Reservoir Fluid Properties

State of the Art and Outlook for Future Development

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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
Typical trends of good lab data

- Good experimental P-V data should follow physical trend.
  - Volume decreases with P
  - \( C_o \) decreases with P
  - \( -\frac{dC_o}{dp} \) decreases with P
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.
Adjustment methods of oil FVF

- **Current Adjustment of** $B_o$

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

- **Suggested Adjustment**

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

  \[ c = \frac{B_{obd} - B_{od}}{(B_{obd} - B_{odn})} \]
At lower pressure formation volume factor, $B_o$ might read a value less than 1.
Adjustment methods of solution GOR

- **Current Adjustment of** \( R_s \)

\[
R_s = R_{sbf} - (R_{sbd} - R_{sd}) \frac{B_{obf}}{B_{obd}}
\]

- **Suggested Adjustment**

\[
R_s = R_{sd} \left( \frac{R_{sbf}}{R_{sbd}} \right)
\]
At lower pressure, the solution gas-oil ratio, $R_s$, extrapolates to negative values.
Problems related to Smoothing experimental data

Smoothing relative total volume data as an example
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 (pink dots)
- Curve 1 (yellow line)
- Curve 2 (blue line)
- Y-fun value (red line)
- YF (orange dot)

Y–Function plot

Pressure vs. Total Relative Volume

Values:
- Pressure: 0, 1000, 2000, 3000, 4000, 5000
- Total Relative Volume: 0, 1, 2, 3, 4, 5, 6
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 deviation 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

\[ \gamma_{\text{api}} / \gamma_{g} \]
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 $B_{ob}$

![Graph showing the effect of API on $B_{ob}$ error](image)

- **Standing**
- **Vazquez & Beggs**
- **Marhoun**

**Oil API Gravity**

- 11.4<API<22 (23)
- 22<API<30 (39)
- 30<API<35 (26)
- 35<API<40 (56)
- 40<API<45 (33)
- 45<API<59.2 (20)

**Error in Bo**

- 0
- 5
- 10
- 15
- 20
- 25
- 30
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”

Property

Min y-error LSM

Min x & y-error
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 $\sum \delta^2$

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<thead>
<tr>
<th>$x$</th>
<th>$y$</th>
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<tbody>
<tr>
<td>1</td>
<td>2.5</td>
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<tr>
<td>2</td>
<td>8.0</td>
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<tr>
<td>3</td>
<td>19.0</td>
</tr>
<tr>
<td>4</td>
<td>50.0</td>
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</tbody>
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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>
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</thead>
<tbody>
<tr>
<td>LSM</td>
<td>2.224</td>
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<td>Iterative</td>
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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.