

Reservoir Fluids

PETE 310

Lab 5: Reservoir Fluid Studies

Constant Composition Expansion, Differential Vaporization, and Separator Tests of a Live Oil Sample

Learning Objectives

Simulate the PVT tests mentioned above using the PVTsimulator-Lab5.xls available from our web site and:

1. Use PVT data from a CCE test to determine bubblepoint pressure and oil compressibility above the bubble point.
2. Interpret PVT data obtained from a DL test to determine B_{oD} and R_{sD} and discuss the effects upon these properties by using different pressure decrements.
3. Understand the importance of selecting optimal separator(s) pressure and temperature to maximize oil production.
4. Use combined CCE, DL, and separator data to produce corrected formation volume factors and solution gas oil ratios for reservoir engineering computations

General Skills

1. Know how to operate our excel PVT simulator
2. Calculate relationships between moles, mass, and molecular weight.
3. Convert between API gravity to specific gravity and/or oil density.
4. Work with different systems of units and convert one set to another.

Background Material

Lectures “Reservoir Fluid Study – Report” and “Reservoir Fluid Study – Lab Procedure” from our class notes (October 19 and 21 in Syllabus), and Chapter 10 pages 257 to 280 from McCain Reservoir Fluids book.

[Follow this link for additional information on PVT equipment](#)

Lab # 5 Tutorial Example

How to Process PVT Information from CCE, DL, and Separator Tests

The following example guides you on how to use and interpret the data from a CCE, a DL test and a separator test. The reservoir temperature is $T = 220^\circ\text{F}$ and the initial reservoir pressure is 2200 psia.

A recorded presentation with hints provides details on how to use the excel file. This tutorial presents the data obtained and the calculations with the data.

Compositional Information						
Component	Mol Weight	Pc (psia)	Tc (F)	Acentric Factor	moles	Zi
methane	16	667.4	-116.9	0.008	48.5	0.36283384
ethane	30	708.5	89.7	0.098	9.67	0.07234234
n-pentane	72.2	489.5	385.3	0.251	10	0.0748111
heptane +	285	206.6614756	966.9623896	0.79371142	65.5	0.49001272

Fig. 1—Compositional information allows users to enter the number of moles of each component.

Constant Composition Expansion (CCE) Results

Table 1 shows the CCE data with pressure steps of 100 psia, here the experiment ends at 1,600 psia .

The output table displays the liquid and vapor fraction, the compressibility factor, and the volumes of oil and gas at each pressure stage. From this table you can find the bubblepoint pressure graphically or numerically as indicated in class.

Table 1—Constant Composition Expansion Results

Pressure	f_o	f_g	z_o	z_g	V_o, cm^3	V_g, cm^3
2200.0	1.0000	0.0000	1.0951	0.0000	30.3196	0.0000
2100.0	1.0000	0.0000	1.0466	0.0000	30.3562	0.0000
1995.5	1.0000	0.0000	0.9958	0.8989	30.3952	0.0001
1800.0	0.9502	0.0498	0.9335	0.9013	30.0161	1.5177
1600.0	0.9012	0.0988	0.8640	0.9050	29.6407	3.4032

From **Table 1** we can see that the bubblepoint pressure for this mixture is between 2100 and 1800 psia. Refining the search provides $p_b = 1995$ psi, note that at this pressure the volume of gas obtained is very small.

Differential Liberation

This experiment begins at the bubblepoint pressure determined from the CCE. The oil sample is subject to a series of expansions as indicated in the lectures.

For this example the pressure steps are 500 psia, you can and will have to discuss the effect of the size of pressure decrements in the computed properties. One stage at 14.7 psia and reservoir temperature and another stage at 14.7 psia and 60°F are automatically added into the experiment.

Table 2 displays the differential liberation results for our example mixture. This output includes the fraction of liquid and vapor, the compressibility factor, and the volume of oil and gas at the specified pressure and temperature. This volume of gas is removed from the cell before the next expansion. Using data from this table you can compute R_{sd} , B_{od} , and B_g using the procedure explained in class.

Table 2—Differential Liberation results at T=220°F

Pressure, psi	f_o	f_g	z_o	z_g	V_o, cm^3	V_g, cm^3
1995.5	1.0000	0.0000	0.9958	0.8989	30.3952	0.0001
1500.0	0.8774	0.1226	0.8268	0.9075	29.4571	4.5187
1000.0	0.8720	0.1280	0.6135	0.9249	28.5852	6.3285
500.0	0.8634	0.1366	0.3449	0.9518	27.7497	12.1138
14.7	0.7850	0.2150	0.0122	0.9946	26.2210	585.2771
14.7 (at 60°F)	1.0000	0.0000	0.0154	0.0000	25.3069	0.0000

Separator Tests

The objectives of the separator tests are to optimize the amount of oil produced at the surface. You will conduct tests with one and two separators; your goal is to find the best pressure and temperature combinations (for one or multiple separators) that maximize liquid production. The stock tank, which acts as another separator at standard temperature and pressure, is included automatically in your computation.

