Simulation of Production Interference in Multi-Well Pads

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Inter-Well Connectivity Challenges

Problem:
Well interference = Suboptimum SRV

Evidence Well-interference:
- Pressure data well shut-ins
- Microseismic events

Key Issues:
1. Physical mechanisms of interference
2. Quantify impact of well interference
3. Design better well spacing

Microseismic events in Eagle Ford shale (SPE 174946)

Pressure response of #5 Well in Wolfcamp shale (URTeC: 2154675)
Model Development Well Interference

Research Focus:
• Combine analytical, semi-analytical, and numerical models to identify, analyze, and visualize the inter-well interference
• Understand the mechanism and intensity of well interference
• Quantify the optimal well pattern / spacing
Three basic interference mechanisms

(a) Through matrix permeability
(b) Through simple hydraulic fractures
(c) Through complex fracture network (natural + hydraulic fractures)
Example Interference through simple HF

Numerical Model

Well 1 shut-in
Well 1 shut-in
Well 2
Well 2

Case 1
Case 2

Pressure profile after 75 days (50 md-ft)

Case 1: No inter-well communication
Case 2: Inter-well communication

Effect of connecting fracture conductivity on pressure change of shut-in well

4 connected HFs

0.1 md-ft
0.5 md-ft
1 md-ft
5 md-ft
10 md-ft
50 md-ft
100 md-ft

Effect of connecting fracture conductivity on pressure change of shut-in well

Numerical Model

4 connected HFs

0.1 md-ft
0.5 md-ft
1 md-ft
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10 md-ft
50 md-ft
100 md-ft

Effect of connecting fracture conductivity on pressure change of shut-in well
Example Well Interference Complex Fractures

Perform a series of sensitivity studies
Effect of Matrix permeability & Fracture properties
- number of connecting fractures
- fracture conductivity
- fracture half-length
- complexity connecting fractures

Semi-Analytical Model: Complex fractures
Numerical Model: Simple fractures

URTeC 2149893
Semi-Analytical Approach

2Nf + Nv Unknowns (constant BHP)

- Pressure at each node (Nf)
- Gas flow rate at each node (Nv)
- Gas flux at each segment (Nf)

2Nf + Nv Governing equations

- Mass balance at each node (Nv)
  \[ f_I = (q_i)_{\text{inflow}} - (q_i)_{\text{outflow}} = 0 \]
- Gas flow at each segment (Nf)
  \[ f_{II} = p_{j1} - p_{j2} - \int_{y_{j1}}^{y_{j2}} D_j q_j(y) + N D_j q_j(y)^2 \, dy = 0 \]
- Pressure solution at center of each segment (Nf)
  \[ f_{III} = p_{j1} - p(x, y, z, t) - \int_{y_{j1}}^{y_{jc}} D_j q_j(y) + N D_j q_j(y)^2 \, dy = 0 \]

\[
p(x, y, z, t) = p_i - \frac{U(t-t_0)}{4\phi c_i ab} \sum_{j=1}^{N_p} \int_0^t q_j(t-t_0-\tau) G_j(x, y, z, \tau) d\tau
\]
Superposition Principle – Interaction Frac Segments

\[ p(x, y, z, t) = p_i - \frac{U(t-t_0)}{4\phi c_i ab} \sum_{j=1}^{N_f} \int_0^t q_j (t-t_0-\tau) G_j(x, y, z, \tau) d\tau q_j \]

Expansion for the center of \( j \) segment \((x, y, z, t)\)

- \( C_1^1 q_1^1 + C_1^2 q_1^2 + \ldots + C_1^n q_1^n \)
- \( \ldots \)
- \( C_{N_f}^1 q_{N_f}^1 + C_{N_f}^2 q_{N_f}^2 + \ldots + C_{N_f}^n q_{N_f}^n \)

**Spatial superposition**

\( j = 1, 2, \ldots N_f \)

**Time superposition**

(time = 1, 2, \ldots n)
Model Verification – Tight Oil

- **Constant oil rate**
- **Constant BHP**
- **Pressure-dependent fracture conductivity**

**Model Assumption**

- Semi-analytical model
- Numerical model with geomechanics

Zhou et al: SPE157367 PA
Analytical Approach – Visualization of SRV

Key algorithm drainage
Velocity field

\[ V(z) = \frac{m_s}{b-a} e^{-i\beta} \left( \log(e^{-i\beta}(z-z_c)) - a \right) - \log(e^{-i\beta}(z-z_c)) - b \]  

Fracture element at location \( Z_c \)

Specify for each fracture segment flux strength, \( m_s(t) \), based on diffusion-based decline.

\[ m = \frac{Q_i}{h} \ [m^2 s^{-1}] \]

Unlimited number of fractures & segments possible

Semi-analytical model provides flux strength

Unrealistic inputs \( m \)

Time of flight contours
1. SRV production allocation between adjacent wells based on complexity of fracture network connected to each well (A).

2. Visualize production depletion front and specify actual recovery factor for the SRV at anyone time (B).

3. Economic limit determines what is the recovery factor cutoff time.

4. Poorly placed fractures will create recovery gaps.

5. When fracture networks between wells are communicating, establish effect of detailed fracture geometries on production and BHP pressure decline profiles for each well.
### Anticipated Outcomes and Deliverables

1. Develop diagnostics for recognizing the dominant physical mechanism of well interference for a particular study area.
2. Visualization of stimulated rock volume and well interference
3. Apply the proposed methodology to wells from the Eagle Ford and Permian Basin.* Shut-in well tests & permeability & fracture data needed
4. Provide reservoir model tools to operators for determining the optimum well spacing

**Related Crisman Proposal:** *Practical Rules for Optimum Frac Spacing and Optimum Well Length in Unconventional Plays*
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