Simulation of Production Interference in Multi-Well Pads

Funded Crisman Project 2016

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3/22/2015

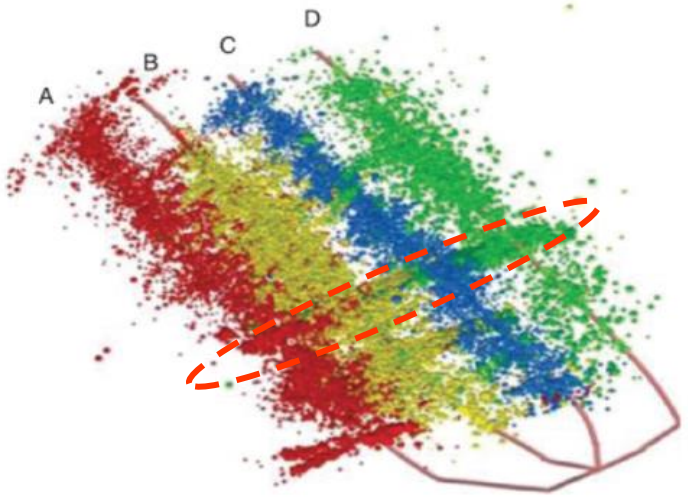
Inter-Well Connectivity Challenges

Problem:
Well interference =
Suboptimum SRV

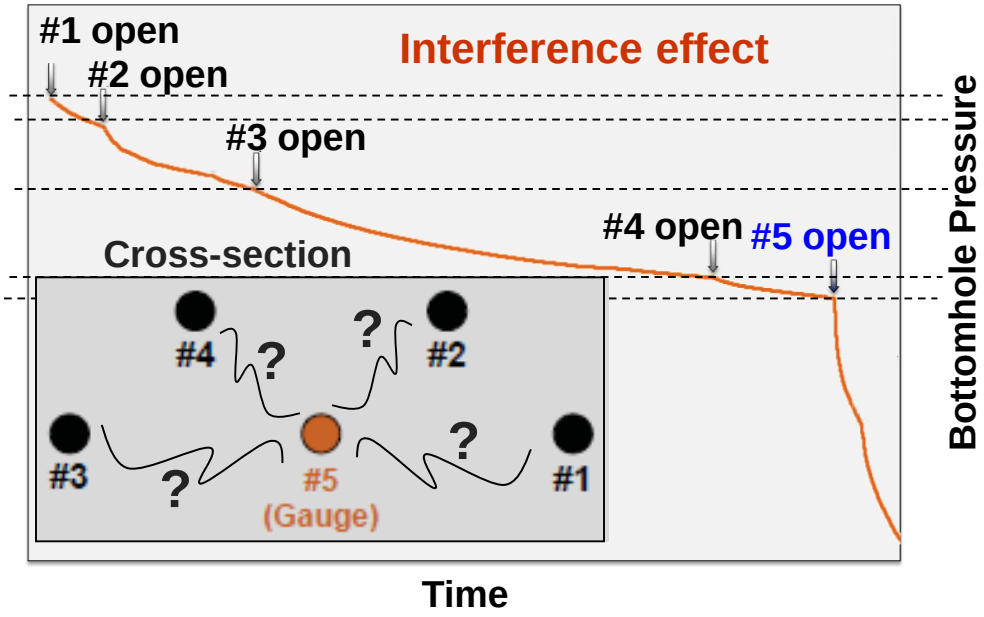
Evidence Well-interference:

