SPE 63085

Compositional Grading

*Theory and Practice*

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“Theory”

Simple 1D Gradient Models

- Isothermal Gravity/Chemical Equilibrium
  - Defining General Characteristics
    - Different Fluid Systems (SPE 28000)
    - Quantifying Variations

- Non-Isothermal Models with Thermal Diffusion.
  - Quantitative Comparisons
    - Different Models
    - Different Fluid Systems
“Practice”

- Using Samples
- Quantifying Uncertainties
  ... Develop a Consistent EOS Model
- Defining Trends
- Fluid Communication
- Initializing Reservoir Models
- Predicting a Gas-Oil Contact
- History Matching
Isothermal Gradient Model

- Balance of chemical and gravity potentials

- Given ... \( \{ H_{\text{ref}} , p_{R\text{ref}} , T_{\text{ref}} , z_{i\text{ref}} \} \) ... calculate
  
  - \( z_i(H) \)
  - \( p_R(H) \)
  - \( p_{\text{sat}}(H) \)

- \( \text{IOIP}(H) \sim z_{C7+}(H) \)
Isothermal Gradient Model

C\textsubscript{7+}, mole fraction

Depth, m

Pressure, bara

Reference
Sample
Reservoir Pressure
Saturation Pressure
$\text{IOIP}(H) \sim z_{C_7^+}(H)$

![Graph showing the relationship between depth and $C_7^+$ concentration.](image-url)
Non-Isothermal Gradient Models

- Component Net Flux = Zero
  - Chemical Energy
  - Gravity
  - Thermal Diffusion ???

- Given … \{ H_{\text{ref}}, p_{R\text{ref}}, T_{\text{ref}}, z_{\text{iref}} \} … calculate
  - \( z_i(H) \)
  - \( p_R(H) \)
  - \( p_{\text{sat}}(H) \)
  - \( T(H) \)
Non-Isothermal Gradients

Thermal Diffusion Models

- Thermodynamic
  - Haase
  - Kempers

- Thermodynamic / Viscosity
  - Dougherty-Drickhamer (Belery-da Silva)
  - Firoozabadi-Ghorayeb

- “Passive”
  - Thermal Diffusion = 0 , $\nabla T \neq 0$
Ekofisk Example

![Diagram showing depth vs. C7+ mole percent for various models: Isothermal GCE, Haase, Kempers, Belery, da Silva (25%), and Firoozabadi-Ghorayeb.](image-url)
Cupiagua

Reference Depth
Isothermal Model
GOC
Field-Data Based Initialization

Pressure, psia
Depth, ft SSL

4000 5000 6000 7000
-15000
-14000
-13000
-12000
-11000
-10000
-9000
-8000
-7000
-6000
-5000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
6000
7000
Cupiagua

- Reference Depth
- GOC
- Field-Data Based Initialization
- Isothermal Model

Depth, ft SSL

C7+ Mole Percent

10 15 20 25 30 35

-15000 -14000 -13000 -12000 -11000
Theory – Summary

• Isothermal model gives maximum gradient

• Convection tends to eliminate gradients

• Non-isothermal models generally give a gradient between these two extremes
Complicating Factors when traditional 1D models are inadequate

- Thermally-induced convection
- Stationary State not yet reached
- Dynamic aquifer depletes light components
- Asphaltene precipitation
- Varying PNA distribution of C$_{7+}$ components
- Biodegradation
- Regional methane concentration gradients
- Multiple source rocks
“Practice”

- Using Samples
- Quantifying Uncertainties
  ... Develop a Consistent EOS Model
- Defining Trends
- Fluid Communication
- Initializing Reservoir Models
- History Matching
Using Samples

- Plot $C_{7+}$ mol-% versus depth

- $z_{C7+} \sim 1/B_0 = \text{OGR}/B_{gd}$ – i.e. $IOIP = f(\text{depth})$

Quantifying Uncertainty

- Use error bars for depth & composition

  - $\Delta C_{7+} \approx \Delta \text{OGR} / (C_0 + \Delta \text{OGR})$

  - $C_0 = (M/\rho)_{7+} (p_{sc}/RT_{sc})$
Develop a Consistent EOS

- Use All Available Samples with
  - Reliable Compositions
  - Reliable PVT Data

- Fit Key PVT and Compositional Data
  - Reservoir Densities
  - Surface GORs, FVF, STO Densities
  - CVD Gas C_{7+} Composition vs Pressure
  - Reservoir Equilibrium Phase Compositions
Defining Trends

Use All Samples Available

- Sample Exploration Wells
  - Separator Samples
  - Bottomhole Samples
  - MDT Samples (water-based mud only)
    - Oil Samples may be Corrected
    - Gas Samples with Oil-Based Mud should not be used
Defining Trends

Use All Samples Available

- Production Wells
  - “Early” Data not yet affected by
    - Significant Depletion
    - Gas Breakthrough
    - Fluid Displacement / Movement
Defining Trends

• Any sample's “value” in establishing a trend is automatically defined by inclusion of the samples error bars in depth and composition.

• Samples considered more insitu-representative are given more "weight" in trend analysis.
Fluid Communication

- Compute isothermal gradient for each and every sample

- Overlay all samples with their predicted gradients
  - Don’t expect complete consistency
  - Do the gradient predictions have similar shape?
  - Do the gradient predictions cover similar range in C_{7+}?
Åsgard, Smørbukk Field
Geologic Layer “A”
Orocual Field
Venezuela

![Diagram showing mid-perforation depth vs. C7+ mole percent for Structurally High Wells in Orocual Field, Venezuela.]
Initializing Reservoir Models

• Linear interpolation between “select” samples
  – Guarantees Automatic “History Matching”
  – Check for consistent of $p_{sat}$ vs depth

• Extrapolation
  – Sensitivity 1: isothermal gradient of outermost samples
  – Sensitivity 2: constant composition of outermost samples
Åsgard, Smørbukk Field

Geologic Layer “A”

Well A DST 1
Well A DST 2
Well B
Well C
Well D
Well E
Åsgard, Smørbukk Field

Geologic Layer “A”
Predicting a Gas-Oil Contact

... “Dangerous” but Necessary

- Use Isothermal Gradient Model
  - Predicts minimum distance to GOC
- Most Uncertain Prediction using Gas Samples
  - 10 – 50 m oil column per bar uncertainty in dewpoint!
  - 2 – 10 ft oil column per psi uncertainty in dewpoint!

... Treat dewpoints (and bubblepoints) with special care