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Physical Models for Inter-Well Interference in Shale Reservoirs: Relative Impacts of Fracture Hits and Matrix Permeability

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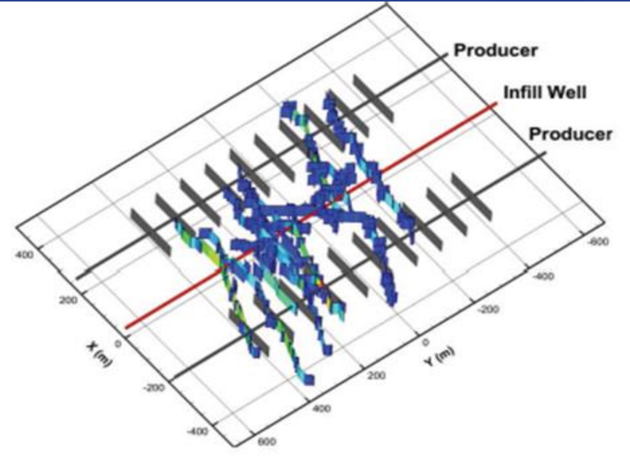
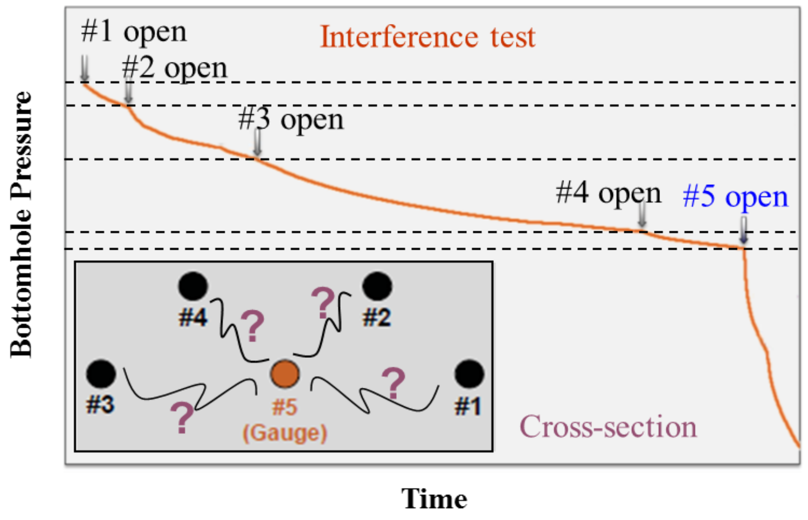
Well Interference

Key Issues

1. Physical mechanisms of interference
2. Quantify impacts of well interference
3. Existing models are limited



Complex fracture hits (URTeC: 2149893)



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

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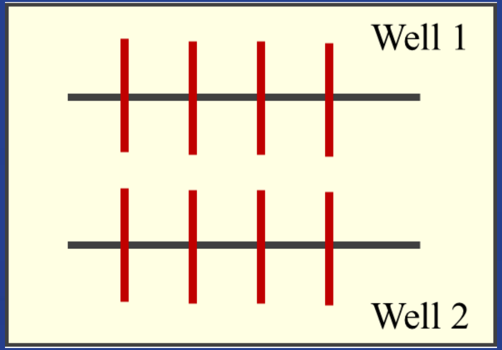
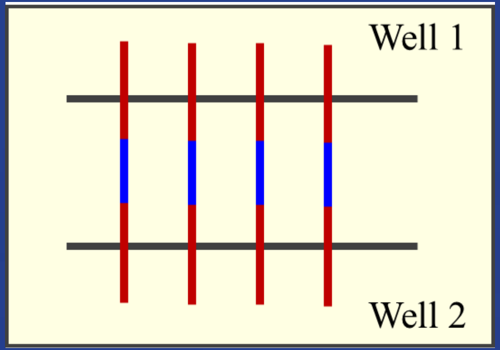
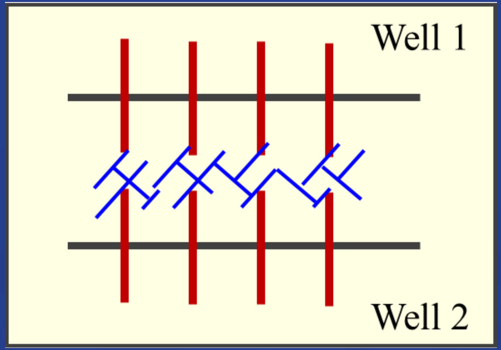
Well Interference Mechanisms



