binary mixture which illustrate an isotherm which is less than the critical temperature. Note specific similarities and differences.
15. Cite pressure-volume diagrams for a pure component and for a binary mixture which illustrate isotherms above and below the critical temperature. Note specific similarities and differences. (Note that the critical point is not the maximum temperature and pressure on the binary diagram.)
16. Rework Example 2-6 and also estimate the specific volume at the critical point.

17. Reference a figure which schematically illustrates a pressure-composition plot. These plots are useful for indicating the state of the mixture at a given temperature and for the determination of mole fractions of liquid and gas in the two-phase region. The equilibrium tie-lines are used to determine these mole fractions.
18. Describe how to determine the liquid and gas mole fractions for a binary mixture using an equilibrium tie-line. Rework Example 2-7.
19. Using your engineering intuition, how would you construct Fig. 2-22? (Hint: Use pressure, temperature, and composition data given in Fig. 2-15).
20. Reference a figure which schematically illustrates a temperature-composition plot. These plots are useful for indicating the state of the mixture at a given pressure and for the determination of mole fractions of liquid and gas in the two-phase region. The equilibrium tie-lines are again used to determine these mole fractions.
21. Note on Fig. 2-24 that the upper curves are dew-point lines and the lower curves are bubble-point lines. Using Fig. 24, describe what happens when the pressure is above the critical pressure for 1 component, and both components.

Chapter 2: Phase Behavior: 3 (and multi-) component systems (p.75-86)

1. What sort of diagram is a convenient method to plot three component system composition data?
2. Give reference to a figure which illustrates a "generic" ternary system. What is the usual convention for plotting the lightest, heaviest, and intermediate components?
3. Using this "generic" ternary diagram, be able to determine, using chord lengths, the composition at any point within the diagram. Also using this diagram, describe the process of adding a third component to a two component system and how the addition of this third component affects the composition of the other two components.
4. Describe Fig. 2-26. Explain the dew-point and bubble-point lines, equilibrium tie-lines, and gas, liquid, and 2-phase regions. Note that this diagram is only valid at 500 psia and 160°F.
5. From Fig. 2-26, describe how to determine the equilibrium molar quantities of gas and liquid along a given tie-line. (Hint: Rework Example 2-8.)
6. Describe Fig. 2-27. Is the presence of a critical point significant? What does this point mean physically?
7. Compare Figs. 2-26 and 2-27. Are the differences in these figures, for an increase in pressure at a constant temperature, predictable? Describe in detail what you see and what you believe causes these differences. (Hint: Consider the behavior of the

pure components and binary mixtures shown in Fig. 2-29 (or Fig. 2-16) and carry them to the three component system.)

8. *Having successfully mastered the previous concept, describe the differences shown in Figs. 2-28.1 to 2-28.8 as the methane/propane/n-pentane system progresses from 14.7 psia to 2350 psia, at a constant temperature of 160°F. Again, use Fig. 2-29 to identify the behavior of each pure component and binary mixture, then carry these to the appropriate graph at a particular pressure in Fig. 2-28.*
9. *Included in the previous question are the following specific tasks. First, identify specific characteristics such as single and two-phase regions for the pure, binary, and ternary systems. Second, identify where critical points exist for the pure, binary, and ternary systems and relate these points in each system. Finally, rework through the logic and comments given in the text from pgs. 79-81.*
10. *Describe the use of ternary diagrams to model the interactions between crude oil composed of a light and a heavy component (or "pseudo-components") and carbon dioxide. Specifically, cite Figs. 2-30 and 2-31, and rework Example 2-9.*
11. *Study and describe the multicomponent systems illustrated in Figs. 2-32 to 2-36. Note specific features such as the critical point of a particular mixture, and the cricondentherm, cricondenbar, and the retrograde region, if these features exist.*
12. *Use your intuition and estimate (given the percent liquid lines inside the two-phase envelope) the types of production (liquid and gas) that would result from lowering the pressure at constant temperatures of 100°F, 150°F, and 200°F (if possible from the graph) for each of the given systems.*

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A quote on Dedication

"The roots of true achievement lie in the will to become the best that you can become."

-Harold Taylor

Chapter 3: Equations of State (Gas): Ideal Gases (p.90-102)

1. *In general, why do the properties of gases and liquids vary so significantly?*
2. *What does the term "equation of state" mean?*
3. *State the three properties of an ideal gas.*
4. *State Boyle's Law. How was this relation developed?*
5. *State Charles' Law. How was this relation developed?*
6. *State Avogadro's Law. What is the physical significance of Avogadro's Law?*
7. *Describe the development of Eq. (3-7) from Eq. (3-1) (Boyle's Law) and Eq. (3-2) (Charles' Law). Eq. (3-7) implies, for a given mass of gas, that pV/T is constant. However, we must prove that Eq. (3-7) is valid for all ideal gases. Describe the proof that shows that Eqs. (3-7) and (3-8) are constant for all ideal gases.*
8. *Give reference to a table where the universal gas constant, R , for various dimensional systems is given.*
9. *State the equation of state for an ideal gas in terms of volume, molar volume, and specific volume. Also give the density form of the ideal gas equation of state (Note: $\rho=m/V$).*
10. *Rework Examples 3-1 and 3-2.*
11. *The temperature of a gas is a measure of what?*
12. *An alternative derivation of the equation of state for an ideal gas is given on pages 98 to 102. Work through this development and state the assumptions made in the development of the ideal gas equation of state from kinetic theory.*
13. *Given the development of Eq. (3-17), show the development of Eq. (3-19).*

14. Verify that Eq. (3-20) is valid and combine it with Eq. (3-19) to yield Eq. (3-21)
15. Work through Eqs. (3-22) to (3-25) to obtain Eq. (3-26). Identify the components of Eq. (3-26) which, when isolated, reduce Eq. (3-26) to Eq. (3-14).

Chapter 3: Equations of State (Gas): Mixtures of Ideal Gases (p.102-112)

1. Define partial pressure. State Dalton's Law and the assumptions under which it is derived. Show the derivation of Dalton's Law (Eq. (3-30)).
2. Rework Example 3-3.
3. State Amagat's Law of Partial Volumes. Show the derivation of Amagat's Law (Eq. (3-34)) and state all pertinent assumptions. What is the physical significance of Amagat's Law expressed as "... for an ideal gas the volume fraction of a component is equal to the mole fraction of that component."?
4. State the relation for the apparent molecular weight of a gas mixture.
5. Rework Example 3-4. (Note: $M_{air}=28.9625$ lb/lbmol or (g/gmol) from GPSA Handbook, 1987).
6. State the relation for the specific gravity of gas. Rework Example 3-5.
7. State the compressibility equation of state (ie, the real gas law).
8. The compressibility factor (or z-factor) is given by Eq. (3.40). What is the physical significance of this statement?
9. Cite a figure where the z-factor is plotted versus pressure for a constant temperature. Note the low pressure and high pressure behavior and comment on the specific behavior of the z-factor. At what condition(s) does the z-factor yield ideal gas behavior (ie, $z=1$).
10. Cite figures where the z-factors for methane, ethane, and propane are plotted versus pressure for various temperatures. Comment on the similarities. Do these curves all appear to have the same features? Could these curves conceivably be overlain in a way that would yield a correlation? Use your intuition, we will discuss this possibility in more detail very soon.
11. Rework Example 3-6.
12. State the Law of Corresponding States. Cite a figure that verifies the use of the Law of Corresponding States for the n-paraffin homologous (remember that word?) hydrocarbon series.

13. Rework Example 3-7 using Fig. 3-3 and Fig. 3-6 to estimate the z-factor of ethane. Is the difference between these values significant? How much error in the specific volume, v , would occur if we assume ethane is an ideal gas (ie, $z=1$)?