- 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

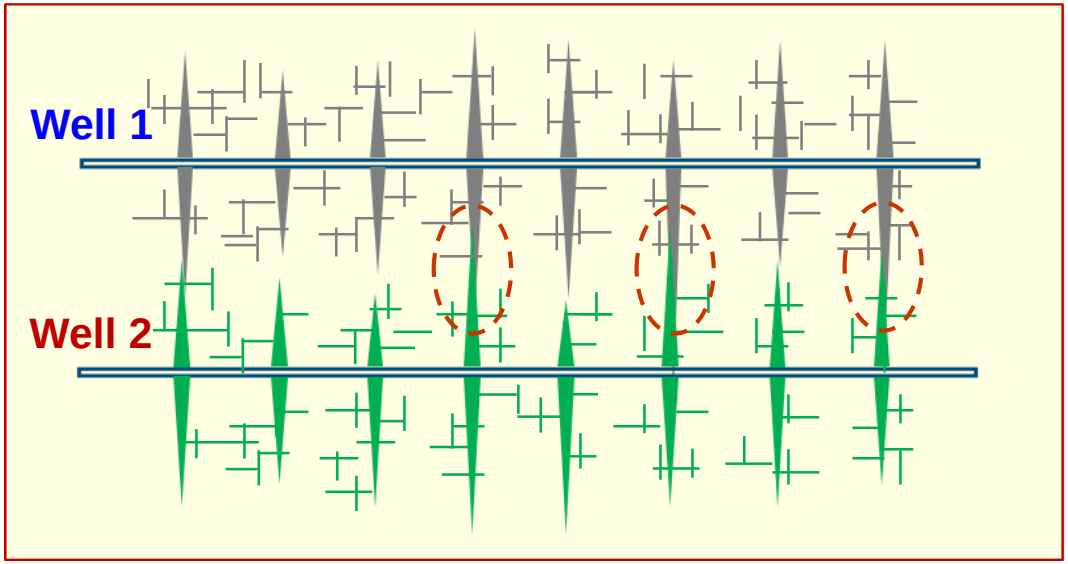


Microseismic events
in Eagle Ford shale (SPE 174946)

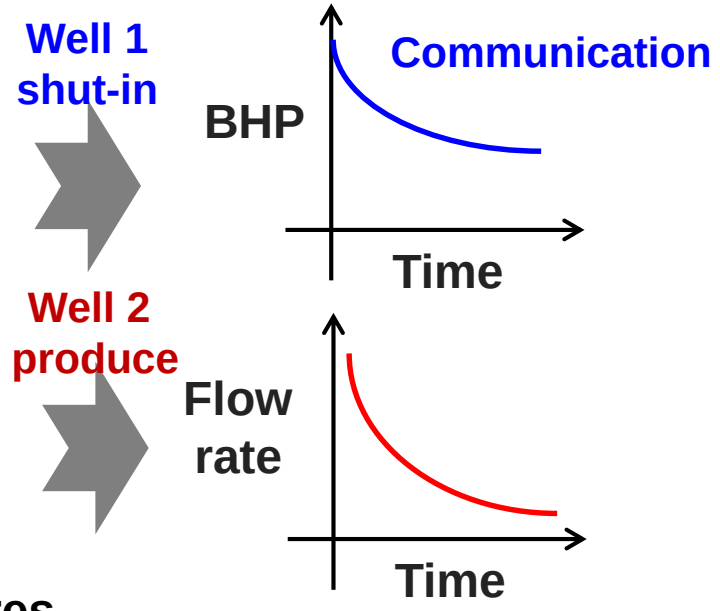


Pressure response of #5 Well
in Wolfcamp shale (URTeC: 2154675)

Model Development Well Interference



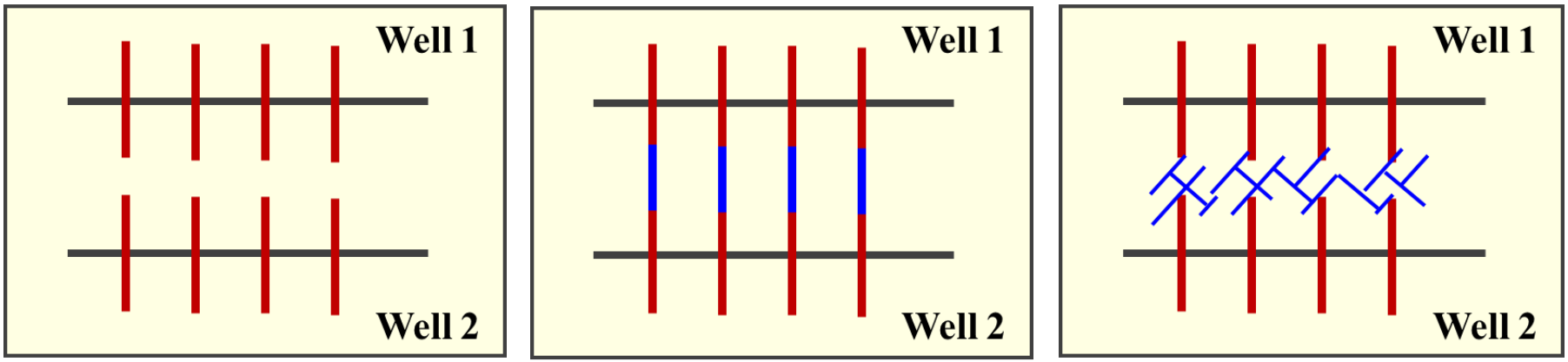
Well communication through connecting fractures



