Reservoir Fluid Properties

State of the Art and Outlook for Future Development

Dr. Muhammad Al-Marhoun
King Fahd University of Petroleum & Minerals
Dhahran, Saudi Arabia
E-mail: marhounm@kfupm.edu.sa
Outline

- Introduction
- State of the Art
- Determination of PVT properties
- Problems related to PVT
  - Experimentation & Calculations
  - Data smoothing & Correlations
- Artificial neural networks
- PVT Reporting
- Conclusions
Introduction

Fluid Properties
The study of the behavior of vapor and liquid in petroleum reservoirs as a function of pressure, volume, temperature, and composition

Importance of PVT Properties
- Determination of hydrocarbon reserves
- Reservoir and simulation studies
- Design of production facilities
State of the Art

- Graphical correlations are reduced to equations
- Correlations have been improved
- Fluid classification in reservoirs is defined
- Laboratory analyses have been standardized
- Chemical analyses of petroleum are made available
- EOS is utilized to calculate gas-liquid equilibria
Determination of PVT properties

- Laboratory measurements using:
  - Bottom hole sample
  - Recombined surface sample
- Equation of state with appropriate calibrations
- Empirical correlations with appropriate range of application
- Artificial neural networks models
Problems related to experimentation

- Reservoir process presentation
- Physical trends of lab data
Reservoir process presentation

- Lab tests do not duplicate reservoir process

- Petroleum engineers consider liberation process in reservoir approaches differential

- Liberation process around well is considered flash

- Actual process is neither flash nor differential

- A combination test may be closest to the reservoir process
Phase transition in oil reservoir

Zone A: above $p_b$
Zone B: below $p_b$, flash
Zone C: differential

Well
Separator
Reservoir

Oil
Gas
Typical trends of good lab data

- Good experimental P-V data should follow physical trend.
  - Volume decreases with P
  - $C_{o}$ decreases with P
  - $dC_{o}/dp$ decreases with P
Abnormal $C_o$ trend

$C_o$ should decrease with pressure
Abnormal $C_0$ derivative trend

- $dC_0/dp$ should decrease with pressure
Problems related to calculations

Adjustment of differential data as an example
Adjustment of differential data to separator conditions - Why?

- $R_s$ and $B_o$ obtained by differential liberation are not the same as $R_s$ and $B_o$ obtained by flash liberation.

- Oil leaving reservoir is flashed to separator, therefore $R_s$ and $B_o$ should be determined by a flash process.

- Flash liberation does not cover whole range of interest, therefore differential data are corrected.
At lower pressure formation volume factor, $B_o$ might read a value less than 1.
At lower pressure, the solution gas-oil ratio, $R_s$, extrapolates to negative values.
Current adjustment method-Properties

Current adjustment method does not honor density at bubble point under reservoir conditions.

The same crude under the same reservoir conditions, but different densities.

\[
\gamma_{ob} = \frac{\gamma_o + 2.18 \times 10^{-4} R_s \gamma_g}{B_{ob}}
\]

<table>
<thead>
<tr>
<th>Property</th>
<th>Adjusted Differential</th>
<th>Flash Liberation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B_{ob})</td>
<td>1.289</td>
<td>1.289</td>
</tr>
<tr>
<td>(R_s)</td>
<td>526</td>
<td>526</td>
</tr>
<tr>
<td>(\gamma_g)</td>
<td>0.9336</td>
<td>0.8024</td>
</tr>
<tr>
<td>(\gamma_o)</td>
<td>0.8448</td>
<td>0.8343</td>
</tr>
<tr>
<td>(\gamma_{ob})</td>
<td>0.738444</td>
<td>0.7186265</td>
</tr>
</tbody>
</table>
Adjustment methods of oil FVF

- Current Adjustment of $B_o$

\[ B_o = B_{od} \cdot \frac{B_{obf}}{B_{obd}} \]

- Suggested Adjustment

\[ B_o = B_{obf} + c \left( B_{odn} - B_{obf} \right) \]

\[ c = \frac{(B_{obd} - B_{od})}{(B_{obd} - B_{odn})} \]
Adjustment methods of solution GOR

- Current Adjustment of $R_s$

$$R_s = R_{sbf} - (R_{sbd} - R_{sd}) \left( \frac{B_{obf}}{B_{obd}} \right)$$

- Suggested Adjustment

$$R_s = R_{sd} \left( \frac{R_{sbf}}{R_{sbd}} \right)$$
Adjustment methods of gas relative density

- **Current Adjustment of** $\gamma_g$

  \[ \gamma_g = \gamma_{gd} \]