Chapter 3: Equations of State (Gas): Real Gases (z-factor calc.) (p.106-124)

1. State the definition of pseudocritical temperature and pressure. Why do we use these "pseudocritical" properties? Are these pseudocritical properties physically realistic?
2. Rework Example 3-8.
3. Cite figures which show the z-factor versus pseudoreduced pressure, p_{pr} , for constant pseudoreduced temperatures, T_{pr} . Give reasons why these plots can be successfully used to estimate the z-factors for gas mixtures.
4. Rework Example 3-9.
5. Why are we concerned with the pseudocritical properties of the C₇₊ fraction of a natural gas? Cite figures which can be used to obtain the pseudocritical properties of the C₇₊ fraction given molecular weight of the C₇₊ fraction.
6. Rework Example 3-10.
7. In practice, often only the gas specific gravity is reported and we must estimate gas properties based on the correlation of the gas specific gravity and the pseudocritical temperature and pressure of natural gases. Cite the figures where pseudocritical temperature and pressure are correlated with the gas specific gravity.
8. Rework Example 3-11.
9. The non-hydrocarbon components in natural gases violate the homologous series assumption that we made earlier for the use of the Law of Corresponding States. Therefore, we must externally correct the pseudocritical temperature and pressure for the effect of the non-hydrocarbon components. Cite the relations (and if desired, the figure) which are used to adjust the pseudocritical properties for the presence of hydrogen sulfide and carbon dioxide.
10. Corrections for other non-hydrocarbon components such as nitrogen and helium are usually ignored because the error that these contaminants introduce is generally of the order of the accuracy of the measurement of the z-factor. Some investigators (and industry operators) feel that the effect of these contaminants should not be ignored, but for the most part, no unique correction has been developed.
11. Rework Example 3-12. (You will have a homework on this type of problem and practice never hurt anyone.)

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A quote on Discipline

"No pain, no palm; no thorns, no throne; no gall, no glory; no cross no crown."

-William Penn

Chapter 4: Equations of State for Real Gases (p. 129-146) and Handout on SOPE.

1. State the van der Waals (vdW) Equation of State (EOS) in general form, in a form which has been solved for pressure, in a form which has been solved for z-factor, and in a form that has been solved for volume.
2. What do the "a" and "b" constants in the vdW EOS physically represent? How can these constants be obtained?
3. State other equations of state in the "spirit of van der Waals," explaining why they are said to be in the "spirit of van der Waals".
4. Using the constraints of first and second partial derivative of pressure with respect to volume at constant temperature at the critical point, derive expressions for the a and b constants in terms of R, T_C , and p_C .
5. Combine the definitions of the a and b constants (in terms of the critical properties as described above) into the pressure form of the vdW EOS. Starting with this form, divide both sides by the critical pressure, p_C , then factor out $0.375(RT_C)/(p_C V_C)$ (which equals 1) of the right-hand-side of the total expression. What does this form suggest?
6. If we define $p_r = p/p_C$, $T_r = T/T_C$, and $V_r = V/V_C$ and substitute into the previous relation we obtain

$$P_r = \frac{8T_r}{3V_r - 1} - \frac{3}{V_r^2}$$

The significance of this equation is that it represents all substances. Therefore, given a particular T_r and p_r we should obtain the same V_r for all substances. This is the Theorem of Corresponding States and it is explicitly valid for a few simple compounds although the theorem has been used successfully to develop correlations for the PVT behavior of similar chemical species. Give an example of a corresponding states correlation for similar chemical species.

7. Why don't we have quadratic equations of state?

8. *Simulate PVT experiments using the software given in class SOPE.*
9. *Describe the process of natural gas liquefaction .*
10. *Simulate retrograde condensation of a binary mixture and plot the amount of liquid produced as the pressure drops at a fixed temperature until all liquid is vaporized.*
11. *Simulate constant volume experiments and determine bubble points.*
12. *Calculate and plot pressure and temperature vs composition for binary mixtures.*
13. *Explain each one of the "data" points in the output provided by SOPE for a) a pure fluid and a binary mixture b) single phase and two-phase region.*
14. *Explain how can you blow-up your cell and indicate the sequence of steps to accomplish that.*
15. *Indicate a process by which you "accidentally" loose all the fluids in your cell (changes in pressure, temperature or number of moles).*

**Petroleum Engineering 310
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A note on Education

"If you think education is expensive - try ignorance."

**-Derek Bok
President, Harvard University**

Chapter 5: Five Reservoir Fluids: Black and Volatile Oils (p.147-158)

1. *It is important to note that 2-component mixtures illustrate the qualitative behavior of multicomponent mixtures. The author refers back to Chapter 2 so be prepared. Using Fig. 2-37, given the comments on p. 147-148, describe the various mixtures of ethane and n-heptane.*
 - a. *Note that mixture 2 is 90 percent ethane. Where is the critical point of this mixture? Where is the retrograde condensation region? What does your intuition tell you about a reservoir fluid that has a similar proportion of light components.*
 - b. *Describe what happens to the location of the critical point, the location of the retrograde condensation region, and the size of the two-phase envelope for mixtures with increasing proportions of n-heptane to ethane.*
 - c. *Describe the phase behavior of a mixture that is predominantly methane. Describe the behavior of mixtures which are composed of mostly heptane and higher hydrocarbons.*
2. *Name the five typical reservoir fluids.*
3. *Give the properties which are used by the "rules of thumb" to identify the reservoir fluid type. What can we do if our fluid does not match the criteria given by the rules of thumb?*
4. *The author warns students not to use these rules of thumb for reservoir fluid identification when reporting to a state agency. Why?*
5. *What is a "black oil"?*

6. *Cite a typical phase diagram (pressure versus temperature) for a black oil. Describe every feature on the figure and be prepared to reproduce these features.*
7. *Note the % liquid lines in Fig. 5-1. These lines are called iso-vols or quality lines. What do these lines mean physically?*
8. *Define the terms saturated and undersaturated.*
9. *What does the line 123 on Fig. 5-1 represent? Describe the state of the fluid along line 12, along line 23, and at the separator conditions.*
10. *Give the field methods used to classify fluids as black oils.*
11. *Give the laboratory methods used to classify fluids as black oils.*
12. *What is a "volatile oil"?*
13. *Cite a typical phase diagram for a volatile oil. Describe every feature on the figure and be prepared to reproduce these features. Compare these features to those for a black oil.*
14. *Note from Fig. 5-2 that the iso-vols are not so evenly spaced as for the black oil case and become separated by successively larger distances for smaller percentages of liquid. What does the location of the critical point and the spacing of the iso-vols suggest about the gas and liquid volumes during production?*
15. *Note line 123 on Fig. 5-2. Describe the state of the fluid along line 12, along line 23, and at the separator conditions.*
16. *The author comments that volatile oils can not use black oil material balance calculations because the gas in the reservoir is wet for a volatile oil and will condense liquids when produced into the wellbore. The black oil material balance methods assume that the gas in the reservoir is dry and yields no liquids. If the reservoir pressure is above the bubble point for a volatile oil, what does your intuition tell you about using black oil material balance methods to determine in-place fluids?*
17. *Give the field methods used to classify fluids as volatile oils.*
18. *Give the laboratory methods used to classify fluids as volatile oils.*

Chapter 5: Five Reservoir Fluids: Retrograde, Wet & Dry Gases (p.154-158)

1. What is a "retrograde gas"?
2. Cite a typical phase diagram for a retrograde gas. Describe every feature on the figure and be prepared to reproduce these features. Compare these features to those for a volatile oil. Note from comparing Figs. 5-2 and 5-3 that the major difference between a volatile oil and a retrograde gas is the location of the critical point and the position of the pressure path in the reservoir. What does this suggest about the composition of these fluids, are they similar?
3. Note line 123 on Fig. 5-3. Describe the state of the fluid along line 12, along line 23, and at the separator conditions. Be very careful about the state of the fluid along line 12, and remember that this process goes to the dew point, not the bubble point.
4. What comment does the author make about the liquid that condenses in a retrograde gas reservoir? Could this liquid conceivably revaporize?
5. Give the field methods used to classify a fluid as a retrograde gas.
6. Give the laboratory methods used to classify fluids as a retrograde gas.
7. What is a "wet gas"?
8. Cite a typical phase diagram for a wet gas. Describe every feature on the figure and be prepared to reproduce these features.
9. Note line 12 on Fig. 5-4. Describe the state of the fluid along line 12 and from point 2 to the separator conditions.
10. Does the term "wet" gas imply the presences of water vapor?
11. Give the field methods used to classify a fluid as a wet gas.
12. What is a "dry gas"?
13. Cite a typical phase diagram for a dry gas. Describe every feature on the figure and be prepared to reproduce these features.
14. Note line 12 on Fig. 5-5. Describe the state of the fluid along line 12 and from point 2 to the separator conditions.
15. The author comments about gas material balance equations. Remark about the application of these equations to retrograde, wet, and dry gases.

