PETE 310

Lecture # 14

Wet Gas – Specific Gravity & Z-factor

(Chapter 7: pages 195-205)
Learning Objectives

- Calculate the specific gravity of a wet gas mixture, given producing GOR (at separator(s) and stock tank and:
  - compositions liquid and gas from stock tank and separator gas
  - or, separator compositions (gas & liquid)
  - or, properties of the separator gas and stock vent gas
- Define the two-phase z-factor and understand the uses of this in reservoir engineering
- Explain the shape of a typical two-phase z-factor isotherm.
- Calculate values of two-phase z-factor using Rayes et al. correlation (SPE paper).
Separators

\[ y_{iSP} \] and GOR (scf / STB)

Wellhead

\[ x_{iSP} \]

\[ y_{iST} \] and GOR (scf / STB)

\[ x_{iST} \]

\[
f_{v_{SP}} = \frac{(lb - mole_{gas})_{SP}}{(lb - mole_{gas} + lb - mole_{oil})_{SP}}
\]

\[
(lb - mole_{oil})_{SP} = (lb - mole_{gas} + lb - mole_{oil})_{ST}
\]

\[
f_{v_{ST}} = \frac{(lb - mole_{gas})_{ST}}{(lb - mole_{gas} + lb - mole_{oil})_{ST}}
\]
Key Points

- What matters is the **molar ratio** of gas to oil so let’s assume one barrel of oil produced

- **Methods to evaluate oil density** will be discussed in Chapter 11 (here it will be provided)

- **To convert °API to oil density**

\[
°API = \frac{141.5}{\gamma_o} - 131.5
\]

\[
\gamma_o = \frac{\rho_o}{\rho_w}
\]
Key Points

- The expression \([=]\) means “has the units of…” For example

\[ \rho_o \left[=\right] \frac{lb}{ft^3} \]

- You are responsible for reading the material that cannot be covered in this lecture

- Rework ALL the example problems in the book

- Procedure 1 - explained in detail here - is simpler and takes less time to solve than the method explained in the book
Recombination procedure when separator gas $y_{i_{SP}}$ and tock tank compositions $(x_{i_{STO}}, y_{i_{ST}})$ are known

(Procedure 1.)
Procedure 1.

- Calculate molecular weight of stock tank oil (STO also referred as STB)

\[ M_{wo} = \sum_{i=1}^{Nc} x_i M_{wi} \]

- Calculate lb-moles of separator gas produced per barrel of STO

\[ \frac{GOR_{SP}}{V_{m}^{id}} \left[ = \right] \frac{(scf/STB)}{(scf/lb - mole)} \left[ = \right] lb - mole_{gas}/STO \]

\[ V_{m}^{id} = 380.7 scf/lb - mole \text{ (ideal gas molar volume)} \]
Procedure 1.

- **Calculate lb-moles of stock gas vented per STO**

\[
\text{GOR}_{\text{ST}} = \frac{\text{scf/STB}}{\text{scf/lb - mole}} \left[= \right] \text{lb - mole}_{\text{gas}} / \text{STO}
\]

- **Calculate lb-moles of oil in 1 barrel of stock tank (need to use molar density)**

\[
\frac{\rho_{\text{oil}}}{M_{\text{wo}}} \left[=\right] \frac{\text{lb/ft}^3}{\text{lb/lb - mole}} \left[=\right] \frac{\text{lb - mole}_{\text{oil}}}{\text{ft}^3}
\]

\[
\frac{\text{lb - mole}_{\text{oil}}}{\text{ft}^3} \times 5.615 \frac{\text{ft}^3}{\text{bbl}} \left[=\right] \text{lb - mole}_{\text{oil}} / \text{STO}
\]
Procedure 1.

\[
f_{VSP} = \frac{(lb - mole_{gas})_{SP}}{(lb - mole_{gas} + lb - mole_{oil})_{SP}}
\]

\[
(lb - mole_{oil})_{SP} = (lb - mole_{gas} + lb - mole_{oil})_{ST}
\]

\[
f_{VST} = \frac{(lb - mole_{gas})_{ST}}{(lb - mole_{gas} + lb - mole_{oil})_{ST}}
\]
Procedure 1.