Matrix permeability



Simplex fracture hits

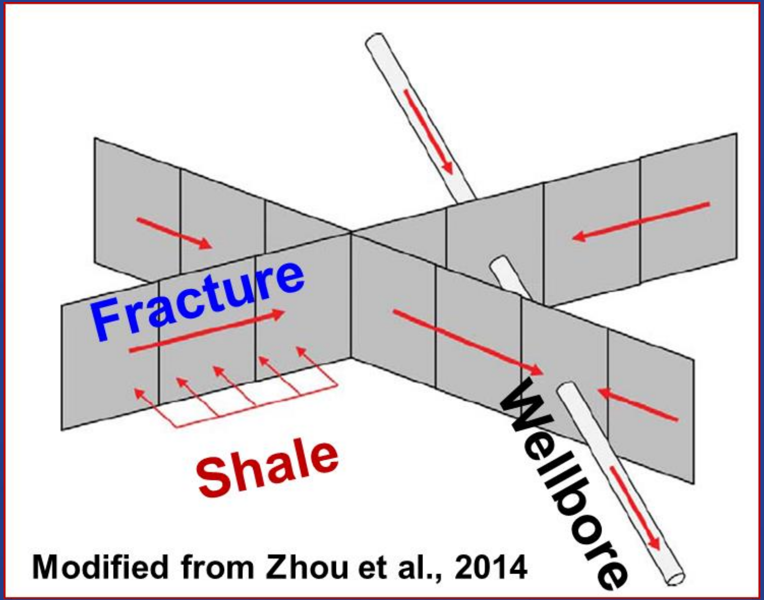


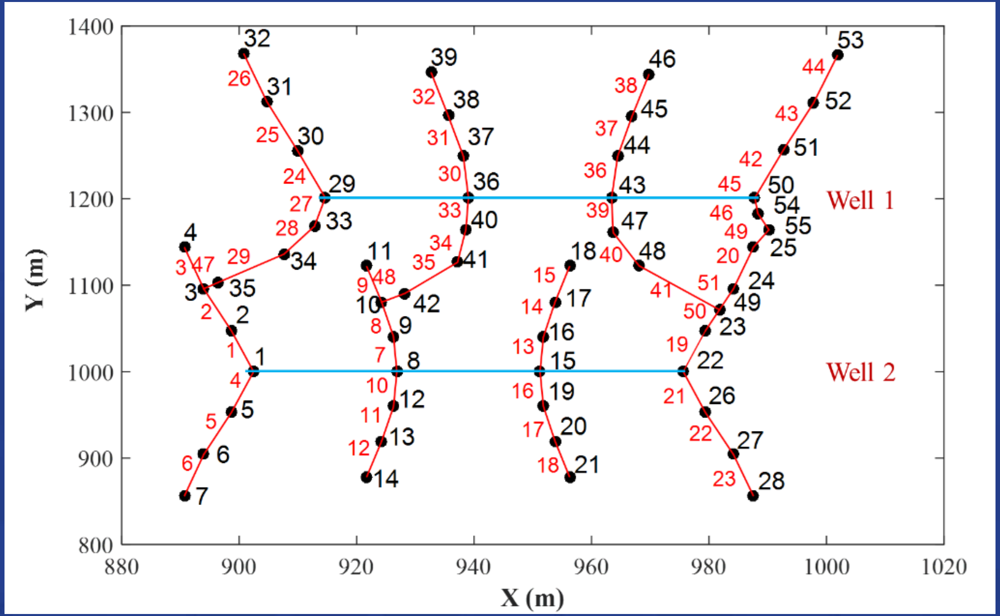
Complex fracture hits

Research Focus

- Develop physical models to analyze and visualize well interference
- Understand mechanisms and intensity of well interference
- Relative impacts of fracture hits and matrix permeability