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A quote on Achievement

"You may be disappointed if you fail, but you are doomed if you don't try"

-Beverly Sills

Chapter 6: Properties of Dry Gases: B_g and c_g and μ_g (p.165-190)

1. State the definition of "standard conditions" and give reference to the value of standard temperature in the U.S. and the values of standard pressure used by various states in the U.S. Cite specifically the Texas base conditions.
2. Derive the numerical constant for the volume occupied by one pound mole of gas at Texas base conditions.
3. Rework Example 6-2 where the mass of a gas is converted to volume at standard conditions.
4. What three calculations that confuse students use a numerical constant close to 14.7? Be sure that you understand the calculations clearly, and refer back to this section if you become confused.
5. Give the definition of a "dry gas". Be very specific.
6. Define the gas formation volume factor, B_g . What are the some of the units of B_g ?
7. Reference a graph which illustrates the typical behavior of B_g with respect to pressure, at a constant temperature.
8. State the definition of B_g in equation form. Note that B_g is a volume ratio for a constant mass of gas.
9. Cite equations based on the real gas law which give the reservoir volume, V_R , and the volume at standard conditions, V_{SC} of a given mass of gas. Cite the equation where these relations are combined using the definition of B_g to yield an equation for B_g in terms of the pressures, temperatures, and z-factors at reservoir and standard conditions.

10. Give the equations where the Texas base conditions are used in the definition of B_g . One equation is in res cu ft/scf and the other is in res bbl/scf. Be able to derive these relations and other relations for arbitrary units of volume.
11. Our old friend the z-factor has again raised his ugly head (as he will many times during our careers). Give reference to methods which can be used to compute z-factors given composition or specific gravity data, and the methods to correct for non-hydrocarbon components.
12. Rework Example 6.3 completely.
13. Give the definition of the coefficient of isothermal compressibility (or simply the gas compressibility), c_g . Where have we seen pressure as a function of volume (or molar volume) for the single and two-phase regions? Since we are considering only gas compressibility, have we seen a relation (or relations) which relate pressure, volume, and temperature of a gas? Your intuition should tell you that we will use these relations in Eq. 6.4 to model gas compressibility.
14. Reference a graph which illustrates the typical behavior of gas compressibility with respect to pressure, defined at a constant temperature.
15. Carefully rework example 6-4. In a practical sense, is the data required in Example 6.4 generally available? Therefore, we would prefer to use an equation(s) which relates pressure, volume, and temperature to make this calculation more practical.
16. State the ideal gas law solved for volume and the derivative of this relation with respect to pressure, at a constant temperature. If we combine these relations with the definition of c_g (Eq. 6-4) we obtain a relation for c_g in terms of pressure only since all of the other variables cancelled. Cite this relation.
17. What is significant about Eq. 6-6? What does this ideal gas relation suggest about the behavior of c_g ? Is this behavior reflected in Fig. 6-3? How accurate would we expect to Eq. 6-6 to be?
18. Rework Example 6-5?
19. State the real gas law solved for volume and the derivative of this relation with respect to pressure, at a constant temperature. If we combine these relations with the definition of c_g (Eq. 6-4) we obtain a relation for c_g in terms of pressure and the z-factor only since all of the other variables cancelled. Cite this relation.
20. What is significant about Eq. 6-8? The $(\partial z/\partial p)_T$ does not look friendly, but it may not be as bad as it appears since we could graphically evaluate this term by differentiation a plot of z-factor versus p along a specified isotherm.

21. Given the comments in the previous question, rework Example 6-6 and state the steps involved in this calculation.
22. Given the Law of Corresponding States and the so called "reduced" variables of pressure, temperature, and volume that we use for the correlation of real gases, it seems natural that we would like to define a "pseudoreduced compressibility". Intuitively, we would derive this pseudoreduced compressibility, c_{pr} , by substituting the definitions of reduced pressure and temperature into Eq. 6-8. This is done on page 175 from Eqs. 6-9 to 6-13. Since the unit of compressibility is inverse pressure, it is no accident that c_{pr} is defined as $c_{pr} = c_g p_{pc}$, as shown in Eq. 6-14. What does your intuition tell you that the advantage of Eq. 6-14 is over Eq. 6-8? (Hint: We usually use the Law of Corresponding States to develop correlations of data.)
23. Cite a figure where a corresponding states correlation of $c_{pr} T_{pr}$ versus p_{pr} for various T_{pr} isotherms is given.
24. Carefully and completely rework Example 6-7 and 6-8.
25. Physically, what is the viscosity of a gas a measure of?
26. Cite a figure which illustrates the behavior of gas viscosity with respect to temperature and pressure. Describe in detail what you see.
27. Why would we prefer to use a gas correlation rather than measure the viscosity experimentally?
28. Cite the figure which illustrates the behavior of the viscosity of ethane with respect to temperature and pressure. Describe in detail what you see and note the existence of the two-phase region in the low temperature range.
29. Given similar species of hydrocarbon molecules, what does your intuition tell you about the likelihood of a corresponding states correlation for gas viscosity being valid? Explain in detail.
30. Reference an equation which can be used to compute the viscosity of a gas mixture if the gas viscosities of each component are available at the pressure and temperature of interest.
31. Reference a figure which illustrates the viscosity behavior of paraffin hydrocarbons and typical non-hydrocarbons at varying temperatures and atmospheric pressure.
32. Rework Example 6-9 completely.

33. *Reference a figure which can be used to compute the viscosity of a gas mixture at atmospheric pressure using the average molecular weight of the gas. Also give reference to the correction graphs for H₂S, CO₂, and N₂.*
34. *Rework Example 6-10 completely and compare your results with those of Example 6-9.*
35. *We are really interested in gas viscosity at high pressures. Reference a method which can use the low pressure gas viscosity and the temperature and pressure of the gas mixture to predict the gas viscosity at high pressure.*
36. *Reference figures which yield the viscosity ratio, μ_g/μ_{g1} , as a function of the reduced temperature and reduced pressure for different ranges of the gas specific gravity. Cite the accuracy of each of these figures as described by McCain (p.184-185).*
37. *Rework Example 6-11 completely.*

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A quote on Growth

"Be not afraid of growing slowly, be afraid only of standing still."

-Chinese proverb.

Chapter 8: Properties of Black Oils: B_O , R_S , B_t , and c_O (p.224-234)

1. *What properties of black oil are usually required for typical reservoir engineering calculations?*
2. *State the definitive equation for the specific gravity of a liquid. What is similar about this definition and the definition of the specific gravity of a gas? What is different? (Hint: Consider the density "standard" for each case. For gas, the standard density is that of air and for liquids it is the density of water.)*
3. *State the definitive equation for °API gravity. Why do we use the °API gravity relation? What is a hydrometer?*
4. *You will use Eqs. 8-1 and 8-2 for the rest of your natural life, so commit them to memory. Rework Example 8-1 once you have committed these equations to memory.*
5. *What three major factors control the shrinkage of crude oil as it changes from reservoir to surface conditions?*
6. *State the definition of the oil formation volume factor, B_O in words. State the definitive equation for B_O .*
7. *What are the units for B_O in the English measurement system? What is the standard temperature for reporting stock tank oil volume?*
8. *Rework Example 8-2. Note that the liberated gas is at surface, not reservoir conditions.*

9. Reference a figure where the typical behavior of B_O for a black oil is shown as a function pressure. Describe in detail what you see. Why does B_O increase with a reduction of pressure from the initial condition to the bubble point and decrease for a reduction of pressure below the bubble point.
10. The author notes that B_O is a function of the method of processing (i.e., the separation facilities). Since we want to minimize B_O so that the stock tank oil volume is maximized, does your intuition suggest that we will study the optimization of separation conditions.
11. State the definitions of the terms "saturated" and "undersaturated" as the author uses them for black oils on p. 228.
12. State the definition of the solution gas-oil ratio, R_S in words. State the definitive equation for R_S .
13. What are the units for R_S in the English measurement system?
14. Reference a figure where the typical behavior of R_S for a black oil is shown as a function pressure. Describe in detail what you see. Why does R_S stay constant with a reduction of pressure from the initial condition to the bubble point and decrease for a reduction of pressure below the bubble point.
15. Rework Example 8-3.
16. State the definition of the total formation volume factor, B_t in words. State the definitive equation for B_t .
17. Reference a figure where the typical behavior of B_t for a black oil is shown as a function pressure. Describe in detail what you see. Why is B_t equal to B_O for pressures above the bubble point and why does B_t increase for a reduction of pressure below the bubble point.
18. Rework Example 8-4.
19. Describe the coefficient of isothermal compressibility of oil, c_O in words. State the definitive equation for c_O for pressures above the bubble point.
20. Reference a figure where the typical behavior of c_O for a black oil is shown for pressures above the bubble point.
21. The author notes on p. 231 that for black oils at pressures above the bubble point, c_O is essentially constant with respect to both pressure and temperature. Holding c_O constant, Eq. 8-7 can be integrated to yield an exponential relation between the volume ratio at reference and desired conditions and the pressure difference at

these conditions multiplied by the constant oil compressibility. Rework through this development (i.e., Eqs. 8-7 to 8-12).