The goal of the one-separator test is to find the separation pressure and temperature such that the solution gas oil ratio at the bubble point is a minimum, the API gravity of the oil at stock tank conditions is a maximum, and the formation volume factor at the bubblepoint (B_{osb}) is a minimum.

One Separator Test Results

Table 3 shows the PVT properties from the example mixture at its bubblepoint (computed earlier) and at a separator pressure and temperature of 150 psia and 100 °F. The standard state computation is added automatically.

Table 3—Single-Separator Test Results

p , psia	T , °F	f_o	f_g	z_o	z_g	V_o , cm ³	V_g , cm ³	ρ_o , lb/ft ³	ρ_o , lb/ft ³
1995.5	220	1.0000	0.0000	0.9958	0.8989	30.3952	0.0001	42.0204	5.4995
150	100	0.6069	0.3931	0.1306	0.9725	26.4932	127.8482	45.8975	0.4791
14.7	60	0.9328	0.0672	0.0145	0.9944	25.9637	128.5327	46.5212	0.0631

The corresponding PVT properties from the separator test are computed as follows

$$B_{osb} = \frac{30.3952 \text{ cm}^3}{25.9637 \text{ cm}^3} = 1.170 \frac{\text{bbl}}{\text{STO}} \quad (1)$$

The volume of gas from the separator **at standard conditions** is

$$V_{sc} = \frac{P_S V_S T_{sc}}{Z_S T_S P_{sc}} = \frac{150 \text{ psia } 127.8482 \text{ cm}^3 (60 + 460)^\circ\text{R}}{0.9725 (100 + 460)^\circ\text{R} \cdot 14.7 \text{ psia}} = 1245.64 \text{ cm}^3 \quad (2)$$

The solution-gas -oil -ratio of the separator is then

$$R_{sb} = \frac{1245.64 \text{ cm}^3 + 128.5327 \text{ cm}^3}{25.9637 \text{ cm}^3} \cdot 5.614 \frac{\text{SCF}}{\text{STO}} = 297.162 \frac{\text{SCF}}{\text{STO}} \quad (3)$$

$$\rho_o (T_{sc}, p_{sc}) = 46.52 \text{ lbm/ft}^3 \rightarrow \text{API} = \frac{141.5}{46.5212} - 131.5 = 58.29 \quad (4)$$

Two Separators

The objective here is the same as with one separator (obtain a maximum API gravity oil), but here you need to optimize the pressure and temperature of two separators . We use the output from one of these tests to illustrate the calculation procedure.

Table 4—Two-Separator Test Results

p , psia	T , °F	f_o	f_g	z_o	z_g	v_o , cm ³	v_g , cm ³	ρ_o , lb/ft ³	ρ_g , lb/ft ³
1995.5	220	1.0000	0.0000	0.9958	0.8989	30.3952	0.0001	42.0204	5.4995
500.0	100	0.7136	0.2864	0.3810	0.9219	27.2734	26.4860	45.2832	1.5931
100.0	80	0.8465	0.1535	0.0903	0.9770	26.3862	51.7565	46.1277	0.3457
14.7	60	0.9451	0.0549	0.0144	0.9935	26.0221	104.3192	46.5016	0.0677

In this example we chose Separator 1 at 500 psia and 100°F and Separator 2 at 100 psia and 80°F.

The PVT properties for this test are then:

$$B_{osb} = \frac{30.3952 \text{ cm}^3}{26.0221 \text{ cm}^3} = 1.168 \frac{\text{bbl}}{\text{STO}} \dots\dots\dots (5)$$

The volume of gas released from each separator **at standard conditions** is:

$$V_{sc1} = \frac{P_s V_s T_{sc}}{Z_s T_s P_{sc}} = \frac{500 \text{ psia } 26.4860 \text{ cm}^3 (60 + 460)^\circ\text{R}}{0.9219(100 + 460)^\circ\text{R} \quad 14.7 \text{ psia}} = 907.4 \text{ cm}^3 \dots\dots\dots (6)$$

$$V_{sc2} = \frac{P_s V_s T_{sc}}{Z_s T_s P_{sc}} = \frac{100 \text{ psia } 51.7565 \text{ cm}^3 (60 + 460)^\circ\text{R}}{0.9770(80 + 460)^\circ\text{R} \quad 14.7 \text{ psia}} = 347.02 \text{ cm}^3 \dots\dots\dots (7)$$