- **Determine reservoir gas composition from fundamental mole balance**

\[
\begin{align*}
  z_i &= y_{iSP} f_{v_{SP}} + x_{iSP} (1 - f_{v_{SP}}) \\
  x_{iSP} &= y_{iST} f_{v_{ST}} + x_{iST} (1 - f_{v_{ST}}) \\
  z_i &= y_{iSP} f_{v_{SP}} + \left[ y_{iST} f_{v_{ST}} + x_{iST} (1 - f_{v_{ST}}) \right] (1 - f_{v_{SP}})
\end{align*}
\]

- **Once reservoir composition is known determine z-factor and specific gravity**
Example for Procedure 1.

EXAMPLE 7–1: A wet gas produces through a separator at 300 psia and 73°F to a stock tank at 76°F. The separator produces 69,551 scf/STB and the stock tank vents 366 scf/STB. The stock-tank liquid gravity is 55.9°API. Compositions are given below. Calculate the composition of the reservoir gas.

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition, separator gas, mole fraction</th>
<th>Composition, stock-tank gas, mole fraction</th>
<th>Composition, stock-tank liquid, mole fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_1</td>
<td>0.8372</td>
<td>0.3190</td>
<td>0.0018</td>
</tr>
<tr>
<td>C_2</td>
<td>0.0960</td>
<td>0.1949</td>
<td>0.0063</td>
</tr>
<tr>
<td>C_3</td>
<td>0.0455</td>
<td>0.2532</td>
<td>0.0295</td>
</tr>
<tr>
<td>i-C_4</td>
<td>0.0060</td>
<td>0.0548</td>
<td>0.0177</td>
</tr>
<tr>
<td>n-C_4</td>
<td>0.0087</td>
<td>0.0909</td>
<td>0.0403</td>
</tr>
<tr>
<td>i-C_5</td>
<td>0.0028</td>
<td>0.0362</td>
<td>0.0417</td>
</tr>
<tr>
<td>n-C_5</td>
<td>0.0022</td>
<td>0.0303</td>
<td>0.0435</td>
</tr>
<tr>
<td>C_6</td>
<td>0.0014</td>
<td>0.0191</td>
<td>0.0999</td>
</tr>
<tr>
<td>C_7+</td>
<td>0.0002</td>
<td>0.0016</td>
<td>0.7193</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Properties of heptanes plus of the stock-tank liquid

Specific gravity 0.794
Molecular weight 113 lb/lb mole
Recombination procedure when separator gas $y_{i_{SP}}$ and liquid compositions $x_{i_{SP}}$ are known

(Procedure 2.)
Example for Procedure 2.

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition, separator gas, mole fraction</th>
<th>Composition, separator liquid, mole fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_1$</td>
<td>0.8372</td>
<td>0.0869</td>
</tr>
<tr>
<td>$C_2$</td>
<td>0.0960</td>
<td>0.0569</td>
</tr>
<tr>
<td>$C_3$</td>
<td>0.0455</td>
<td>0.0896</td>
</tr>
<tr>
<td>$i-C_4$</td>
<td>0.0060</td>
<td>0.0276</td>
</tr>
<tr>
<td>$n-C_4$</td>
<td>0.0087</td>
<td>0.0539</td>
</tr>
<tr>
<td>$i-C_5$</td>
<td>0.0028</td>
<td>0.0402</td>
</tr>
<tr>
<td>$n-C_5$</td>
<td>0.0022</td>
<td>0.0400</td>
</tr>
<tr>
<td>$C_6$</td>
<td>0.0014</td>
<td>0.0782</td>
</tr>
<tr>
<td>$C_7+$</td>
<td>0.0002</td>
<td>0.5267</td>
</tr>
<tr>
<td></td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Properties of heptanes plus of separator liquid:

- Specific gravity: 0.794
- Molecular weight: 113 lb/lb mole
Procedure 2.

\[ z_i = y_iSP f_{v_{SP}} + x_iSP \left(1 - f_{v_{SP}}\right) \]

- Additional information given is the separator/stock tank volume ratio as
  
  \[
  \frac{bbl \ SP \ oil \ at \ (T,P \ of \ separator)}{bbl \ STB \ (at \ standard \ conditions)}
  \]

- Use this to convert from scf/STO → scf/Separator Oil

- Proceed as in procedure 1.