Chapter 8: Properties of Black Oils: c_o , m_o , b and interfacial tension (p. 234-241)

1. State the definitive equation for c_o for pressures below the bubble point. Also, work through the development of this relation (i.e., work through Eqs. 8-20 to 8-24).
2. Reference a figure where the typical behavior of c_o for a black oil is shown for pressures above and below the bubble point. Explain the discontinuity at the bubble point.
3. State the definition for the coefficient of viscosity. What are the units of viscosity in the English system that we use for field computations?
4. Explain the behavior of oil viscosity with respect to temperature, pressure, solution gas-oil ratio, and the size and complexity of the hydrocarbon molecules which make up the oil.
5. Reference a figure which illustrates the behavior of oil viscosity at pressures above and below the bubble point. Note that the minimum oil viscosity occurs at the bubble point.
6. Describe the coefficient of isobaric thermal expansion of oil, b , in words. State the definitive equations for b in terms of volume and in terms of density.
7. The author notes that b is usually assumed to be constant and therefore Eq. 8-25 can be integrated in the same manner as Eq. 8-7. This result is used to predict liquid volume and/or density as a function of temperature. The author also notes that these relations are not typically used by petroleum engineers because most reservoir engineering processes are isothermal not isobaric.
8. The author also introduces the physical property called thermal expansion. Describe this property in words and in equation form, also discuss its use.
9. Rework Example 8-6.
10. Describe the physical property known as interfacial tension.
11. Cite the figure which illustrates the imbalance of forces at a gas-liquid interface. Discuss the theoretical basis for interfacial tension in terms of the attractive forces between molecules and the mass of the molecules.

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A quote on Initiative

"It is the greatest of all mistakes to do nothing because you can do only a little. Do what you can."

-Sydney Smith.

Chapter 10: Properties of Black Oils from Reservoir Fluid Studies: Flash and Differential Vaporization (p. 257-276)

1. *What are the 5 main procedures in a black oil reservoir fluid study (RFS)?*
2. *What physical properties of oil are determined from a black oil RFS?*
3. *What physical properties of gas are determined from a black oil RFS?*
4. *What properties and quantities of separator oil and gas are determined in a black oil RFS?*
5. *What two types of fluid samples are obtained? At what time during production should the reservoir fluid sample be taken?*
6. *Reference a table which presents formation and well characteristics and sampling conditions for a typical black oil RFS.*
7. *The author notes that it would be impossible to determine all of the different chemical species which make up black oils and for this reason only a few light hydrocarbon fractions are reported. In addition, one plus component (or lumped component) for all of the heavier components is reported. Given that discussion, what specific hydrocarbon fractions are usually reported in a black oil RFS?*
8. *Reference a table from a typical black oil RFS which presents a composition determination for a black oil.*
9. *Describe the flash vaporization process. You should use Fig. 10-1 which illustrates this process.*
10. *A table of pressure and total volume in the cell is constructed from a flash vaporization test. From this table a plot of pressure versus total volume is constructed. Where the slope changes from being relatively constant at higher pressures to a different slope or curve is the bubble point pressure. This pressure is determined graphically as illustrated on Fig. 10-2.*

11. Rework Example 10-1. What is the purpose of this example?
12. Describe the differential vaporization process. You should use Fig. 10-3 which illustrates this process.
13. What is "residual oil" or "residual oil from vaporization" and how is it determined?
14. What is "relative oil volume" and how is it determined?
15. How is the z-factor determined for the gas which is expelled from the cell during differential vaporization.
16. What is the "relative total volume" and how is it determined? Be sure to understand the origin and development of all variables in this relation.
17. Example 10-2 illustrates all of the important points of differential vaporization calculations. Please rework this example carefully and thoroughly. Several homework problems will pertain to these calculations and this is a good place to start.

Chapter 10: Properties of Black Oils from Reservoir Fluid Studies: Separator Tests, m_o, m_g (p. 276-292)

1. Describe a "separator test". It may help to use Fig. 10-4.
2. Give the definition of formation volume factor of oil, B_{oS_b} , as defined by Eq. 10-2. Also give the conditions (pressure and temperature) for each variable in Eq. 10-2.
3. Give the definition of solution gas-oil ratio, R_{S_b} , as defined by Eq. 10-3 and give the conditions for each variable in this relation.
4. Define the "separator volume factor".
5. Rework Example 10-3 completely.
 - a. Explain how to compute the separator gas-oil ratio at separator conditions.
 - b. Explain how to compute the stock tank gas-oil ratio at stock tank conditions.
 - c. Explain how to compute the separator and stock tank gas-oil ratios based on stock tank oil at standard conditions. Note that the total of these two ratios is the solution gas-oil ratio, R_{S_b} . See p. 265, row 2 (100 psig separator pressure).
 - d. Explain how to compute the formation volume factor of oil, B_{oS_b} .
 - e. Explain how to calculate the separator and stock tank shrinkage factors, and the API gravity of the stock-tank oil.
6. How is oil viscosity usually measured for a black oil RFS?
7. How is gas viscosity usually estimated for a black oil RFS?

8. *What process do we assume in the reservoir for pressures below the bubble point? Why?*
9. *What process do we assume from the bottom of the well to the stock tank? Why?*
10. *What process do we assume in the reservoir for pressures above the bubble point? Why?*
11. *To compute fluid properties above the bubble point the results of what tests are used?*
12. *To compute fluid properties below the bubble point the results of what tests are used?*
13. *Cite a table of nomenclature for black oil reservoir fluid studies. Make sure that you are familiar with each variable and its meaning.*
14. *What is the criterion given by the author as the optimum separator condition?*
15. *Rework Example 10-4. State all variables considered and their magnitudes (ie, tell whether these values are minima or maxima at the optimum separator condition).*
6. *Reference the relation used to compute the formation volume factor of oil, B_O , at pressures above the bubble point. Perform dimensional analysis of this relation to prove its validity. Dimensional analysis is reduction of units in a relation to confirm the stated or implied units of the relation (eg, Eq. 10-5).*
17. *Reference the relation used to compute B_O at pressures below the bubble point. Perform dimensional analysis of this relation to prove its validity.*
18. *Rework Example 10-5.*
19. *Reference the relation used to compute the solution gas-oil ratio, R_S , at pressures above the bubble point.*
20. *Reference the relation used to compute R_S at pressures below the bubble point. Perform dimensional analysis of this relation to prove its validity.*
21. *Rework Example 10-6. What is the purpose of this example?*
22. *How do we compute the total formation volume factor, B_t , at pressures above the bubble point?*
23. *Reference the relation used to compute the total formation volume factor, B_t , at pressures below the bubble point. Perform dimensional analysis of this relation to prove its validity. Note that either Eq. 8-6 or Eq. 10-11 can be used to compute B_t .*

24. *Rework Example 10-7.*
25. *Reference the relation used to compute the coefficient of isothermal compressibility of oil, c_o , at pressures above the bubble point.*
26. *Rework Example 10-8.*
27. *Reference the relation used to compute c_o at pressures below the bubble point. Note that Eqs. 10-15, 10-16, and 10-17 are modifications of Eq. 8-24. These modified equations can be used to compute c_o from lab data.*
28. *Rework Example 10-9. Work every part of this example very carefully.*

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A quote on Kindness

“Guard well within yourself that treasure, kindness. Know how to give without hesitation, how to lose without regret, how to acquire without meanness.”