Semi-Analytical Model Development



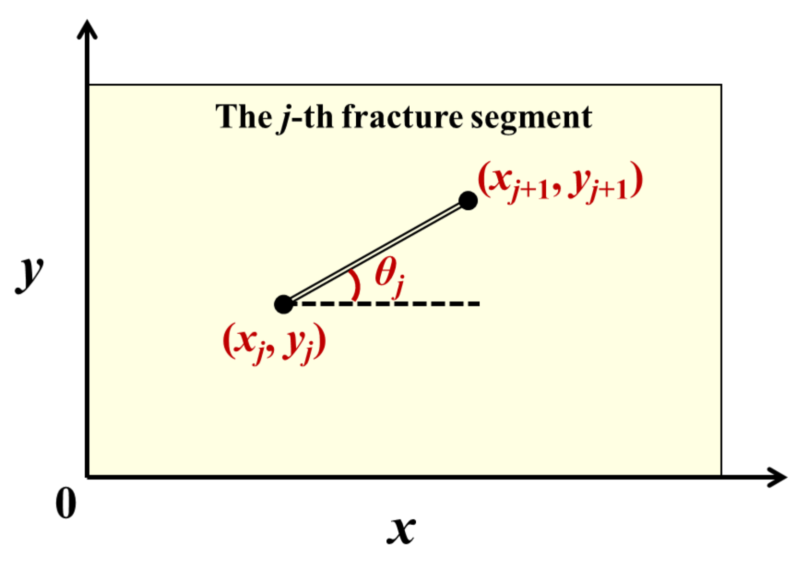


Fracture discretization into segments

Analytical Solution for Each Segment

$$\eta_x \frac{\partial^2 p}{\partial x^2} + \eta_y \frac{\partial^2 p}{\partial y^2} = \frac{\partial p}{\partial t}$$

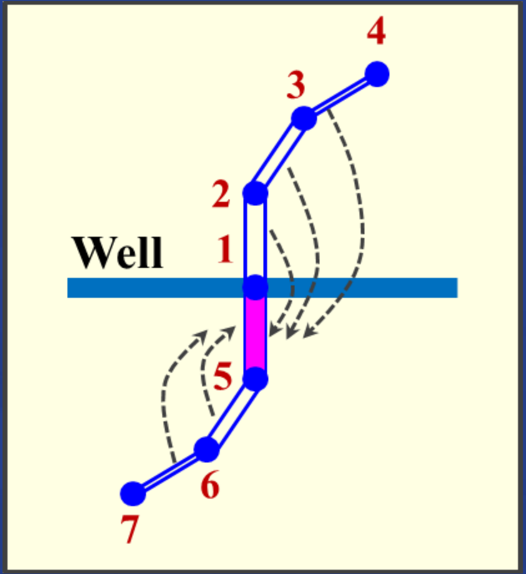
$$p(x,y,t) = p_i - \frac{U(t-t_0)}{4\pi h_f c_t \rho \phi \eta} \int_0^{t-t_0} \int_{-dl_j/2}^{dl_j/2} \frac{q_{fj}(\tau)}{t-t_0-\tau} \times e^{-\frac{\left(x+x'\cos\theta_j - \frac{x_j+x_{j+1}}{2}\right)^2 + \left(y+x'\sin\theta_j - \frac{y_j+y_{j+1}}{2}\right)^2}{4\eta(t-t_0-\tau)}} \mathrm{d}x'\mathrm{d}\tau$$



Each segment is a plane sink

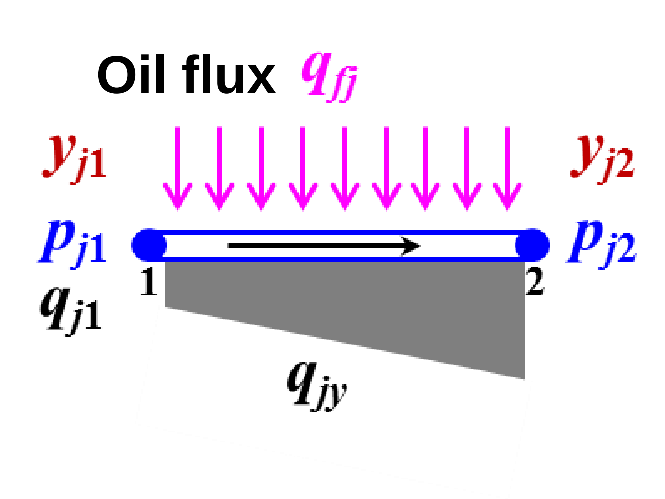
Superposition Principle

$$p(x,y,t) = p_i - \frac{U(t-t_0)}{4\pi h_f c_t \rho \phi \eta} \sum_{j=1}^{N_f'} \int_0^{t-t_0} \int_{-dl_j/2}^{dl_j/2} \frac{q_{fj}(\tau)}{t-t_0-\tau} \times e^{-\frac{\left(x+x'\cos\theta_j - \frac{x_j+x_{j+1}}{2}\right)^2 + \left(y+x'\sin\theta_j - \frac{y_j+y_{j+1}}{2}\right)^2}{4\eta(t-t_0-\tau)}} \mathrm{d}x'\mathrm{d}\tau$$