The total solution-gas –oil-ratio is the sum of all volumes of gas released in each stage divided the oil volume at standard conditions

$$R_{sb} = \frac{907.4 \text{ cm}^3 + 347.02 \text{ cm}^3 + 104.3192 \text{ cm}^3}{26.0221 \text{ cm}^3} 5.614 \frac{\text{scf}}{\text{STB}} = 293.13 \frac{\text{scf}}{\text{STB}} \dots (8)$$

The oil density and API gravity are

$$\rho_o(T_{sc}, p_{sc}) = 46.5016 \text{ lbm/ft}^3$$

$$API = \frac{141.5}{\frac{46.5016}{62.4}} - 131.5 = 58.37$$

In this case, we have lower solution-gas –oil-ratio, lower B_{osb} , and higher API gravity than in the previous case. Clearly, by adding a separation stage we will have a better oil quality and less gas production.

What happens if we don't have a separator and just produce directly to the tank?

Table 5—Test Results With No Separator

p , psia	T , °F	f_o	f_g	z_o	z_g	v_o , cm ³	v_g , cm ³	ρ_o , lb/ft ³	ρ_g , lb/ft ³
1995.5	220	1.0000	0.0000	0.9958	0.8989	30.3952	0.0001	42.0204	5.4995
14.7	60	0.5495	0.4505	0.0148	0.9958	25.7392	1421.4707	46.5814	0.0550

$$B_{osb} = \frac{30.3952 \text{ cm}^3}{25.7392 \text{ cm}^3} = 1.18 \frac{\text{bbl}}{\text{STB}} \dots (9)$$

$$R_{sb} = \frac{1421.4707 \text{ cm}^3}{25.7392 \text{ cm}^3} 5.614 \frac{\text{scf}}{\text{STB}} = 310 \frac{\text{scf}}{\text{STB}} \dots (10)$$

$$\rho_o(T_{sc}, p_{sc}) = 46.5814 \text{ lbm/ft}^3$$

$$API = \frac{141.5}{\frac{46.5814}{62.4}} - 131.5 = 58.05 \dots (11)$$

As expected, we got the highest B_{osb} and the highest solution-gas-oil-ratio.

Once you have read this tutorial you are ready to begin with the lab.

Lab # 5

Reservoir Fluid Report: Constant Composition Expansion (CCE), Differential Liberation (DL) and Separator Tests of a Live Oil Sample

Conduct a Reservoir Fluid Analysis for PETE 310 Oil Well (Great Oil Field). Compare the results obtained with the reservoir fluid analysis from Oil Well 4 from your text book and discuss the results obtained. The reservoir temperature is 235 °F and the initial reservoir pressure is 4500 psia.

Table A—Composition of Reservoir Fluid Sample

Super Aggie Well: PETE 310

Component	Composition mol%
Methane	38.12
Ethane	10.75
Propane	6.84
n-Butane	4.89
iso-Butane	1.96
n-Pentane	1.27
iso-pentane	2.93
n-Hexanes	1.96
C ₇ ⁺	31.28
M _w C ₇ ⁺	236.00
SG C ₇ ⁺	0.87

Procedure

After listening the recorded tutorial studying the background material and the example problem accompanying this lab download the PVTsimulator.xls file from our web site and begin the lab.

- Select the Data worksheet
- Select the components for the fluid sample given to you.
- Enter the number of moles of each component in the mixture and the molecular weight for the C₇⁺ fraction.

Constant Composition Expansion Tests (CCE)

This test will be used to determine the bubblepoint pressure and isothermal oil compressibilities for all pressures above the bubblepoint pressure.

- Select the CCE worksheet and set the temperature to the reservoir temperature (235°F).
- Type the pressure steps for the experiment. Start at 5,000 psia pressure. End the experiment at 1,200 psia.
- Copy your output table into an Excel file for analysis in your report.

Differential Liberation Tests (DL)

This test will be used to determine the oil and gas formation volume factors and solution-gas-oil ratios.

- Select the DL worksheet and set the temperature to the reservoir temperature (235°F).
- Start the experiment at the bubblepoint pressure you estimated from the CCE experiment. Select pressure steps of ~400 psia. End the experiment at 100 psia. The software will automatically add a stage at 14.7 psia and reservoir temperature and another at 14.7 psia and standard temperature.
- Copy the output into an Excel file for analysis.
- Repeat the DL experiment, but now choose pressure decrements of 100 psia.
- Copy the output tables to an Excel file for future analysis.

Separator Tests

The objective of the separator tests is to find a separator (s) pressure and temperature such that the amount of stock tank liquid is maximized. You will test the system with a single separator and next with two separators. Be sure to develop conclusions to address the relative advantages / and disadvantages of each.