-George Sand

Chapter 11: Properties of Black Oils - Correlations: p_b , R_S , r_o (p. 296-307)

1. *What practical reasons would we have for using correlations to estimate the values for physical properties of black oils?*
2. *What physical properties of black oils are estimated from the correlations presented in Chapter 11?*
3. *Cite a figure which can be used to estimate the bubble point pressure, p_b , for a black oil. What properties of the oil and gas must we know in order to use Fig. 11-1? What is the stated range of accuracy of Fig. 11-1 for estimating p_b ?*
4. *Rework Example 11-1 completely and understand clearly the origin of all of the variables required to use Fig. 11-1.*
5. *Could Fig. 11-1 also be used to estimate the solution gas-oil ratio, R_S ? How would this be done relative to the procedure to estimate the bubble point pressure?*
6. *Could R_S be estimated at any pressure below the bubble point using Fig. 11-1?*
7. *Rework Example 11-2 completely.*
8. *Why would we need to know the density of the reservoir liquid at reservoir conditions?*
9. *The author states that we will use ideal liquid solution theory. Describe in detail an ideal liquid solution.*

10. *Let's try a simple example. If you mix 1 liter of pure water with one liter of alcohol at the same conditions you will obtain about 1.9 liters of mix. Is a mixture of alcohol and water an ideal mixture? Why or why not? (Hint: Ideal liquid mixture theory dictates that the total volume of an ideal mixture is exactly equal to the sum of the volumes of the pure components.)*
11. *Let's try our intuition. We have just determined that there is no such thing as an ideal liquid mixture. However, if we recall the law of corresponding states for gases we find that substances that are chemically similar exhibit the same type of behavior. Using your intuition, what does this tell you about applying ideal liquid solution theory to mixtures of paraffin hydrocarbons?*
12. *Ah, but there's a wrinkle. We will first determine the liquid density at standard conditions and then adjust this value to reservoir conditions. What about paraffin hydrocarbons that aren't liquids at standard conditions? (In particular at 14.696 psia, for methane $T_{boil} = -258.73^{\circ}\text{F}$ and for ethane $T_{boil} = -127.49^{\circ}\text{F}$.) Since the well stream (liquids and gases coming through the wellhead) typically contain significant quantities of methane and ethane, we will have to overcome the fact that these components aren't liquids at standard conditions.*
13. *The author notes that the liquid mixture calculations made in this section are made at 60°F and 14.696 psia. Why?*
14. *Example 11-3 gives the fundamental calculations for ideal liquid mixtures. You should know these calculations backwards, forwards, and in your sleep.*
15. *The author notes two problems in calculating the density at standard conditions and adjusting this value to reservoir conditions. What are these problems and how does the author propose to overcome them?*
16. *The solution to the first problem (methane and ethane being gases at standard conditions) is Fig. 11-2 which is a plot of the "pseudoliquid" densities (or apparent liquid densities) of methane and ethane versus the density of the mixture (with all components) at standard conditions.*
17. *Fig. 11-2 presents a practical computational problem. The pseudoliquid densities of methane and ethane are functions of the liquid density at standard conditions, which is unknown. Therefore, an iterative procedure arises and we must use a trial and error determination of the density at standard conditions. We do not like iterative procedures, but they pop up now and then and we must be prepared to solve them.*
18. *Once we have determined the correct density at standard conditions, we must adjust this value for temperature and pressure. The author describes two figures which can be used for this purpose. Cite these figures and give the authors comments as to their application.*
19. *Rework Example 11-4 completely. You will have several homeworks of this type so you may as well get started!!!*

Chapter 11: Properties of Black Oils - Correlations: r_o , B_o (p. 307-322)

1. *The author notes that he does not like the iterative procedure to compute r_o any more than we do. He solves this iteration problem by the development of a chart which correlates the quantities of methane and ethane (and nitrogen) with the pseudoliquid density at standard conditions. Cite the figure where this chart is given.*
2. *The variables W_1 and W_2 are new to us. Cite the definitions of these variables and state the origin of all of the components of these two variables.*
3. *Give the author's comments about the accuracy of this technique to compute liquid density at reservoir conditions compared to experimentally determined densities for both black oils and volatile oils.*
4. *The author also describes a correction for hydrogen sulfide. Cite the figure and computational techniques required by this correction.*
5. *Rework Example 11-5. You will see problems like this again as homework problems.*
6. *The author points out that usually only the specific gravity of the stock tank liquid rather than composition is known (along with the gas composition and producing gas-oil ratio). Therefore, the author gives a method to compute the well stream density at standard conditions using these variables.*
7. *This method is best demonstrated by example so the author uses Example 11-6 to develop the method. We will talk through this example in class, but make sure that you have carefully reworked this example.*
8. *The author also provides a method which uses the only the specific gravity of the stock tank liquid, gas specific gravity, and the producing gas-oil ratio. This method requires a correlation which gives the apparent density of the dissolved gas at standard conditions as a function of the gas and stock tank liquid specific gravities. Cite the figure where this correlation is given. Also give the author's estimate of the accuracy of this method compared to the experimental determination of liquid density.*
9. *This method is also best illustrated by example. Rework Example 11-7 prior to class.*
10. *Compare p_{pO} calculated by Eq. 11-3 to the value computed on p. 315.*
11. *Describe the procedure to compute the liquid density at pressures above the bubble point .*

12. Cite the fundamental relation of density for pressures above the bubble point. At what pressure should the isothermal coefficient of compressibility, c_o , be computed for use in Eq. 8-19.
13. Rework Example 11-8 completely.

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1. The liquid densities at reservoir and standard conditions can be used to estimate the formation volume factor of oil, B_o . What 3 specific cases did we consider previously for the calculation of reservoir liquid density?
2. Cite the 2 relations given to compute B_o from reservoir liquid density. As a challenge, derive Eq. 11-5 from Eq. 11-4.
3. Rework Examples 11-9 and 11-10 completely.
4. Usually we do not know the reservoir liquid density and we may not have sufficient information to estimate it. In this case we should use a correlation which approximates B_o based on the solution gas-oil ratio, and the specific gravities of the separator gas and stock tank liquid. Cite the figure where such a correlation is given.
5. Rework Example 11-11 completely.
6. Why is B_o at pressures above the bubble point less than B_o at the bubble point?
7. Cite the relation which gives B_o for pressures above the bubble point for a specified B_o at the bubble point pressure and a given coefficient of compressibility of oil, c_o . Be able to derive this equation from Eq. 8-9.
8. Rework Example 11-12 completely.

Chapter 11: Properties of Black Oils - Adjustment of B_o , R_s for p_b and correlations for B_t (p. 322-326)

1. How can we significantly improve the results from correlations to estimate B_o and R_s ?
2. Describe the simple procedure given by the author that can be used to adjust B_o and R_s for a value of the bubble point pressure different than the value observed in the field?
3. Rework Example 11-13.

4. We need to estimate the total formation volume factor, B_t . Recall the defining equation for B_t . Consider the variables in this relation and where we would obtain them for this computation?
5. Under what conditions does the author specify that the separator gas gravity can be used to approximate the reservoir gas gravity?
6. Standing has also developed a correlation which approximates B_t based on the solution gas-oil ratio, and the specific gravities of the separator gas and stock tank liquid. Reservoir temperature and pressure must also be known to use this correlation. Cite the figure where this correlation is given.
7. What degree of accuracy does the author estimate for the Standing B_t correlation?
8. Rework Examples 11-14 and 11-15 completely.

Chapter 11: Properties of Black Oils - Correlations: c_o , m_o and s (p. 326-338)

1. Cite the equations given in Chapter 8 which are defined for the coefficient of isothermal compressibility of oil, c_o , for pressures above and below the bubble point pressure.
2. Given that there are different relations for c_o above and below the bubble point, what does your intuition tell you about whether one or more correlations will be required to model the behavior of c_o at pressures above and below the bubble point?
3. Cite the figure where the correlation for c_o above the bubble point pressure is given.
4. What comments does the author make about the accuracy of the correlation presented in Fig. 11-11?
5. Rework Example 11-16 completely.
6. Cite the figure where the correlation for c_o below the bubble point pressure is given.
7. What comments does the author make about the accuracy of the correlation presented in Fig. 11-12?
8. Rework Example 11-17 completely.
9. Do not underestimate the use of Figs. 11-11 and 11-12 (or the equations from which these figures are derived). These correlations are very useful for reservoir engineering calculations. In particular, accurate estimates of c_o are required for

material balance calculations and for calculations used for reservoir performance prediction and well testing.