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

Inter-Well Interference Mechanisms



(a) (b) (c)

Three basic interference mechanisms

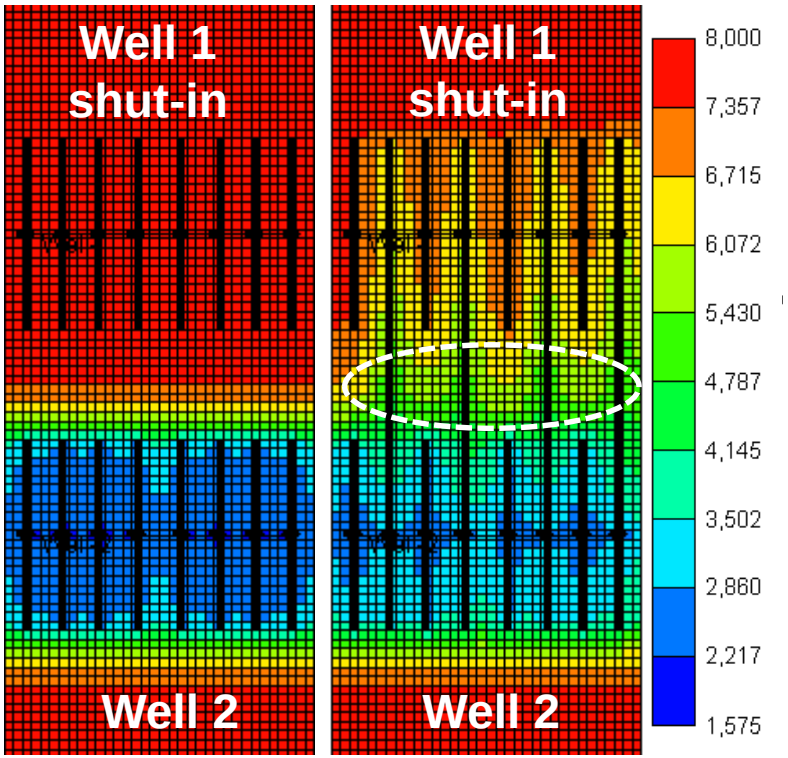
(a) Through matrix permeability

(b) Through simple hydraulic fractures

(c) Through complex fracture network (natural + hydraulic fractures)