One-Separator Test

- Select the Separator Test worksheet and start the test at the bubblepoint pressure that you estimated from the CCE experiment and reservoir temperature.
- Enter the desired pressure and temperature of the separator. An extra stage at standard conditions is added automatically.
- Copy the output table into an Excel file for future analysis.

The search for the best combination of separator pressure and temperature should be done systematically. You may find it convenient to test pressures at increments of 100 psia or so and

temperature at increments of 30 to 50°F. Please document the strategy followed to search for the best pressure and temperature.

Evaluate the pressure effect for a fixed separator **temperature** and the temperature effect for a fixed separator **pressure**. Discuss the observations you make.

You will have to provide plots similar to Fig. 10.5 from McCain.¹ (**similar**, you do not need to work with three different axes, two y-axis at a time is fine).

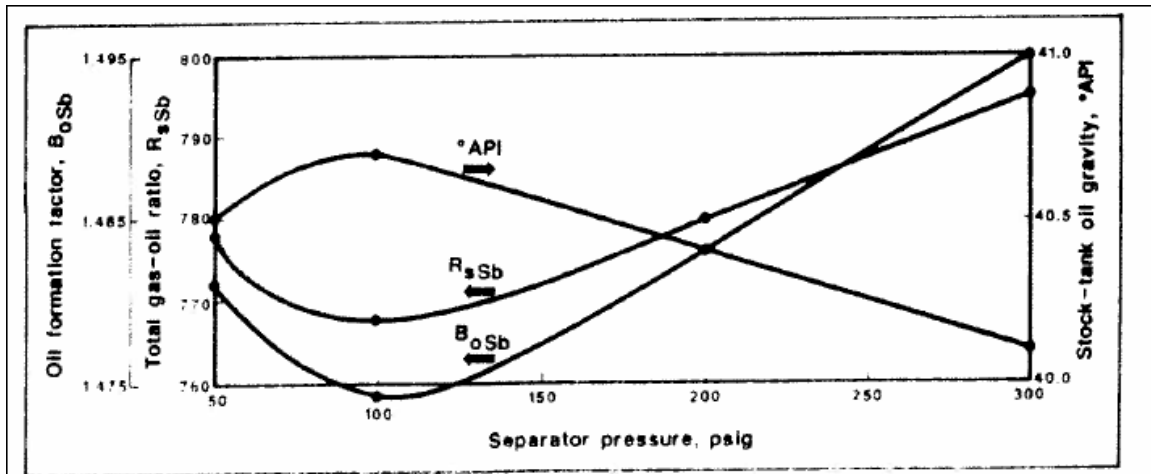


Fig. 10-5. Results of separator tests for Good Oil Co. No. 4 (part of solution to Example 10-4).

Two Separators

- Select the Separator Test worksheet.
- Start the test at the bubblepoint pressure that you estimated from the CCE experiment and reservoir temperature.
- Enter the pressure and temperature of each separator you want to use. An extra stage at standard conditions will be added automatically.
- Copy the output table into an Excel file for future analysis.

Constraints

- Separator 1 pressure should be higher than Separator 2 pressure.
- Separator 1 temperature should be higher than or equal to Separator 2 temperature, and both should be higher than or equal to the standard temperature (not lower).

Required Reporting

All required PVT properties will be properly documented either in graphical and tabular form or in both when specifically requested. Make sure to document all observations, problems, followed methodology, etc.

- From the CCE experiment plot (V_t/V_b) versus pressure and verify that the bubblepoint pressure is obtained from the intersection of two lines.
- Evaluate the oil compressibility for all pressures above the bubblepoint determined in the previous step.
- Evaluate the oil and gas formation volume factors and the solution-gas-oil-ratio versus pressure for the two DL experiments you've run using different pressure decrements (100 and 400 psia). Discuss the differences (if any) of these results, including the advantages and disadvantages of each procedure. Remember that the volume of gas reported in the DL worksheet is at the pressure and temperature specified, not at standard conditions
- Plot oil API gravity, solution-gas-oil-ratio and formation volume factor at the bubblepoint from the separator test for all the runs you made with one separator. Label your graphs properly.
- Plot oil API gravity, solution-gas-oil-ratio and formation volume factor at the bubblepoint from the separator test for all the runs you made with two separators. Label your graphs properly.
- Combine the results obtained from your best-case separator scenario with your results from the best DL run ($p = 100$ or 400 psia) and provide a table of adjusted reservoir engineering properties B_o and R_s versus pressure from all these combined tests. Use the adjusted reservoir properties indicated in the class notes.
- Calculate and plot B_{tD} versus pressure from

$$B_{tD} = B_{oD} + (R_{sDb} - R_{sD})B_g \cdot \dots\dots\dots$$