10. *Discuss the behavior of the oil viscosity, m_o , as related to the types of molecules which make up the oil.*
11. *As with c_o , what does your intuition tell you about whether one or more correlations will be required to model the behavior of m_o at pressures above and below the bubble point?*
12. *Cite the figure where the correlation for the "dead oil" (or gas free oil) viscosity is given as a function of stock tank gravity and reservoir temperature.*
13. *Cite the figure where the correlation for the saturated black oil viscosity (ie, the viscosity of the oil at and below the bubble point pressure) is given as a function of the dead oil viscosity and the solution gas-oil ratio.*
14. *Rework Example 11-18 completely.*
15. *Cite the figure where the correlation for the undersaturated black oil viscosity (ie, the viscosity of the oil above the bubble point pressure) is given as a function of the saturated black oil viscosity, the reservoir pressure, and the bubble point pressure.*
16. *Rework Example 11-19 completely.*
17. *Why is the oil viscosity at pressures greater than the bubble point greater than the oil viscosity at the bubble point pressure.*
18. *What comments does the author make about the accuracy of the correlation presented in Figs. 11-13 to 11-15?*
19. *Describe the physical property of interfacial tension. Specifically, note the behavior of interfacial tension with temperature and at the critical point.*
20. *For the purposes of this course it is sufficient that you be able to use Fig. 11-16 to estimate the interfacial (or surface) tension of various substances with temperature. As a practical note, interfacial tension is used in some semi-analytical studies of multiphase flow through porous media and to estimate theoretical gas flowrates required to lift a certain amount of liquid out of the wellbore.*

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A quote on Life

"Make your life a Mission - not an intermission."

-Arnold Glasgow.

Chapter 12: Gas-Liquid Equilibria - Ideal Solutions(347-354)

1. *Draw a multicomponent phase diagram and show the region where gas and liquid exist in equilibrium.*
2. *What does equilibrium mean?*
3. *What three calculation procedures will be covered in this chapter?.*
4. *Why do we study ideal solutions (review question)?*
5. *What are the properties of an ideal solution? What are two important conclusions that can be drawn about ideal solutions based on their properties? Why do you think these are practical conclusions - how can we as petroleum engineers use them?.*
6. *State Raoult's equation in words and equation form. What are the implications of this equation?*
7. *State Dalton's equation in words and equation form. What are the implications of this equation? Does this equation look familiar - when have we seen this equation before?*
8. *What are the differences between Raoult's and Dalton's equations - aren't they both used for calculating the same thing ??.*
9. *How can we combine these two equations in a useful form?.*
10. *Define the terms n , n_L , n_g , z_j , x_j , and y_j . What do the products $z_j n$, $x_j n_L$, and $y_j n_g$ represent?*
11. *What is Eq. 12-3 - in other words, where does it come from?*
12. *Derive Eq. 12-5 and 12-6. State the use of these equations. How can we simplify the calculations?*
13. *How are Eqs. 12-8 and 12-9 used? Give a detailed calculation procedure.*
14. *Work through Ex. 12-1. What is the purpose of this example?*

15. How do we calculate the bubble or dew point of ideal solutions? Explain why we use the procedure we use.

Chapter 12: Gas-Liquid Equilibria: Nonideal Solutions (p. 354-362)

1. The author gives three reasons why we can not apply the relations we developed for ideal solutions. Cite these reasons and make sure that you are familiar with them.
2. How does the author propose to overcome the nonideal behavior of these mixtures? Specifically, are we going to use analytical expressions or experimental correlations?
3. The author defines the equilibrium ratio, $K_j = y_j/x_j$. We can use Eq. 12-2 to develop an equation $K_j = p_{vj}/p$. From this equation, we see that for an ideal solution, K_j is a function of pressure and temperature ($p_{vj} = f(T)$). However, for a real substance K_j is a function of pressure and temperature and the type of the substances present in the mixture.
4. Cite the typical modifications of Eq. 12-8 and 12-9 that are used for non-ideal vapor-liquid equilibria computations.
5. We are going to have to use correlations of experimentally determined K-values. What parameters must these correlations take into account?
6. The author makes a comment about the accuracy of Eqs. 12-17 and 12-18. State this comment and make sure that you understand this limitation.
7. Rework Example 12-4. The K-factor charts in Appendix A should be used.
8. Eqs. 12-17 and 12-18 are very useful, but you must understand the behavior of these relations inside and outside of the two-phase region. Cite the figures which illustrate the behavior of Eqs. 12-17 and 12-18.
9. Describe Fig. 12-1 in detail. You must understand all lines and regions of interests.
10. Describe Fig. 12-2 in detail. You must understand all lines and regions of interests.
11. Figs. 12-1 and 12-2 can be used as one method to perform the iterative procedure we discussed. You could choose a grid of points (say 0 to 1.0 by 0.1) and determine the curve predicted by the particular equation. Once you have established if there is a root (ie. $S=1$ for trial values greater than zero) and approximately where that root is, you could refine your trial value by linear interpolation until you obtain the root.
12. The procedure outlined above is tedious and certainly not efficient, but as a simple, effective learning tool, this procedure is quite adequate.

13. As we mentioned before, we need to develop a relation to identify the bubble point of a real mixture. If we set $\bar{n}_g=0$ (or $\bar{n}_L=1$), and combine this with Eq. 12-16 we obtain $\sum z_j K_j=1$ (Eq. 12-21). Since Eq. 12-21 is also iterative, what does your intuition tell would be a good starting guess for the bubble point pressure, p_b ?
14. From Fig. 12-2 we note that at $\bar{n}_L=1$ if $\sum z_j K_j \leq 1$ (Eq. 12-18) then the state of the mixture is all liquid. Therefore, we can check beforehand and if $\sum z_j K_j \leq 1$ then we know the state of the mixture is all liquid and a trial and error solution is not necessary.
15. We also need to develop a relation to identify the dew point of a real mixture. If we set $\bar{n}_L=0$ (or $\bar{n}_g=1$), and combine this with Eq. 12-15 we obtain $\sum z_j / K_j=1$ (Eq. 12-22). What does your intuition tell would be a good starting guess for the dew point pressure, p_d ?
16. From Fig. 12-1 we note that at $\bar{n}_g=1$ if $\sum z_j / K_j \leq 1$ (Eq. 12-19) then the state of the mixture is all gas. Therefore, we can check beforehand and if $\sum z_j / K_j \leq 1$ then we know the state of the mixture is all gas and a trial and error solution is not necessary.
17. From questions 14 and 16 we identified two extremely critical facts. The are
 1. If $\sum z_j K_j \leq 1$ then mixture is all liquid.
 2. If $\sum z_j / K_j \leq 1$ then mixture is all gas.

Therefore, before we attempt any other computation we should compute $\sum z_j K_j$ and $\sum z_j / K_j$. If both quantities are greater than 1.0, then the state of the mixture is two-phase. If not, the mixture is either all liquid or all gas, depending on which sum is less than (or equal to) 1.0.

Chapter 12: Gas-Liquid Equilibria: Phase Envelope, Flash & Differential Vaporization (p. 362-369)

1. Review the flash vaporization procedure we studied in Chapter 10. Why are the calculations we have been doing in Chapter 12 for non-ideal solutions (Eqs. 12-17 & 12-18) considered flash calculations? How can we compare these results to results from Reservoir Fluid Studies?
2. Review the differential vaporization procedure we studied in Chapter 10. Explain what happens to n_L moles of a liquid during differential vaporization as shown in Fig. 12-4.
3. Realizing that after each successive removal of evolved gas, the liquid composition changes, how do we calculate these compositional changes?