Example Interference through simple HF

Numerical Model

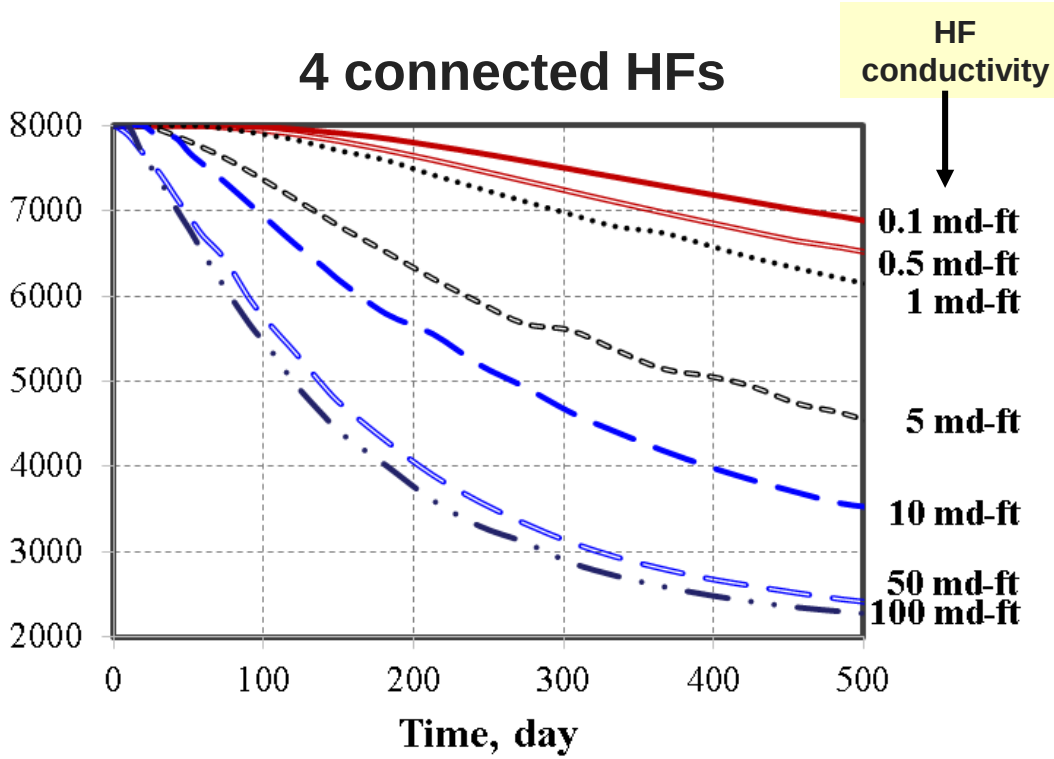


Case 1 Case 2

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

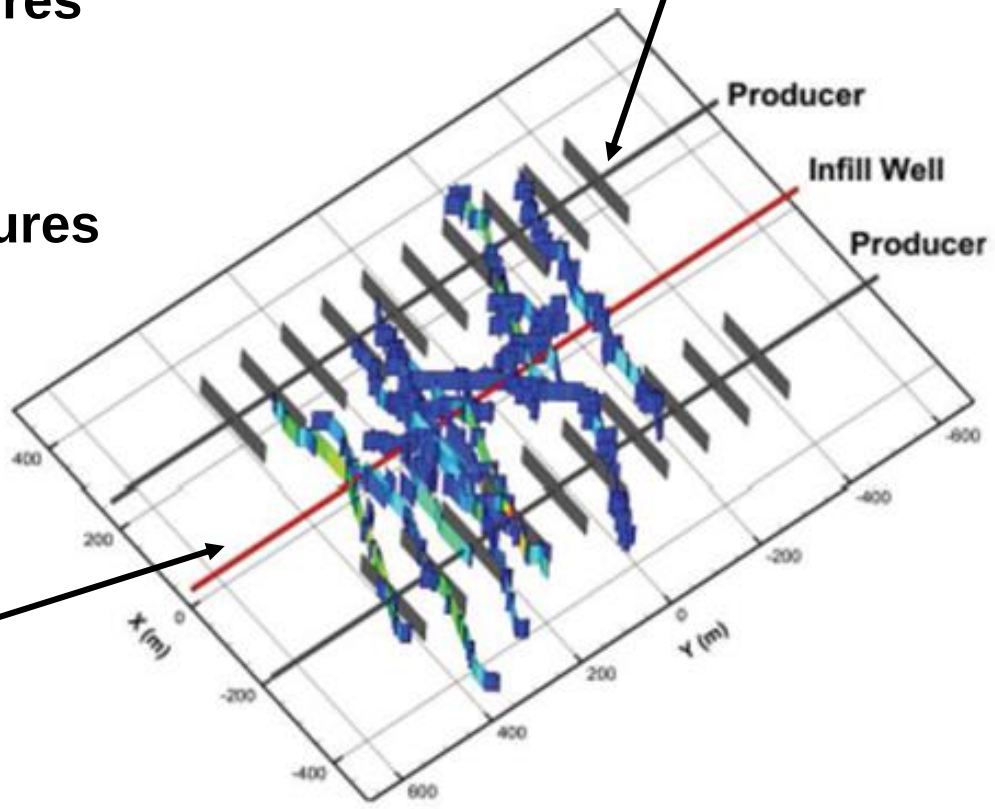
Example Well Interference Complex Fractures

Perform a series of sensitivity studies

Effect of Matrix permeability & Fracture properties

- number of connecting fractures
- fracture conductivity
- fracture half-length
- complexity connecting fractures