- Rework example 7.2 in textbook
Recombination procedure when only separator gas and stock vent gas properties are known

(Procedure 3.)
Procedure 3.

- For two-stage separators

\[ \gamma_g = \frac{R_{SP} \gamma_{gSP} + R_{ST} \gamma_{gST}}{R_{SP} + R_{ST}} \]

\[ R = R_{SP} + R_{ST} \]

- For three-stage separators ... derive expressions
Procedure 3.

- Mass of one stock tank barrel

\[
m_R = \left( \frac{R \text{ scf}}{\text{STB}} \right) \left( 29 \gamma_e \text{ lb mole gas} \right) \left( \frac{\text{lb gas}}{\text{lb mole gas}} \right) \left( \frac{62.37 \gamma_o \text{ lb oil}}{\text{cu ft oil}} \right) \left( 5.615 \text{ cu ft oil} \right) ,
\]

\[
m_R = 0.0762R \gamma_e + 350.2 \gamma_o .
\]
Procedure 3.

Moles in one stock tank barrel

\[ n_R = \frac{R \frac{\text{scf}}{\text{STB}}}{380.7 \frac{\text{scf}}{\text{lb mole gas}}} + \frac{350.2 \gamma_o \frac{\text{lb oil}}{\text{STB}}}{M_o \frac{\text{lb oil}}{\text{lb mole oil}}} \]

\[ n_R = 0.00263R + 350.2\gamma_o/M_o . \quad (7-6) \]
Procedure 3.

- And the gas gravity at reservoir conditions is

\[
\gamma_{gR} = \frac{R \gamma_g + 4,600 \gamma_o}{R + 133,300 \gamma_o / M_o}
\]

- An approximation for \( M_o \) (when not given is)

\[
M_o = \frac{5,954}{\text{API} - 8.8} = \frac{42.43 \gamma_{STO}}{1.008 - \gamma_{STO}}
\]
Once Gas Specific Gravity is Known

- Evaluate Tpc and Ppc (previous paper using K and J and including corrections for impurities N₂, CO₂, H₂S)
- If dew-point pressure is not known
  - Use dry-gas z-factor when C7+ < 4%
  - Or when wellstream gravity < 0.911
- If p_d is known
  - if reservoir p is lower than p_d evaluate z-2phase using equation from SPE 20055 paper
  - If reservoir p is greater than p_d, evaluate z as for a dry gas (single-phase)
Correlation of Specific Gravities for a wet gas

\[ z_{2p} = A_0 + A_1(p_r) + A_2 \left( \frac{1}{T_r} \right) + A_3(p_r)^2 + A_4 \left( \frac{1}{T_r} \right)^2 + A_5 \left( \frac{p_r}{T_r} \right), \]

................................. (5)

for 0.7 \leq p_r \leq 20.0 and 1.1 \leq T_r \leq 2.1, where \( A_0 = 2.24353, A_1 = -0.0375281, A_2 = -3.56539, A_3 = 0.000829231, A_4 = 1.53428, \) and \( A_5 = 0.131987. \)