4. *Develop Eq. 12-23 from scratch, explaining what each term in the equation means.*
5. *Derive Eq. 12-29 from Eq. 12-23. Is this equation valid for real solutions? What are the assumptions for Eq, 12-29.*
6. *For which variable in Eq. 12-29 are we trying to solve? How can we achieve this?*
7. *State the two different types of differential vaporization calculations petroleum engineers consider. Make sure you know the requirements for each calculation (known variables & conditions, variables we must solve for ...)*
8. *Give a procedure for calculating final liquid composition for a differential vaporization process when final pressure is known.*
9. *Rework Example 12-8. Make sure you understand every calculation in this example - you will do this for homework.*
10. *Give a procedure for calculating final liquid composition for a differential vaporization process when the number of moles to be vaporized is known.*
11. *Rework Example 12-9. Make sure you understand every calculation in this example - you will do this for homework.*
12. *How can we minimize error introduced by the assumption that K_j values are constant for the range of pressures considered?*

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A quote on Listening

***"Know how to listen, and you will profit even from those who talk badly."
-Plutarch.***

Chapter 13: Surface Separation: Surface Sep. Calc. for Black Oils (374-383)

1. Give a common example of flash vaporization in the field.
2. What variables control the pressure and temperature of a separator?
3. Cite a figure which schematically illustrates examples of two-stage and three-stage separation processes.
4. What physical properties of black oils can be calculated from "separator calculations"?
5. Outline the six-step procedure to perform separator calculations for a two-stage separation process.
6. Cite the figure which illustrates the molar quantities of separator feed, separator liquid and separator gas for a two-stage separation process. Make sure you understand and can effectively use the nomenclature given in Fig. 13-2.
7. Describe the calculation procedure for Steps 1 and 2 given on p. 375.
8. Describe how to compute the liquid density at standard conditions as required in Step 3.
9. Step 4 requires computation of separator and stock tank gas-oil ratios. Make sure that you understand and can develop all terms in Eqs. 13-1, 13-2 and 13-3. Describe this development and define all terms.
10. Step 5 requires the computation of the liquid density at reservoir conditions. Describe this calculation.
11. Step 6 illustrates the development of the oil formation volume factor at the bubble point, B_{Ob} , for a two-stage separation system. Make absolutely sure that you can work through Eqs. 13-6 to 13-9. Describe this development and define all terms.
12. As with previous concepts, the author presents Example 13-1 to illustrate the step-wise procedure to compute the variables just described. I strongly urge you to rework Example 13-1 in its entirety as you will have no fewer than 3 homework problems on this material.
13. How do the results from Example 13-1 compare to the laboratory results for this sample?
14. We could repeat the calculations of Example 13-1 to determine the "optimum" separator conditions. What are the criteria for determining the optimum separator conditions?
15. Explain, in detail, the behavior illustrated by the gas-oil ratios shown in Fig. 13-3.

Chapter 13: Surface Separation: Surface Separator Calculations for Other Fluids and K-factors for Separator Calculations (383-386)

1. Give examples of reservoir fluids which typically undergo three stages of separation.
2. Cite relations for producing gas-oil ratios at each stage of separation and the total producing gas-oil ratio. When is the solution gas-oil ratio at the bubble point, R_{sb} , equal to the producing gas-oil ratio, R ?
3. Cite the relation for the oil formation volume factor at the bubble point, B_{ob} , for a three stage separation system.
4. You should familiarize yourself with the derivation of Eqs. 13-10, 13-11, 13-12, and 13-14. Some of these derivations will be required as homework.
5. Cite relations for predicting liquid recovery based on surface and reservoir gas recoveries. Also cite the relation for the wet gas formation volume factor, B_{wg} .
6. Give the typical ranges of convergence pressure (used to correlate K-factors) for black oils, volatile oils, and retrograde and wet gases.
7. Why is it acceptable to use K-factors for a convergence pressure of 5000 psia for black oils to work problems involving low pressure separators?
8. Cite a relation which can be used to predict the K-factors for carbon dioxide at low concentrations.
9. What does the author recommend to use for estimating the K-factors of the C₇₊ fraction? Why?

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A quote on Mistakes

“Better ask twice than go wrong once.”

-German proverb.

Chapter 14: Equilibrium Ratio Correlations: Convergence Pressure (395-403)

1. Cite the defining relation of the K-factor (generic, non-ideal mixtures).
2. Cite the defining relation of the K-factor for ideal mixtures.
3. What properties do K-factors for real mixtures depend upon?
4. Cite figures which show K-factors as functions of temperature and pressure for two typical petroleum mixtures. Describe the behavior of these curves at low pressures. How does this behavior compare with that predicted by Eq. 14-1 (ideal solution relation)?
5. Describe the behavior of Fig. 14-1 and 14-2 for high pressures. Is this behavior predicted by the ideal solution relation (Eq. 14-1)?
6. Note that the curves on Figs 14-1 and 14-2 "converge" to 1.0 at high pressures. Do the curves for each mixture converge to approximately to the same pressure?
7. In the special case where the mixture is at its critical temperature the K-factors converge to 1.0 at the critical pressure. This suggests that the gas and liquid phases have become one, or more specifically the properties of the gas and liquid are the same and the mixture is at its critical point. So the convergence pressure at the critical temperature is the critical pressure, but this is a special case and in general the convergence pressure and the critical pressure are not the same. For all other temperatures and pressures above the bubble and dew points of the mixture we can not measure liquid and vapor properties (because the fluid is single-phase), therefore we must extrapolate the K-factor vs. pressure curve to the convergence pressure.
8. The author notes that the convergence pressure and the critical pressure are only the same by coincidence. However, as we have used the critical pressure to correlate gas properties (using the Law of Corresponding States), we can also use the convergence pressure to characterize the behavior of the mixture. This means that the convergence pressure will be the correlation variable used for K-factors of real mixtures.

9. *The determination of the correct convergence pressure for a given mixture is a trial and error procedure. Cite the relation which estimates the first trial value of the convergence pressure.*
10. *Describe the procedure to determine the convergence pressure.*
11. *Rework Example 14-1 completely. Make sure that you understand how to normalize the weight fractions of the heavier-than-methane components.*
12. *On page 402 the author makes a very important comment about errors in convergence pressures as they relate to flash calculations for a given operating pressure. What is this comment?*
13. *Give the convergence pressures typically used for black oils, retrograde gases, and volatile oils.*

Chapter 14: Equilibrium Ratio Correlations: Effect of Inaccurate Values of K-factors and Correlating and Smoothing of K-factors (404-411)

1. *Since general comments about the accuracy of computed liquid and vapor compositions due to inaccurate K-factors are not possible, the author chose to look at the flash calculation results of three typical cases. Cite the figures for these cases. Which variables are the most sensitive to the accuracy of K-factors for these cases?*
2. *Describe the behavior of Figs. 14-5, 14-6, and 14-7 for each component. Why is methane usually the most sensitive component? (hint: We are considering errors in the liquid volume. Methane does not want to be a part of the liquid and any error in the K-factor of methane is going to magnify the non-ideal behavior of methane in liquid mixtures.)*
3. *What does the author suggest as the best source of K-factors?*
4. *In dealing with any experimental data we will encounter (hopefully) minor inconsistencies which we call experimental error. Experimental error is random in nature and not some systematic variation in the results. In general, we can smooth experimental errors if we have predictive relation. For example, if we know that a set of y versus x data should be linear, then we can fit a linear equation to this data and smooth the experimental or random error. Similarly, we want to smooth experimental K-factors. Cite the relation that we assume models the $\log(pK_j)$ product, for a specific pressure, as a function of temperature and boiling point temperature.*
5. *Fig. 14-8 suggests that a plot of $\log(pK_j)$ versus Eq. 14-3 should be linear. Once the data are plotted and a best fit straight line is drawn, the smoothed pK_j are interpolated and smooth K-factors are computed.*
6. *Rework Example 14-2 completely.*

7. *The author shows the behavior of experimental data for several pressures using the plotting functions discussed above in Fig. 14-8. Note that for each line (ie, pressure) the slope and intercepts differ systematically. For instance, as pressure decreases the slopes increase and as pressure decreases the intercepts (ie, the $\log(pK_j)$ values at $x=0$) decrease. If we wanted to correlate all of the data on this plot we would try to develop equations which model the behavior of the slopes and intercepts as functions of pressure. The author illustrates this concept in Example 14-3 using Figs. 14-10 and 14-11.*
8. *Describe the behavior illustrated in Figs. 14-10 and 14-11. Are both the slopes and intercepts linear functions of pressure?*
9. *At the convergence pressure all K-factors equal 1 and the slope of the $\log(pK_j)$ line is zero. Since the slopes versus pressure are linear and can be extrapolated, what do we obtain if we extrapolate this line to a slope of zero?*
10. *Rework Example 14-3 completely.*
11. *The author states on page 411 that this method could conceivably be used for variations in temperature according to Eq. 14-3. What does your intuition tell you about extrapolation using only one (temperature) data point? What does the author say?*

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A quote on Rightness

“When you are right you cannot be too radical; when you are wrong, you cannot be too conservative.”