Numerical Model:
Simple fractures



Semi-Analytical Model:
Complex fractures

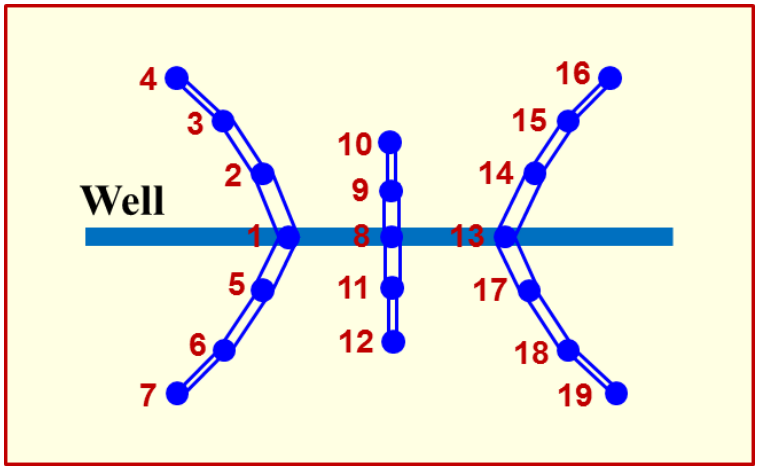
URTeC 2149893

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)

Nf fracture segments, Nv nodes
Nv = Nf +1



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)

$$f_{II} = p_{j1} - p_{j2} - \int_{y_{j1}}^{y_{j2}} D_j q_j(y) + N D_j q_j(y)^2 \, dy = 0$$

SPE 178747- STU
Wei Yu 2015

- Pressure solution at center of each segment (Nf)

$$f_{III} = p_{j1} - p(x,y,z,t) - \int_{y_{j1}}^{y_{jc}} D_j q_j(y) + N D_j q_j(y)^2 \, dy = 0$$

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

Superposition Principle – Interaction Frac Segments

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

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

$$C_1^1 q_1^1 + C_1^2 q_1^2 + \quad \cdots\cdots \quad + C_1^n q_1^n$$

$$\cdots$$

$$\cdots$$

$$C_j^1 q_j^1 + C_j^2 q_j^2 + \quad \cdots\cdots \quad + C_j^n q_j^n$$

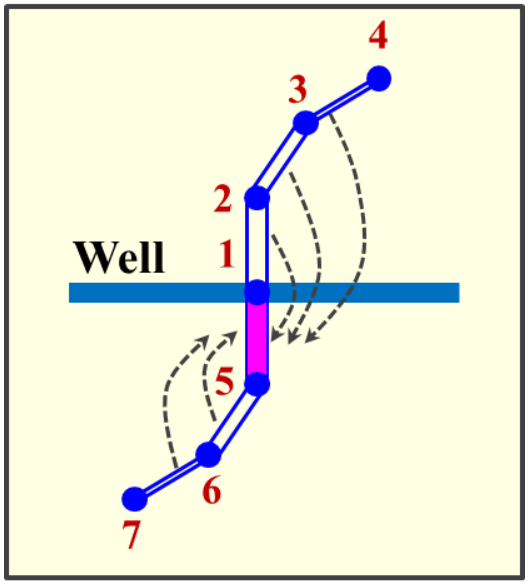
$$\cdots$$

$$\cdots$$

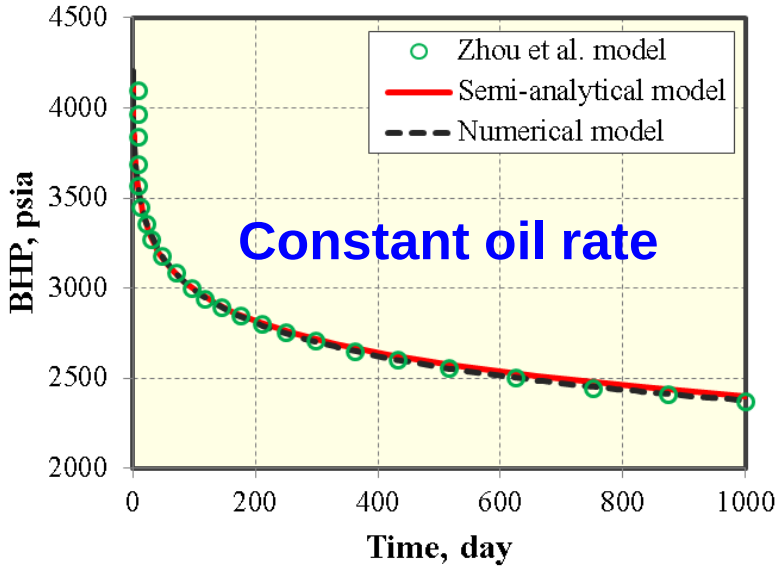
$$C_{Nf}^1 q_{Nf}^1 + C_{Nf}^2 q_{Nf}^2 + \quad \cdots\cdots \quad + C_{Nf}^n q_{Nf}^n = p(x,y,z,t)$$