- **Suggested Adjustment**

  \[ \gamma_g = \gamma_{gf} + d (\gamma_{gd_{n-1}} - \gamma_{gf}) \]

  \[ d = (\gamma_{gd_1} - \gamma_{gd}) / (\gamma_{gd_1} - \gamma_{gd_{n-1}}) \]
Gas relative density

<table>
<thead>
<tr>
<th>Pressure, psia</th>
<th>Gas relative density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.8</td>
</tr>
<tr>
<td>500</td>
<td>1.6</td>
</tr>
<tr>
<td>1000</td>
<td>1.4</td>
</tr>
<tr>
<td>1500</td>
<td>1.2</td>
</tr>
<tr>
<td>2000</td>
<td>1.0</td>
</tr>
<tr>
<td>2500</td>
<td>0.8</td>
</tr>
</tbody>
</table>

- **Differential**
- **Current**
- **Suggested**
Adjustment methods of oil relative density

- Current Adjustment of $\gamma_o$

$$\gamma_o = \gamma_{od}$$

- Suggested Adjustment

$$\gamma_o = \gamma_{of} + c(\gamma_{od} - \gamma_{of})$$
Live oil relative density

\[ \gamma_{or} = \frac{\gamma_o + 2.18 \times 10^{-4} R_s \gamma_g}{B_o} \]

- Differential
- Current
- Suggested
Problems related to Smoothing experimental data

Smoothing relative total volume data as an example
Smoothing relative total volume data

- To obtain P-V data, conduct a flash liberation experiment on a gas-oil mixture at a constant temperature
- Data analysis defines
  - volume & pressure at bubble point
  - FVF above $p_b$ & total FVF below $p_b$
- The experimental data as reported are accompanied by measurement errors. Therefore, the data are usually smoothed
Y-function properties

- Only the experimental data at pressures below $p_b$ are utilized to obtain $p_b$
- Bubble point volume is not corrected
- Y-Correlation with an error in the bubble point volume may yield a straight line but with the wrong $p_b$
Y–Function plot

- Volume
- Curve 1
- Curve 2
- Y-fun value
- YF

Graph showing the relationship between Total Relative Volume and Pressure.
Smoothing relative total volume data

- **Current**

\[
y = \frac{(p_b - p)}{p} = \frac{(v_t - v_b) / v_b}{a_1 + a_2 p}
\]

- **Suggested: add x-function beside y-function**

\[
x = \frac{(v_b - v_o)}{v_b} = \frac{(p - p_b)}{v_b} = a_3 + a_4 p
\]
X-Y Function plot

<table>
<thead>
<tr>
<th></th>
<th>YF</th>
<th>1944.5</th>
<th>1.2637</th>
</tr>
</thead>
<tbody>
<tr>
<td>XY</td>
<td>2014.2</td>
<td>1.262208</td>
<td></td>
</tr>
</tbody>
</table>

**Total Relative Volume**

**Pressure**

- **volume**
- **curve-1**
- **curve-2**
- **XY-Curve**
- **XY**
Problems related to correlations

- Correlation application
- Properties of correlations
- Physical trends of correlations
- Pitfalls of least square method
Correlation application

Correlations normally used to determine:

- Bubble-point pressure, \( P_b \)
- Solution gas-oil ratios, \( R_s \)
- Density of liquids
- Oil FVF, \( B_{ob} \) & total FVF, \( B_t \)
- Adjustment of \( B_{ob} \) and \( R_s \)
- Oil compressibility, \( C_o \)
- Oil viscosity, \( \mu_o, \mu_a, \mu_l \)
- Interfacial tension, \( \sigma \)
Properties of correlations

- Correlations typically match employed experimental data, with deviations less than a few percent.
- When applied to other fluids, a much higher deviations are observed.
- If fluids fall within the range of tested fluids, an acceptable accuracy can be expected.
- Fluid composition could not be explained by gross properties.
- Errors in some PVT correlations are not acceptable.
Physical trends of correlations

Trend tests are to check whether the performance of correlation follows physical behavior or not:

- Trend tests on predicted values
- Trend tests on errors
Correlation with two equations

- Modeling physical properties with two equations might produce non-physical trend
Correlation with non-physical constraint

- Restriction of correlation model gives non-physical trend

![Graph showing Gas Relative Density vs Oil FVF with lines for Standing, Marhoun, and Vazquez & Beggs models.](image)
Correlation with limited data

- Correlation development for limited data will give a good fit, but might lead to non-physical trend.
Trend Tests on Error: Effect of API On $B_{ob}$
Trend Tests on Error: Effect of GRD On $B_{ob}$

Gas Relative Density (Air=1.0)

