New Frontiers in Modeling Unconventional Reservoirs

Overview
Overview:

● Orientation:
  ■ Major challenges in modeling of unconventional reservoirs.
  ■ Emerging and peripheral trends in modeling.
  ■ Phase behavior aspects of unconventional reservoirs.
  ■ "Grand challenges" in the modeling of unconventional reservoirs.
  ■ Basic/advanced flow concepts in unconventional reservoir systems.

● How Small is Small?: *(nano-scale pores)*
  ■ "Conventional" Petrophysics Concepts.
  ■ Nelson Pore Size/Molecule Size Chart.
  ■ Continuum vs. Molecular (Knudsen Number).

● The Modeling Stuff:
  ■ The flow physics ("proxy" permeability?).
  ■ Orientation — *Horizontal Multi-Fracture Well (HMFW)* Model.
  ■ Perspectives of others.

● Almost done…
  ■ The "it-rhymes-with-itch" list...
  ■ What Keeps Us (Reservoir Engineers) Up at Night.

● Summary
New Frontiers in Modeling Unconventional Reservoirs

Orientation
Orientation: **Points of Focus**

- Major challenges in modeling of unconventional reservoirs.
- Emerging and peripheral trends in modeling.
- Phase behavior aspects of unconventional reservoirs.
- "Grand challenges" in the modeling of unconventionals.
- Basic/advanced flow concepts in unconventional reservoir systems.

Orientation: **Major Challenges in Modeling**

- **[Fracture]** The nature and orientation of shear-mode fractures (3D).
- **[Fracture]** Placement/settling of the proppant in the fractures (3D).
- **[Fracture]** Stress shadowing and impact of previous fracture stages.
- **[Fracture]** Hysteretic closure of the hydraulic fractures (3D).
- **[General]** Nonlinearities require extreme gridding/small time-steps.
- **[General]** Key drivers affecting performance and development.
- **[General]** Model calibration — requires data which may not exist.
- **[General]** Each play is different, cannot "transpose" model(s).

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Orientation: **Emerging and peripheral trends in modeling**

- Modeling geomechanical effects.
- Fully unstructured gridding for modeling fractures and visualization.
- Recognize limitations in mechanistic/deterministic models.
- Integration of fracture propagation modeling with reservoir modeling.
- Model conditioning: faults, fractures, microseismic, DPS/DTS, PLTs.
- Surrogates (e.g., dual porosity) versus true model (e.g., DFN systems).

Orientation: **Phase behavior of unconventional reservoirs**

- **Undersaturated oil**, $p_b$ suppression (nano-pore volumes/distributions).
- **Volatile oil/critical fluid**, nano-volume effects less an issue ($IFT/p_c$).
- **Gas condensates** — composition issues/variations in $p_{Crit}$ and $T_{Crit}$.
- Need molecular dynamics work to resolve/validate PVT in nano-pores.

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**Phase diagrams of confined and unconfined heavy gas condensate mixture (Pedersen et al, 1989).**

(vertical red line is the reservoir temperature)

**The percentage of liquid drop out (% by volume) of a heavy gas condensate mixture (Pedersen et al, 1989) at 400°F.**

(400°F is reservoir temperature — see plot at left)

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Orientation: Grand challenges — modeling unconventional

- Fully integrated (not coupled) geomechanical/flow simulation model.
- Models may not be properly "parameterized" — no data to validate.
- Statistical versus deterministic models (system is "too complex").
- Use models to establish/validate/bound drainage volumes.
- Use models to constrain assumptions about geomechanics/fluid flow.

Pressure gradient after 8 months (top) and 10 years (bottom) of production (Note times for different regimes, this is a relatively high permeability shale analog case).

Typical transient response where PSS is seen in the SRV (Note times for different regimes, this is a relatively high permeability shale analog case).