-Dr. Martin Luther King, Jr.

Chapter 16: Properties of Oilfield Waters: composition, ρ_b , B_w , r_w , R_{sw} (438-451)

1. *What 8 (eight) properties of formation waters will we study in this chapter?*
2. *Cite the typical ranges of total solids concentrations in formation waters. What is the total solids concentration of seawater?*
3. *Name the common and occasional cations found in formation waters. Also name the common and occasional anions.*
4. *What are the common units used to report the solids present in formation waters?*
5. *Describe how to compute the solids concentration in milliequivalents per liter.*
6. *Cite the table where the nomenclature and units for concentration of dissolved solids are summarized.*
7. *Rework Examples 16-1 and 16-2.*
8. *The author notes that a convenient method to view and compare the compositions of formation brines is to use a graphical plot of the concentrations on a milliequivalents per liter basis. This method was proposed by Stiff (yes, that is his name) and typical "Stiff" diagrams are shown in Fig. 16-1.*
9. *Rework Example 16-3.*
10. *What does the author comment about the mixing of brines from different locations and how this can be detected in the field? What is a "soft scale" and how is it formed?*

11. *What is the definition of the bubble point pressure of a formation brine that is in contact with oil? Does this definition make sense?*
12. *What is the bubble pressure of a formation brine in contact with gas? Why is the definition valid? Rework Example 16-4.*
13. *What are the three major factors affecting the formation volume factor of the formation water, B_W ? What comments does the author make about these factors and the resulting magnitude of B_W ?*
14. *Cite the figure which illustrates the behavior of B_W with respect to pressure. Be sure to note the author's comments about this behavior on pages 445 and 446.*
15. *Cite the relation which can be used to estimate B_W from the changes in the water volume due to pressure and temperature.*
16. *Cite the figures where the coefficients ΔV_{WT} and ΔV_{Wp} are shown? What comments does the author make about using Eq. 16-1 and Figs. 16-6 and 16-7 to estimate B_W for oilfield waters with widely varying brine concentrations?*
17. *Rework Example 16-5.*
18. *Cite the figure which gives the density of oilfield brine at standard conditions as a function of total dissolved solids.*
19. *The author suggests dividing the density at standard conditions by the formation volume factor B_W to obtain the brine density at reservoir conditions. Does this procedure make sense? Verify this methodology for yourself.*
20. *Rework Examples 16-6 and 16-7.*
21. *Cite the figure where the solubilities of butane, propane, ethane and methane in pure water at 200°F are given as a function of pressure. What does the author conclude from this figure?*
22. *Cite the figure which illustrates the solubility of methane in pure water as a function of temperature and pressure.*
23. *Note that Fig. 16-10 is only for solubility of methane in pure water. Obviously, formation brines are not pure water and the values from Fig. 16-10 must be adjusted. Cite the figure where the adjustment for solubility is given as a function of temperature and total dissolved solids.*
24. *Rework Example 16-8.*

Chapter 16: Properties of Oilfield Waters: c_w, m_w, \dots etc. (451-467)

1. *The author notes that the coefficient of isothermal compressibility of water, c_W , is very similar in behavior to that for oil (c_O). For instance, c_W exhibits a discontinuity at the bubble point pressure and the same type of behavior above and below the bubble point as does oil. What does your intuition tell you about using the definitions of compressibilities to estimate c_W ?*
2. *Cite the defining relations for c_W at pressures above the bubble point. It is very important that you understand each variable in this relation and where it could be obtained or estimated for this calculation.*
3. *Rather than use the definitions of c_W (Eq. 16-2), the author presents Fig. 16-12 as a correlation of c_W as a function of pressure and temperature. Although it was not necessary to adjust B_W for the solids content, a recent study suggests that we need to correct c_W for the solids content. This correction is found in Fig. 16-13.*
4. *Rework Example 16-9.*
5. *Cite the defining relation for c_W at pressures below the bubble point. It is absolutely critical that you understand all variables in this relation and where these variables could be obtained for computational procedures.*
6. *Note that the gas formation volume factor, B_g , is required by Eqs. 16-3 and 16-4. In order to compute B_g we must have the gas composition or at least the gas gravity. What does the author say about this? Is what he suggests reasonable?*
7. *We also need a derivative.. Where does the author suggest that this term can be obtained? What is the stated accuracy of Fig. 16-14?*
8. *Rework Example 16-10 carefully and completely.*
9. *Cite the figure which exhibits the typical behavior of formation brine viscosity as a function of pressure. What does the author note about the effect of dissolved gas on m_W ?*
10. *Analogous to the previous correlations for oil and gas viscosity, the author presents a correlation for water viscosity at one atmosphere and reservoir temperature and another correlation which relates the water viscosity at reservoir pressure to the viscosity at one atmosphere, as a function of pressure. Cite the figures where these correlations are given.*
11. *Rework Example 16-11.*
12. *It is imperative that you understand that gas and water vapor may be produced simultaneously from an otherwise "dry" gas. That is, a gas which produces little or*

no hydrocarbon liquids. Cite the figures which predict the water vapor content (at the dew point) of dry natural gases as a function of pressure and temperature.

13. *Why are the lines truncated at higher temperatures? (Note the upper left hand corner of each figure.)*
14. *What does the author state about the water vapor content of retrograde and wet gases? Recall that Figs. 16-18 and 16-19 were developed for dry gases.*
15. *What about the water content of gases with substantial amounts of carbon dioxide and hydrogen sulfide? Gases with helium and nitrogen?*
16. *What effect do dissolved solids have on the water content of natural gases? Cite the figure which can be used to adjust the moisture content for waters with dissolved solids.*
17. *Rework Example 16-12 carefully and completely.*
18. *The behavior of gas-water interfacial tension is fairly difficult to correlate. Cite the figure that the author recommends as a correlation for gas-water interfacial tension. What comments does the author make about the accuracy of Fig. 16-23? What about the effect of dissolved solids on the behavior of the gas-water interfacial tension?*

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A quote on Self-Esteem

“If you really do put a small value upon yourself, rest assured that the world will not raise your price.”

-Anonymous.

Chapter 17: Gas Hydrates: Conditions for Formation (474-485)

1. Describe the physical state of a "gas hydrate".
2. Cite the figure which predicts the molecules that will form a gas hydrate with free water. What does the author say about molecular size and geometric configuration?
3. What is the most important consideration in gas hydrate formation?
4. At what temperatures do seed crystals begin to form? At what pressures?
5. Cite the figure which illustrates the phase behavior of water and hydrocarbons. Describe what you see. Be able to reproduce the various lines, points, and regions on Fig. 7-2.
6. Identify the line of most practical concern on Fig. 7-2.
7. Cite the figure which illustrates conditions for hydrate formation when paraffin hydrocarbons are in the presence of free water.
8. What conclusion can be reached from Fig. 17-3 about the tendency of methane to form hydrates, as opposed to other paraffin hydrocarbons?
9. Cite the figure which illustrates the conditions for hydrate formation of methane-propane mixtures. What is the significance of Fig. 17-4?

10. *Cite the figure which illustrates the conditions for hydrate formation of natural gas mixtures. What is the accuracy of Fig. 17-6 in terms of predicting the pressures and temperatures for hydrate formation? Describe the effect of H₂S and CO₂ on the data given in Fig. 17-6.*
11. *Rework Example 17-1.*
12. *Cite the figure which describes the effects of dissolved solids on hydrate formation temperature. Note the labels on the curves. What does this figure imply from a practical standpoint?*
13. *Cite the figure which describes the effect of methanol and diethylene glycol on hydrate formation temperature. What comments does the author make about these inhibitors?*
14. *Rework Example 17-2.*
15. *Describe what effect liquid hydrocarbons in contact with free water has on the hydrate formation temperature? Cite the figure which illustrates a specific case. What comments does the author make concerning Fig 17-9?*
16. *Since gas hydrates also form as a result of the expansion of a gas in the presences of free water (the reduction of pressure and resulting reduction of temperature), charts have been developed to predict hydrate formation conditions for specified initial conditions. Cite the figures where these correlations are presented for various gas gravities. How where these correlations developed?*
17. *Describe in detail the applications of the correlations presented in Figs. 17-10 to 17-14.*
18. *Rework Example 17-3.*

A quote on Success

"Try not to become a man of success but rather to become a man of value. "

-Albert Einstein.

The End