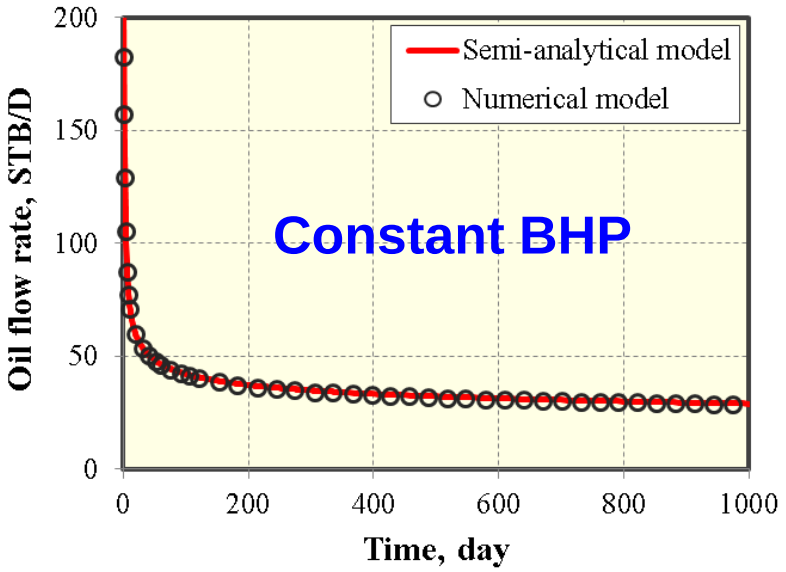
Spatial superposition
j* = 1, 2, … *Nf

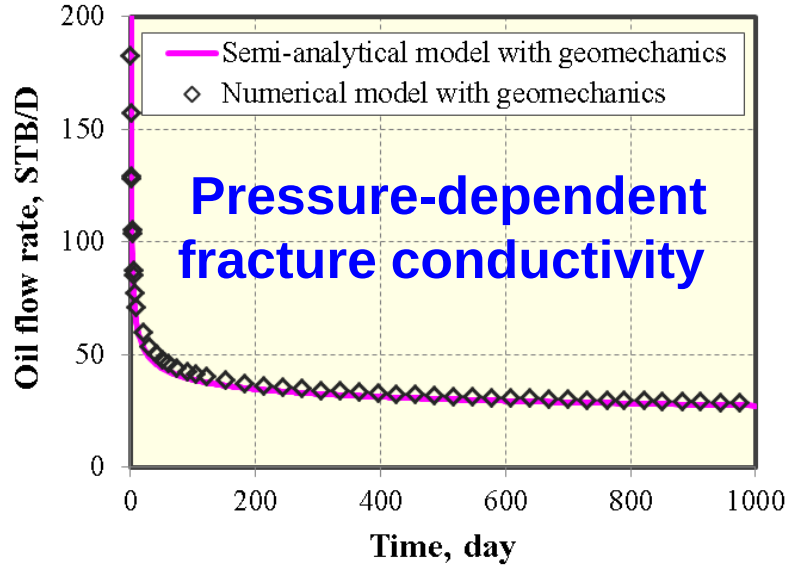
Time superposition (time = 1, 2, … n)