Darcy Flow at Each Segment

$$p_j - p_{j+1} = \int_{y_j}^{y_{j+1}} \mu / \rho h_f \left(k_f w_f\right)_j q_j\left(y\right) dy$$



Oil flow rate at segment

$$q_j\left(y\right) = q_j + q_{fj}\left(y - y_j\right) / \sin\theta_j$$

Governing Equations

- Mass balance at each node

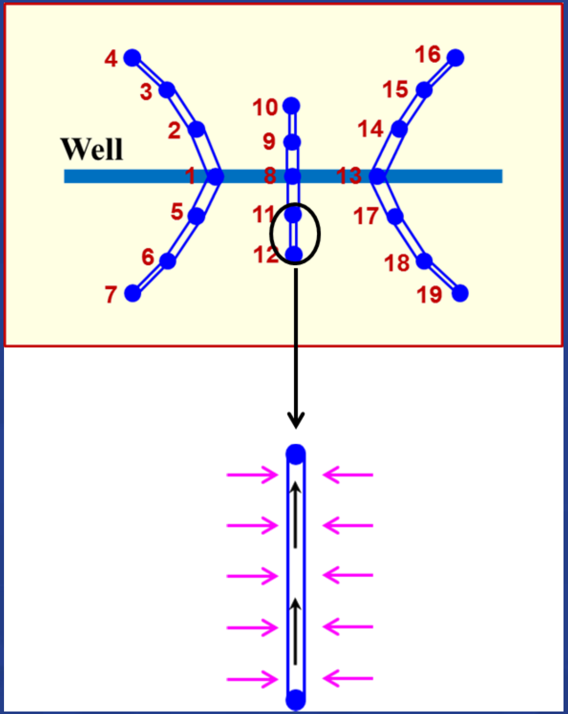
$$f_I = (q_i)_{inflow} - (q_i)_{outflow}$$

- Darcy flow at each segment

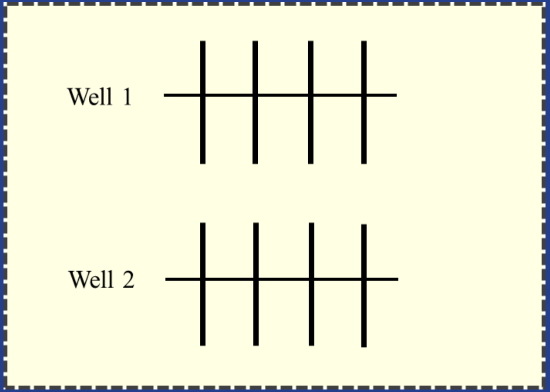
$$f_{II} = p_{j1} - p_{j2} - \int_{y_{j1}}^{y_{j2}} D_j q_j(y)dy$$

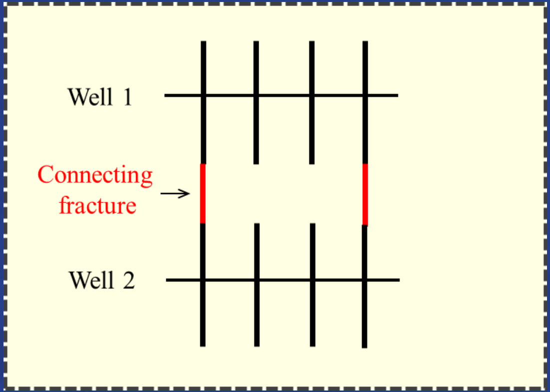
- Pressure continuity at center of segment