- 0.525 - 0.7 (23)
- 0.7 - 0.75 (25)
- 0.75 - 0.8 (24)
- 0.8 - 0.85 (24)
- 0.85 - 0.9 (22)
- 0.9 - 1.0 (27)
- 1.0 - 1.25 (30)
- 1.25 - 1.7 (21)

Error in $B_{ob}$

- Vazquez & Beggs
- Standing
- Marhoun
Pitfalls of least square method

Used to estimate the regression coefficients in model

\[ y = f(x) \]

- Basic assumption of LSM is the independent variable \( x \) is determinate, i.e. it has no error.
- But \( x \) and \( y \) involve measurement errors, therefore.
- Do not rely entirely on a method when its basic assumption is violated.
Comparison of the “Best fit line”

- Min y-error LSM
- Min x & y-error

Graph showing data points and two lines representing different error minimization methods.
Pitfalls of logarithmic equivalence

logarithmic equivalent used to linearize equations

- Given the problem \( y = kx^n \)
- Use the logarithmic equivalent

\[
\log y = \log k + n \log x
\]

- Apply LSM to minimize error
- Compare errors \( \Sigma \delta^2 \)

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>8.0</td>
</tr>
<tr>
<td>3</td>
<td>19.0</td>
</tr>
<tr>
<td>4</td>
<td>50.0</td>
</tr>
</tbody>
</table>
Comparative error analysis

Error using logarithmic equivalent

\[
\delta = \log y(\text{estimated}) - \log y(\text{given})
\]

Error using original values

\[
\delta = y(\text{estimated}) - y(\text{given})
\]

<table>
<thead>
<tr>
<th>Method</th>
<th>(k)</th>
<th>(n)</th>
<th>(\Sigma \delta^2) (logarithmic equivalent)</th>
<th>(\Sigma \delta^2) (original problem)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSM</td>
<td>2.224</td>
<td>2.096</td>
<td>0.02098</td>
<td>100.2</td>
</tr>
<tr>
<td>Iterative</td>
<td>0.474</td>
<td>3.36</td>
<td>0.56838</td>
<td>13.9</td>
</tr>
</tbody>
</table>
Artificial neural networks

- Definition
- Advantages
- Problems & Challenges
Artificial neural networks

A mathematical model that can acquire artificial intelligence. It resembles brain in two respects by

- Acquiring knowledge through learning process
- Storing knowledge through assigning inter-neuron connection strengths known as weights
Neural network architecture
ANN Advantages

- Model function does not have to be known
- ANN learns behavior by self-tuning its parameters
- ANN has the ability to discover patterns
- ANN is fast-responding systems and provides a confident prediction
- ANN can accept more input to improve accuracy; such continuous enrichment or “knowledge” leads to more accurate predictive model
ANN Problems & Challenges

- Design of ANN:
  - Number of hidden layers
  - Number of neurons in each hidden layer
  - Learning constant to control speed of training
ANN Problems & Challenges

- Generalization Vs. Over Fitting
  - New training algorithms (cross validation)
  - Hybrid systems (expert systems)
  - Number of adjustable weights is large which is not justified unless the PVT data is huge

- Is the neural network the ultimate solution?
PVT Reporting

- Typical PVT report
- PVT report shortcoming
- Suggested improvement
Typical PVT Report

- Sampling information
- Hydrocarbon analysis of reservoir fluid
- Oil compressibility
- Pressure volume relationship (smoothed data)
- Differential liberation
- Separator tests
- Hydrocarbon analysis of lab flashed gases
- Liquid and gas viscosity data
- Mixture density
PVT Report - Shortcoming

- Reports smoothed results only
- Does not include raw data
- Does not verify data consistency
PVT Report - Suggested improvement

- **Raw data reporting**
  - Pressure volume (experimental data)
  - Differential liberation (experimental data)
  - Viscosity (experimental data)

- **Data consistency**
  - Mixture density calculation & verification
  - $C_0$ calculation & verification
Conclusions

More improvement in the following areas:

- **Problems related to experimentation**
  - Reservoir process presentation
  - Physical trends of lab data

- **Problems related to calculations**
  - Adjustment of differential data

- **Problems related to data smoothing**
  - Y-function
  - XY-function
Conclusions

• Problems related to correlations
  - Physical trends of correlations
  - Pitfalls of least square method

• Artificial neural networks
  - Design of ANN
  - Over Fitting

• PVT Reporting
  - Raw data reporting
  - Data consistency
Final Comment

There are challenges in addressing these problems, but there are untapped scientific tools as well.

We explored these challenges and examined possible solutions.
Thank You