READ - SPE 20055
# Ranges of Compositions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_2S$</td>
<td>0.99</td>
<td>0.00</td>
<td>28.16</td>
</tr>
<tr>
<td>$CO_2$</td>
<td>2.54</td>
<td>0.00</td>
<td>63.52</td>
</tr>
<tr>
<td>$N_2$</td>
<td>1.84</td>
<td>0.01</td>
<td>12.74</td>
</tr>
<tr>
<td>$C_1$</td>
<td>73.23</td>
<td>19.37</td>
<td>94.20</td>
</tr>
<tr>
<td>$C_2$</td>
<td>7.58</td>
<td>1.95</td>
<td>16.66</td>
</tr>
<tr>
<td>$C_3$</td>
<td>3.94</td>
<td>0.62</td>
<td>12.27</td>
</tr>
<tr>
<td>i$C_4$</td>
<td>0.85</td>
<td>0.18</td>
<td>2.53</td>
</tr>
<tr>
<td>n$C_4$</td>
<td>1.48</td>
<td>0.25</td>
<td>5.02</td>
</tr>
<tr>
<td>i$C_5$</td>
<td>0.61</td>
<td>0.12</td>
<td>1.62</td>
</tr>
<tr>
<td>n$C_5$</td>
<td>0.63</td>
<td>0.08</td>
<td>2.09</td>
</tr>
<tr>
<td>$C_6$</td>
<td>0.85</td>
<td>0.14</td>
<td>2.04</td>
</tr>
<tr>
<td>$C_7+$</td>
<td>5.40</td>
<td>0.85</td>
<td>12.68</td>
</tr>
<tr>
<td>Molecular weight of $C_7+$</td>
<td>154.0</td>
<td>108.0</td>
<td>253.0</td>
</tr>
<tr>
<td>Specific gravity of $C_7+$</td>
<td>0.794</td>
<td>0.736</td>
<td>0.850</td>
</tr>
<tr>
<td>$\gamma_g(air = 1)$</td>
<td>1.018</td>
<td>0.644</td>
<td>1.557</td>
</tr>
<tr>
<td>$z_d$</td>
<td>1.048</td>
<td>0.704</td>
<td>1.775</td>
</tr>
<tr>
<td>$p_d$, psia</td>
<td>5,240.0</td>
<td>1,930.0</td>
<td>11,844.0</td>
</tr>
<tr>
<td>$T$, °F</td>
<td>239.0</td>
<td>94.0</td>
<td>325.0</td>
</tr>
</tbody>
</table>
Single vs Two-phase z-factor

p/z-2phase vs z-2phase

- z-gas (one phase)
- z-2phases

Pressure (psia)

z,z-2phase vs z-2phase

0.6

0.8

1.0

1.2
Applications Material Balance

- Estimate of original gas in place (OGIP)
Volumetric Calculations

Oil in place = \( N \)

\[
N = \frac{Area \times h_{net} \times \phi \times (1 - S_w)}{B_o}
\]

\[
\text{[STB]} = \text{Conversion factor} \times L^3 \times \frac{STB}{bbl}
\]
Generalized Material Balance Equation

**GENERAL MATERIAL BALANCE EQUATION (GMBE)**

- Approximates reservoir as a tank with given boundaries and uniform T and P.
- MB Calculation is a very gross approximation of the reservoir performance, but one that is very useful in practice.
Stirred Tank – Diffusive Process in Reservoir Simulation

Fig. 2.1—A well-stirred tank analog of a simulator grid system.
Conventional Material Balance Assumptions

- There are 2 hydrocarbon components: stock-tank oil and surface-gas.
- The surface gas can dissolve into both the reservoir oil- and gas- phases (accounted for by $R_s$).
- The stock-tank oil (also called surface oil) cannot be volatilized into the gas phase.
Dry gas reservoirs - Material balance methods

- Volumetric reservoirs
- Non-Volumetric reservoirs

\[ PV = znRT \]

- Pore volume filled with gas
Volumetric gas material balance

Moles of gas

\[ n_1 = \frac{PV}{z_1RT} \quad \text{V = X} \]

\[ n_2 = \frac{PV}{z_2RT} \quad \text{V = X} \]

Original pressure at reservoir temperature

New pressure at reservoir temperature

Time 1

Time 2
A Simple Mass Balance

Mass Balance: \( M_E - M_B = \Sigma M_I - \Sigma M_P \)

On a volumetric basis

\( V_E - V_B = V_I - V_P \)
Volumetric gas material balance

Moles of gas produced = \( n_1 - n_2 \)

380.7 scf per lb mol of gas in Texas (@60 deg F and 14.65 psia)

Volume of gas produced = 380.7*(\( n_1 - n_2 \)) scf
$P/z$ plot  Volumetric reservoir graphic interpretation

$$\frac{p}{z} = \frac{p_i}{z_i} \left(1 - \frac{G_p}{G}\right)$$

$P/z$ @original pressure

$G_p = G @ P=0$
Estimates of Gas in Place: Use the two-phase Z-factor