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

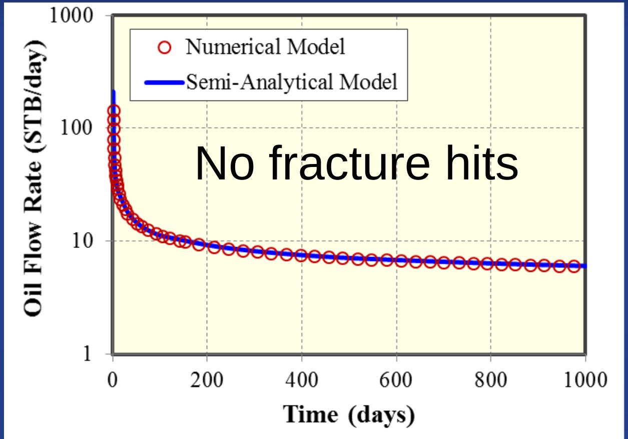


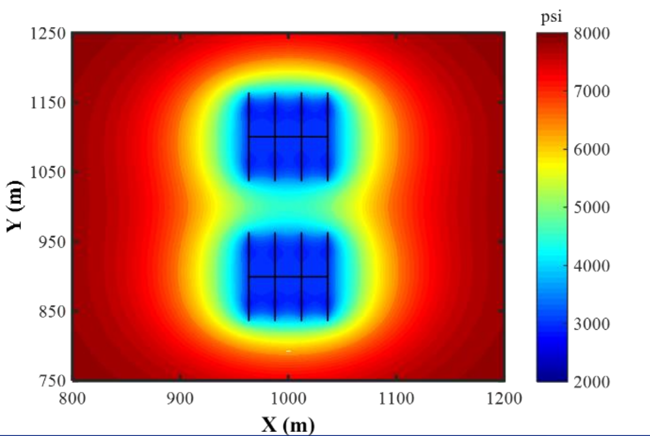
Model Verification for Oil Flow Rate

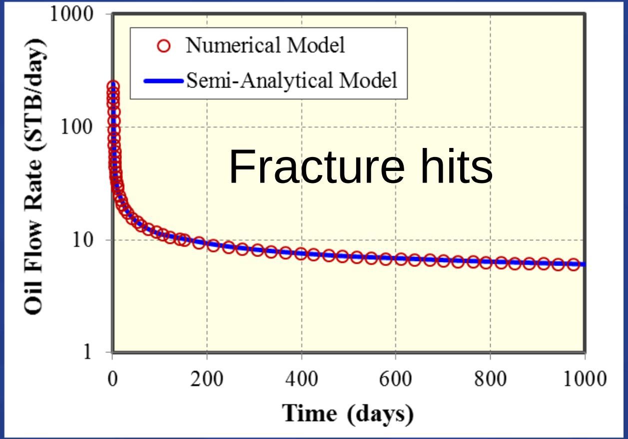


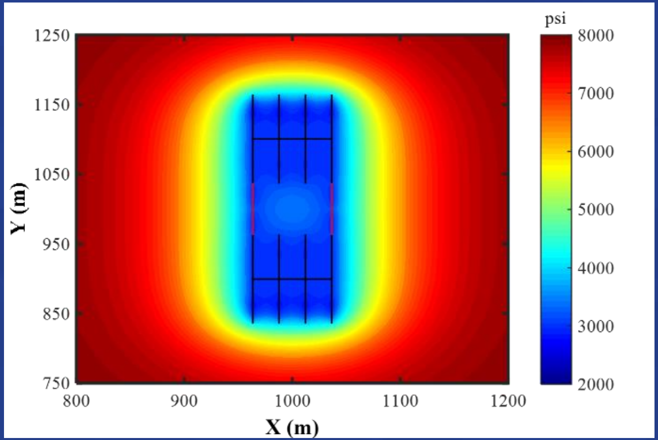


Parameter	Value	Unit
Initial reservoir pressure	8,000	psi
Reservoir temperature	240	^oF
Reservoir thickness	50	ft
Reservoir permeability	0.01	mD
Reservoir porosity	7%	-
Oil viscosity	0.6	cp
Formation volume factor	1.273	bbl/STB
Fracture spacing	80	ft
Total compressibility	1×10^{-6}	psi^{-1}
Fracture half-length	210	ft
Fracture conductivity	100	md-ft
Fracture height	50	ft
Fracture width	0.01	ft

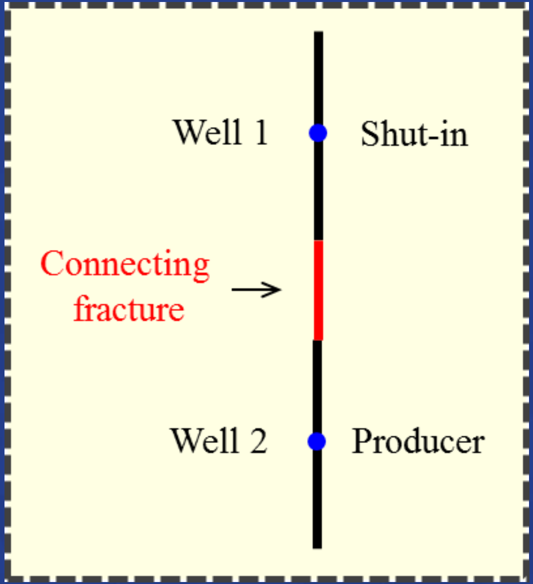

Numerical Model
Semi-Analytical Model
No fracture hits
Oil Flow Rate (STB/day)
Time (days)
1000
100
10
1
0
200
400
600
800
1000

