# National Exams May 2013

## 98-Pet-A7, Secondary and Enhanced Recovery

3 hours duration

**NOTES:**

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. This is an OPEN BOOK EXAM. Any non-communicating calculator is permitted.
3. FOUR (4) questions constitute a complete exam paper. The first four questions as they appear in the answer book will be marked.

**Problem 1 (30 points)**

The oil and water relative permeability curves for a particular line drive waterflood are given as follows:

$$k_{rw} = k_{rw}^0[(S_w - S_{wc})/(1 - S_{wc} - S_{or})]^2$$
$$k_{ro} = k_{ro}^0[(S_o - S_{or})/(1 - S_{wc} - S_{or})]^2,$$

where $k_{rw}$ : Water relative permeability
$k_{ro}$ : Oil relative permeability
$S_w$ : Water saturation
$S_o$ : Oil saturation
$k_{rw}^0 = 0.20$
$k_{ro}^0 = 0.80$
$S_{wc} = 0.20$
$S_{or} = 0.30.$

Other pertinent data are given below.

Distance between the wells: 2700 ft
Cross sectional area for the line drive: 3000 $ft^2$
Porosity: 0.25
Initial $S_w$: 0.20
Oil viscosity: 3.0 cp
Water viscosity: 1.0 cp
Constant water injection rate: 250 STB/Day

a. (10 points) Calculate and plot the fractional flow curve for the water phase without gravity and capillarity. Use the attached graph sheet. Perform the Welge tangent-line construction.

b. (10 points) Calculate the water breakthrough time in days.

c. (10 points) Plot the expected 1-D water saturation profile at 0.20 pore-volumes of water injected. The plot should have the water saturation on the y axis and the distance from the injector on the x axis.

## Problem 2 (20 points)

Phase behavior for one mole of a mixture containing 30 mol% pentane and 70 mol% $CO_2$ is measured in a PVT cell. Refer to Figure 1 and answer the following questions:

a. (5 points) The mixture is separated into liquid and vapor at 230°F and 825 psia. What is the critical pressure of the vapor phase? What is the critical temperature of the liquid phase?

b. (5 points) What are the compositions of equilibrium liquid and vapor? How many moles of the liquid phase are present?

c. (5 points) What is the state of the mixture at 230°F and 1000 psia?

d. (5 points) There still exist two equilibrium phases at a higher pressure of 1345 psia at 230°F. Are these two phases closer to a critical state than those in Part b? Explain why or why not in a quantitative manner.

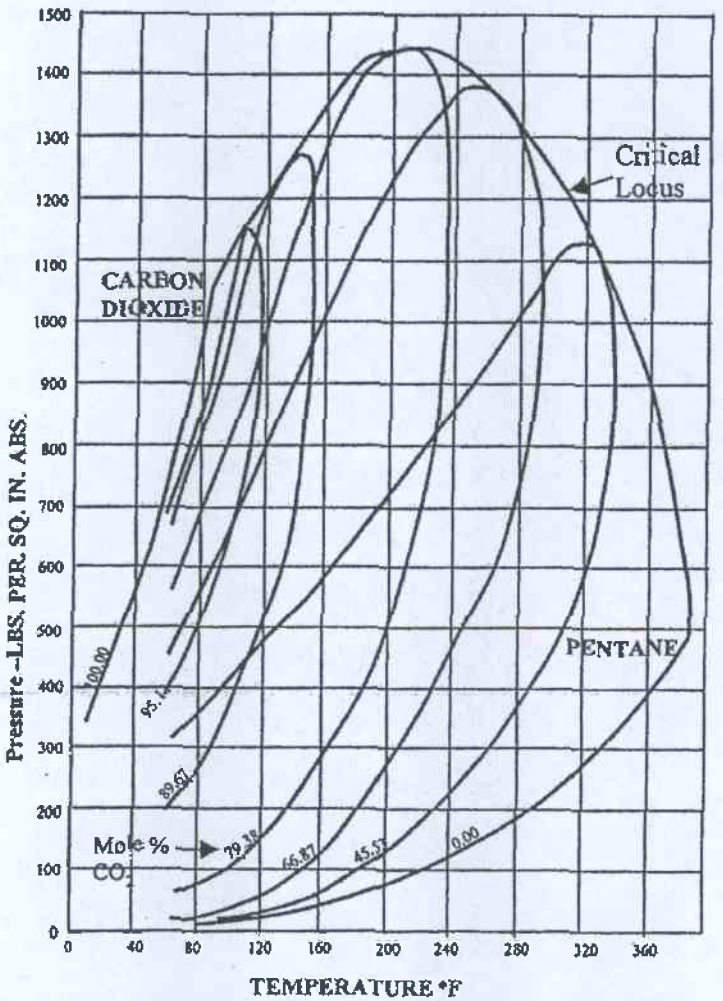



Figure 1. Pressure-temperature diagram for binary mixtures of $CO_2$ and Pentane.