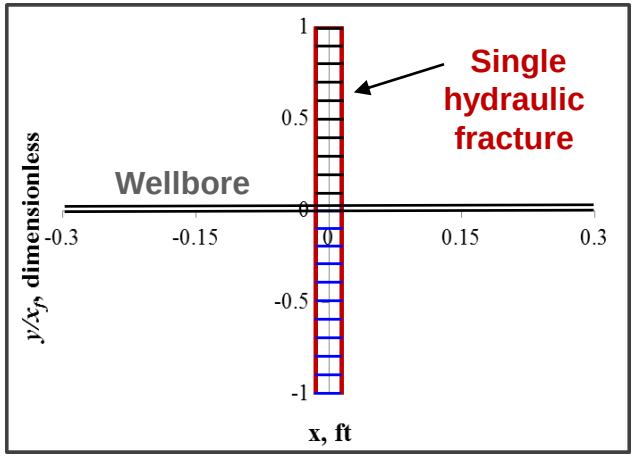
Model Verification – Tight Oil







Model Assumption



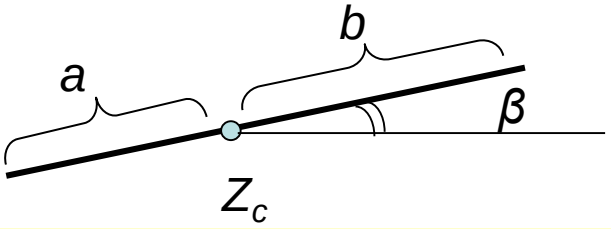
Zhou et al: SPE157367 PA

Analytical Approach – Visualization of SRV

Key algorithm drainage Velocity field

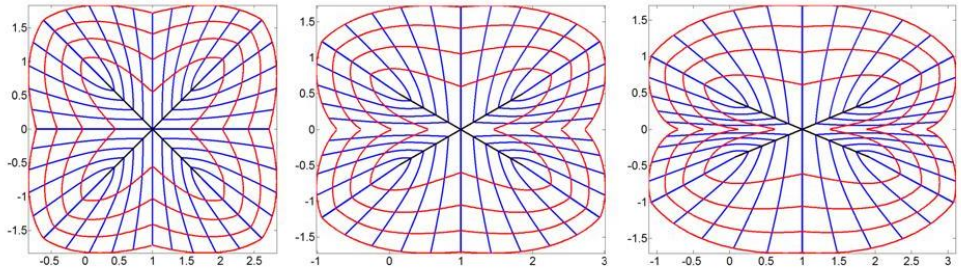
$$V(z) = \frac{m_s}{b-a} e^{-i\beta} \left(\log(e^{-i\beta}(z - z_c) - a) - \log(e^{-i\beta}(z - z_c) - b) \right)$$

Fracture element at location Z_c

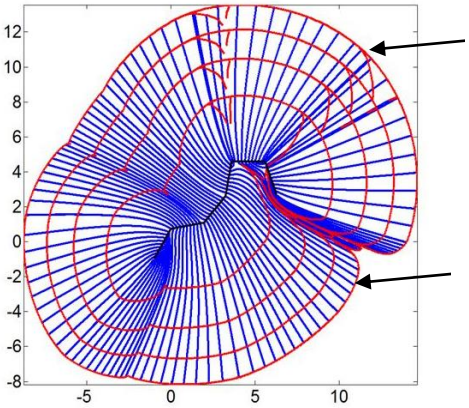


Specify for each fracture segment flux strength, $m_s(t)$, based on diffusion-based decline.

$$m = Q_i / h \quad [\mathrm{m^2 s^{-1}}]$$



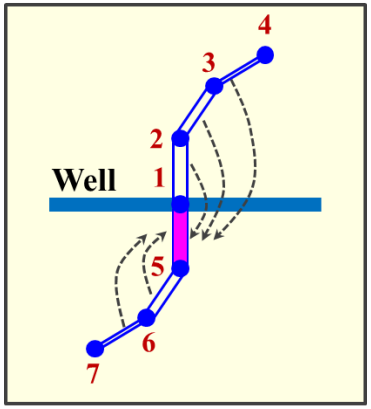
Unlimited number of fractures & segments possible