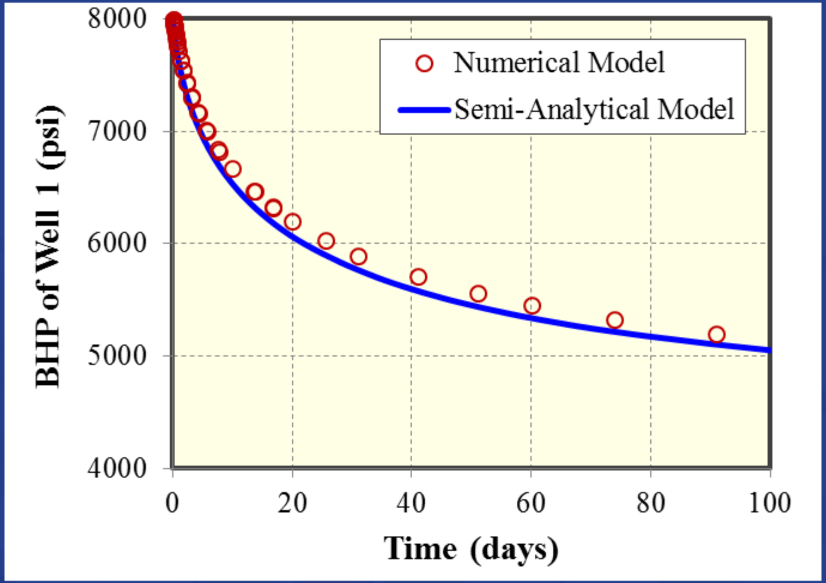

psi
8000
7000
6000
5000
4000
3000
2000
Y (m)
X (m)
1250
1150
1050
950
850
750
800
900
1000
1100
1200


Numerical Model
Semi-Analytical Model
Fracture hits
Oil Flow Rate (STB/day)
Time (days)
1000
100
10
1
0
200
400
600
800
1000


psi
8000
7000
6000
5000
4000
3000
2000
Y (m)
X (m)
1250
1150
1050
950
850
750
800
900
1000
1100
1200