**Problem 3 (25 points)**

Preliminary screening criteria for thermal methods indicate that the following conditions are favourable:

- Porosity higher than 0.25
- Reservoir pressure lower than 1300 psia.

a. (10 points) Please explain why the two conditions given above are favourable for thermal methods in general.

b. (5 points) Propagation of thermal fronts can be quite slow in steam flooding. Please explain the effect(s) of porosity on the propagation rate of thermal fronts in steam flooding.

c. (10 points) A typical steam quality in thermal methods is 0.7. The quality of flowing steam in the reservoir, however, is always quite low. Consider a water saturation of 0.25, an oil saturation of 0.35, and a steam saturation of 0.4 in a certain portion of a reservoir under steam flooding at 1.0 MPa. For liquid and vapor water to be present, both must be saturated. Calculate in-situ steam quality and confirm that the fluids are just barely inside the saturated liquid line in the H-P (enthalpy-pressure) diagram for water. The density of saturated liquid and vapor water (steam) is 885 and 5.31 $kg/m^3$ at 1.0 MPa, respectively.

**Problem 4 (25 points)**

Please answer the true and false questions given below. Briefly explain reasons for each of your answers.

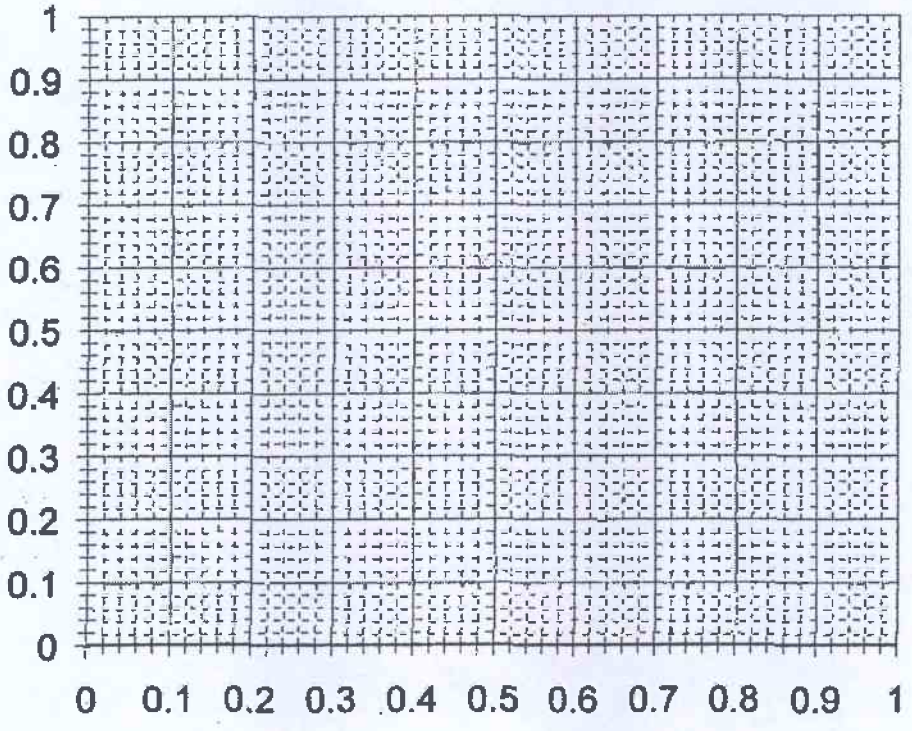
a. (5 points) In a horizontal waterflood with the line drive, breakthrough of water can be delayed by adding polymer in the injection water: True or false? Why?

b. (5 points) Steam flooding is more efficient for a reservoir that has higher water saturations because the convective energy flow is more efficient for such a reservoir: True or false? Why?

c. (5 points) Dispersion can enhance local displacement efficiency of a miscible gas flood: True or false? Why?

d. (5 points) The effect of dispersion on oil recovery from a miscible gas flood in the lab is likely the same as in the field: True or false? Why?

e. (5 points) Steam flooding can achieve 100% local displacement efficiency: True or false? Why?


1
0.9
0.8
0.7
0.6
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0.3
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0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

## Marking Scheme

1. (a) 10 marks (Fractional flow plot: 5 marks, Welge tangent-line: 5 marks)
   (b) 10 marks
   (c) 10 marks
2. (a) 5 marks
   (b) 5 marks
   (c) 5 marks
   (d) 5 marks
3. (a) 10 marks
   (b) 5 marks
   (c) 10 marks
4. (a) 5 marks (True/false question: 3 marks, Reasoning: 2 marks)
   (b) 5 marks (True/false question: 3 marks, Reasoning: 2 marks)
   (c) 5 marks (True/false question: 3 marks, Reasoning: 2 marks)
   (d) 5 marks (True/false question: 3 marks, Reasoning: 2 marks)
   (e) 5 marks (True/false question: 3 marks, Reasoning: 2 marks)