From: KAPPA Consortium on Unconventional Resources (Draft project document) 7th February 2011 (www.kappaeng.com).
Orientation: *Basic and advanced flow concepts*

- Bottleneck from basic flow phenomena to reservoir-scale models.
- Flow in ultra-low permeability media involves very sharp transients.
- Diffusion dominates PVT (changing compositional distributions).
- Non-laminar flow in fractures, not just "finite conductivity" concept.

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Knudsen "microflow" model
(Modified from Karniadakis and Beskok, 2002).

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How Small is Small?
(nano-scale pores)
Nano-Pores: "Conventional" Petrophysics Concepts

Systematic "mapping" of the inter-relation of petrophysical properties. Note that Archie observed that permeability was "connected" to saturation, porosity, and electrical properties — but the relationship was vague, as it remains today.

Severe influence of clay minerals in this reservoir system — production shown to be uniquely tied to reservoir quality and effectiveness of well stimulation.

**Nano-Pores: Nelson Pore Size/Molecule Size Chart**

**Perspective:**
- The concept of pores and pore throats begins to break down at these scales.
- The flow path can be as small as 10-20 molecular diameters (or less).

**Issues:**
- How do the fluids move?
  - Darcy flow?
  - Dispersion (gases)?
  - Knudsen flow?
- How are the fluids stored?
  - In the organic matter?
  - Adsorbed?
  - Another mechanism?

**Question(s):**
- How small are pores in shale gas?
  - Note that the size of the pores is on the order of 10-20 times the size of the fluid molecule.

Nano-Pores: *Continuum vs. Molecular (Knudsen Number)*

- Knudsen number is typically used to classify fluid flow regimes.

\[ Kn = \frac{\lambda}{L} \]

- Represents the representative physical length scale.
- Mean free path — average distance travelled by a fluid particle.

**Large \( \lambda \) (e.g., low density gas)**

**Small \( L \) (e.g., nano-pores)**

Nano-Pores: *Phase Behavior at the Nano-Scale*

Intuitive, but Zarragoicoechea and Kuz show by derivation and data that there is a shift in critical temperature due to pore size, they also postulate a similar relation for critical pressure but note that no data existed (at that time) to validate the pressure relation.

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The Modeling Stuff
**Modeling: Florence "Proxy" Permeability**

- Compute "proxy" permeability for each individual gas species.
- Lighter species experience higher "proxy" permeability.
- In this concept proxy permeability increases with drawdown.

Modeling: *Horizontal Multi-Fracture Well (HMFW)*

**Discussion: "Standard" Horizontal Multi-Fracture Well**
- Repetitive element used to represent flow of individual fractures.
- Fracture interference modeled by a no-flow boundary.

Modeling: **HMFW — Gridding (SPE 124961)**

- Single fracture element:
  - Repetitive element simulated using extremely fine grids.
  - 500,000 – 1,000,000 cells (5m x 5m x 50m system).
  - Accounts for wellbore, fracture interference.

![Diagram of repetitive element and pressure map results](image.png)

- a. Repetitive element of system.
- b. Pressure map results, z-direction slices in time.
Modeling: **Perspectives of Others (Ertekin)**

*Pressure maps via discrete fracture representation.*

*Pressure maps via SRV representation.*

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**5 YEARS**  **25 YEARS**  **50 YEARS**  **70 YEARS**
Modeling: *Perspectives of Others (Ertekin)*

Pressure maps at 15 years of production — various well configurations.
**Modeling:** *Perspectives of Others (Ilk — SPE 160076)*

**Analysis:**
- **Model:** Horizontal well with multiple fractures, non-linear analysis.
- Input PVT lab data in the model (volatile oil).
- Recommend tuning an EOS based on laboratory PVT data to create an EOS model for generating black-oil properties which should be applicable for many wells.
- Excellent match of oil and gas rate data with models until shut-in.
Modeling: **Perspectives of Others (Ilk — SPE 160076)**

**Forecast:**
- Constant pressure simulation results are imposed on productivity index and cumulative production plots.
- No dominant straight line behavior is observed.
- Forecast is different with respect to drainage area.