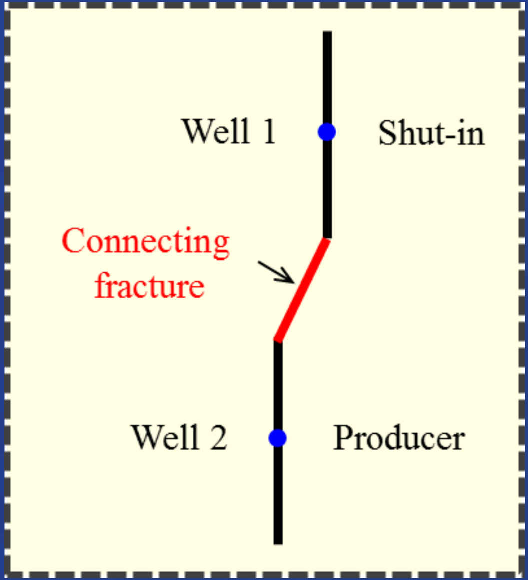
Model Verification for BHP Response

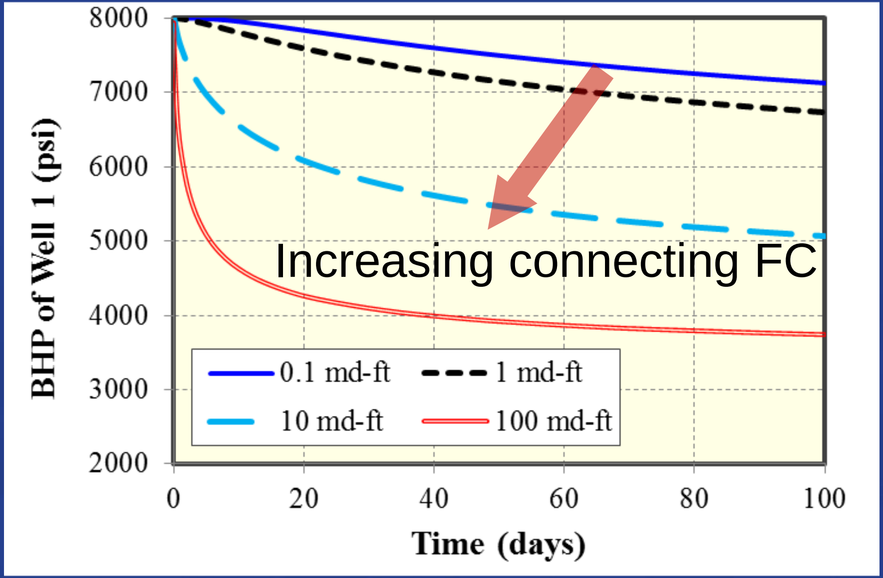




Single straight fracture hit

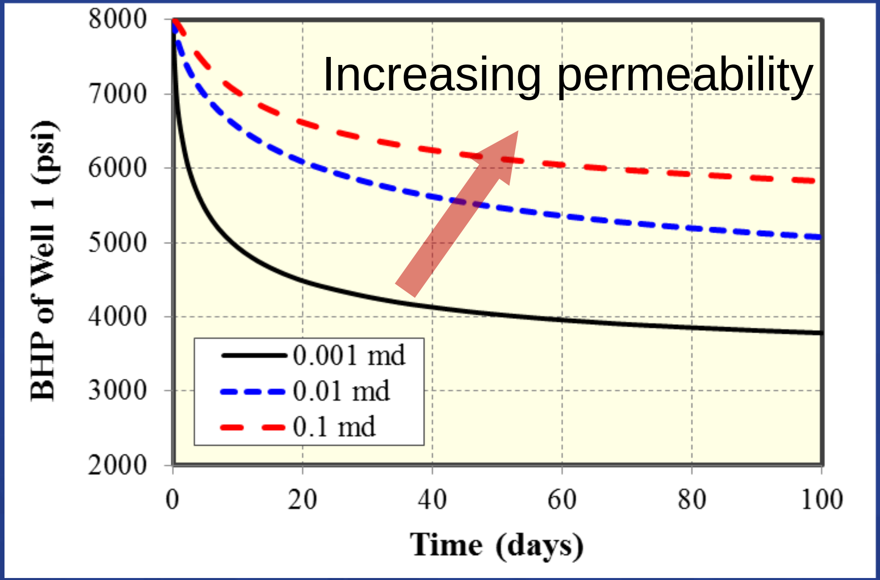
Single Slanted Fracture Hit



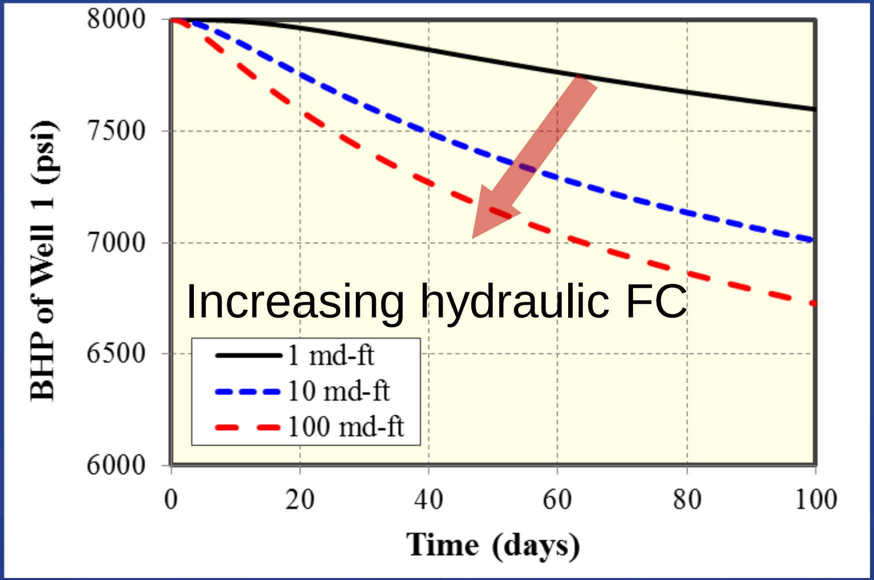


