

## **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<sup>2</sup>

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

- (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.
- (10 points) Calculate the water breakthrough time in days.
- (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<sub>2</sub> is measured in a PVT cell. Refer to Figure 1 and answer the following questions:

- (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?
- (5 points) What are the compositions of equilibrium liquid and vapor? How many moles of the liquid phase are present?
- (5 points) What is the state of the mixture at 230°F and 1000 psia?
- (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.

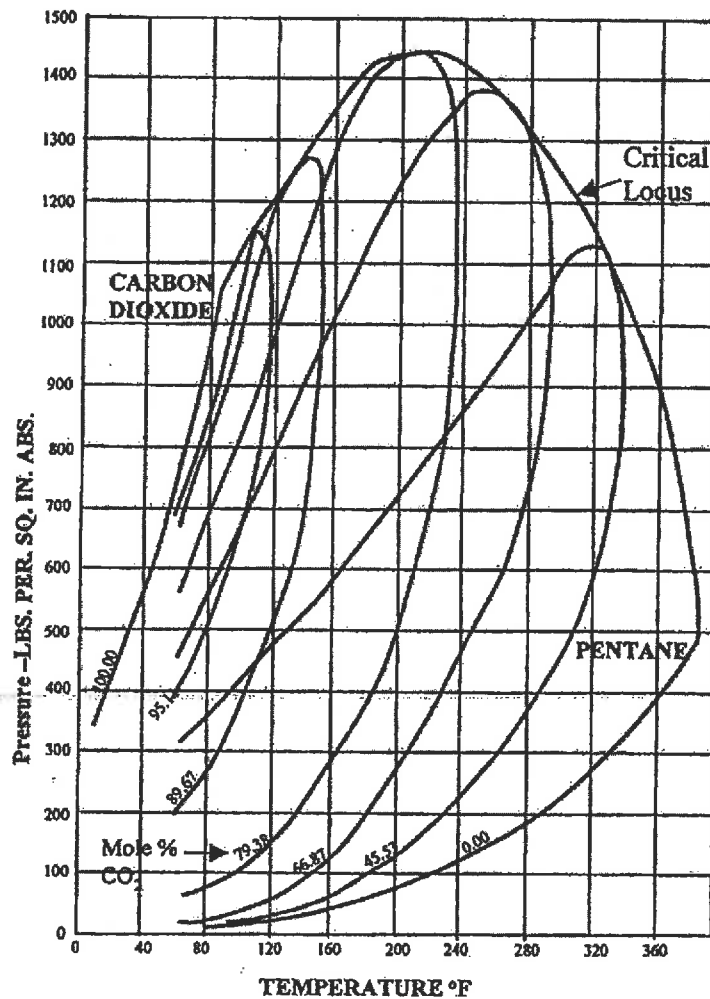


Figure 1. Pressure-temperature diagram for binary mixtures of CO<sub>2</sub> and Pentane.

### Problem 3 (25 points)

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

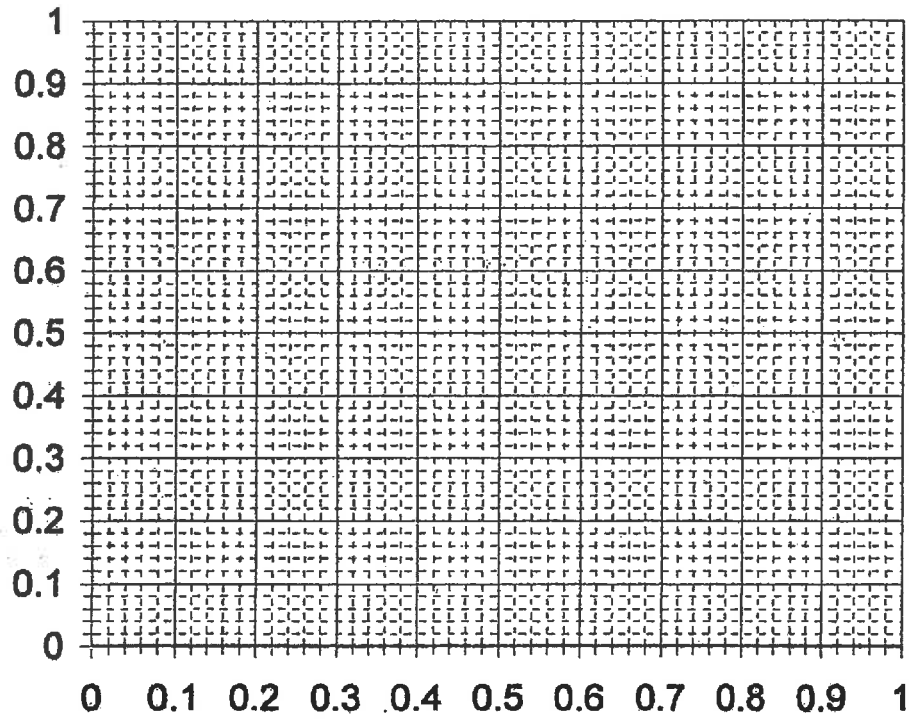
- Porosity higher than 0.25
- Reservoir pressure lower than 1300 psia.

- 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<sup>3</sup> 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?



**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)