**Oil productivity index and cumulative oil production plot.**

**Gas productivity index and cumulative gas production plot.**
Modeling: **Perspectives of Others (Ilk — SPE 160076)**

- Assumed development wells have the same well configuration.
- Assumed development wells have the same reservoir and fluid properties.
- Vary distance between two wells to investigate the effect of spacing on EUR (Distance between wells corresponds to drainage area).
Modeling: *Perspectives of Others* (Ilk — SPE 160076)

- Pressure Distribution — 1 Year
- Pressure Distribution — 5 Years
- Pressure Distribution — 3 Years
- Pressure Distribution — 8 Years

- 80 acres well spacing is assumed for the multi-well simulation run.
Modeling: *Perspectives of Others* (Ilk — SPE 160076)

- Pressure Distribution — 13 Years
- Pressure Distribution — 20 Years
- Pressure Distribution — 16 Years
- Pressure Distribution — 30 Years

■ (80 acres) Effects of well interference are observed almost after 3 years.
Modeling: *Perspectives of Others* (Ilk — SPE 160076)

- Pressure Distribution — 1 Year
- Pressure Distribution — 5 Years
- Pressure Distribution — 3 Years
- Pressure Distribution — 8 Years

- 200 acres well spacing is assumed for the multi-well simulation run.
(200 acres) No effects of well interference are observed at 30 years.
Discussion:

- EUR is a function of well spacing for less than 100 acres drainage area, assumption (not affected over 100 acres).
- EUR values are estimated at 30 years of production.
- In our simulation runs, 100 acres drainage area corresponds to 738 ft distance between two wells.
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Summary
The "it-rhymes-with-itch" list:

- **Fractures:**
  - How do we model the SRV (or enhanced permeability region, etc.)?
  - Most appropriate approach for modeling hydraulic fractures.
  - Does fracture modeling (really) matter?
  - What is the holy grail for creation, propagation, transport in fractures?

- **Matching Performance:**
  - What do pressure-dependent properties mean in a physical sense?
  - Is a simple numerical model match meaningful?
  - Is an analytical model match meaningful?
  - Can we do something different? (e.g., use some sort of surrogate?).

- **Phase Behavior:**
  - Enormous investment in theory, computing, validation — is it worth it?
  - Will we (ever) be able to correctly model EOR processes in shales?
  - Are there reasonable surrogates for this complex PVT?

- **Wish List:**
  - See "genetic" behavior in well performance — use as empirical model?
  - Phase behavior — molecular modeling is fine, but not (ever?) practical.
  - Correctly modeling fracture creation and function (i.e., flow behavior).
  - Connecting a well model to the reservoir (for artificial lift).
  - Understanding when we can use Darcy's law — and when we cannot.
Summary:

● Modeling
  ■ Hydraulic Fractures  (... probably highest priority)
  ■ Natural Fractures  (... the road to practicality is paved with ... pain)
  ■ Phase Behavior  (... most important "differentiator"?)
  ■ Reservoir Models  (... what scale(s) can we afford?)
  ■ Surrogate Models  (... what basis? [performance, petrophysics,?])
  ■ Establishing drainage volume influence  (... uncertainty is very high)

● Integration
  ■ Modeling as interpretation  (... probably best place to start)
  ■ Modeling constraints  (... flow physics? too many unknowns?)
  ■ Modeling for validation  (... will be extremely challenging)

● Priorities
  ■ Hydraulic Fracture Models  (... must understand "where fluids go")
  ■ PVT Models  (... PVT = f[pore size, p, ...])
  ■ Simplified Models...  (... threshold for being sufficient?)
  ■ Empirical/Observational Models...  (... relevance? uniqueness?)
  ■ Full Domain Models? [one model covers all scales]  (... feasibility?)