Unrealistic inputs *m*

Time of flight contours

Semi-analytical model provides flux strength



Semi-Analytical and Analytical Model Goals

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

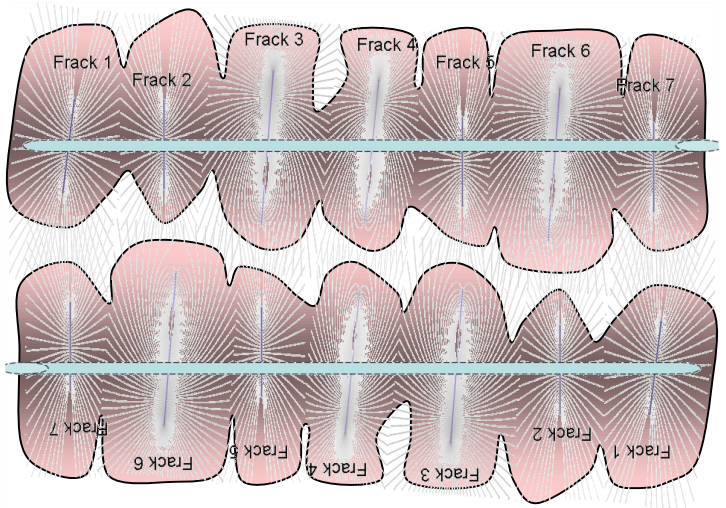
2. Visualize production depletion front and specify actual recovery factor for the SRV at anyone time (B).

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

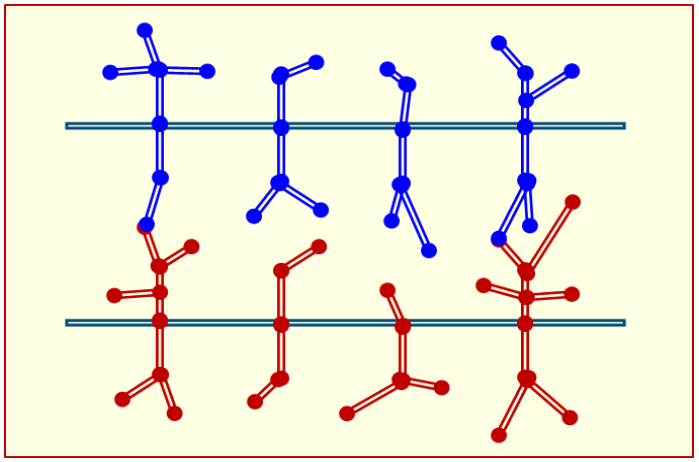
4. Poorly placed fractures will create recovery gaps.

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

B) SRV (interference) Visualization



A) Production (interference) Model



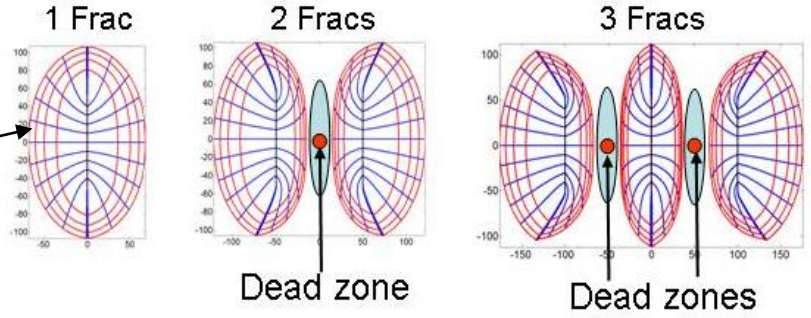
Anticipated Outcomes and Deliverables

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

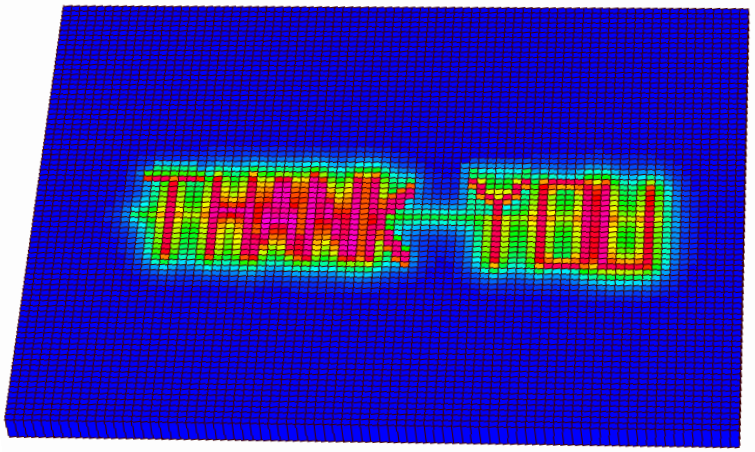
*** Shut-in well tests & permeability & fracture data needed**

4. Provide reservoir model tools to operators for determining the optimum well spacing

Time of flight contours



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



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