Effect of connecting fracture conductivity

Single Slanted Fracture Hit

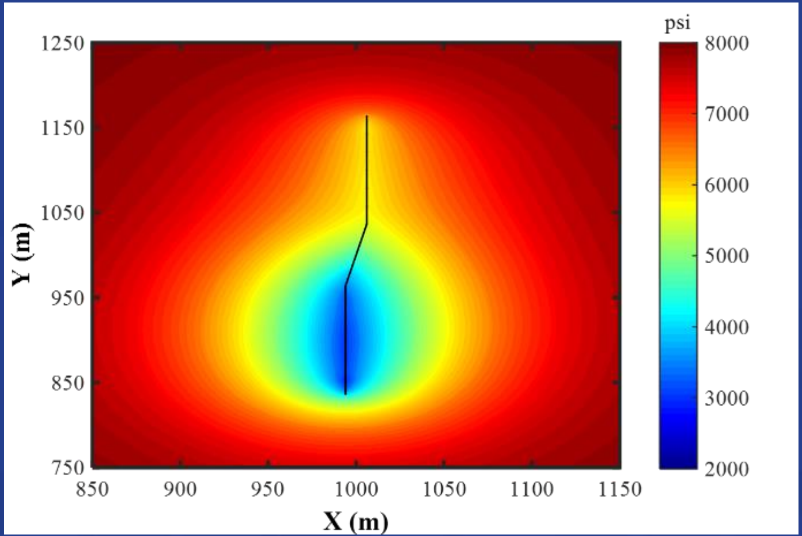


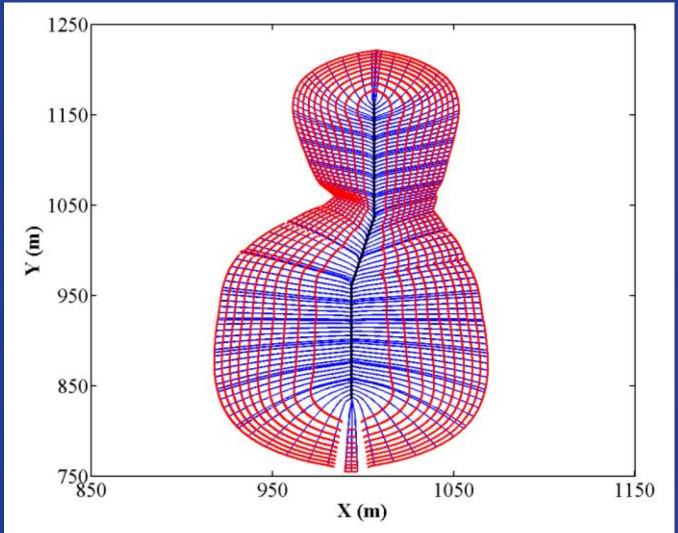
Effect of matrix permeability



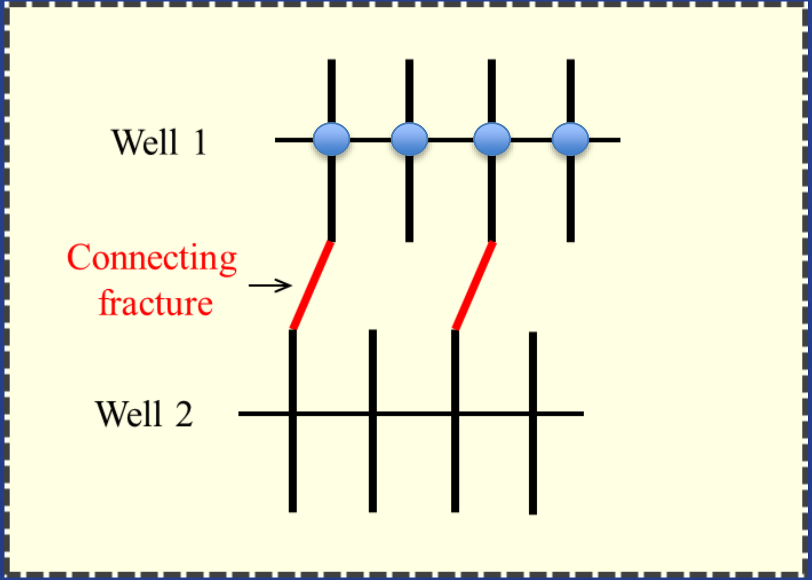
Effect of hydraulic fracture conductivity

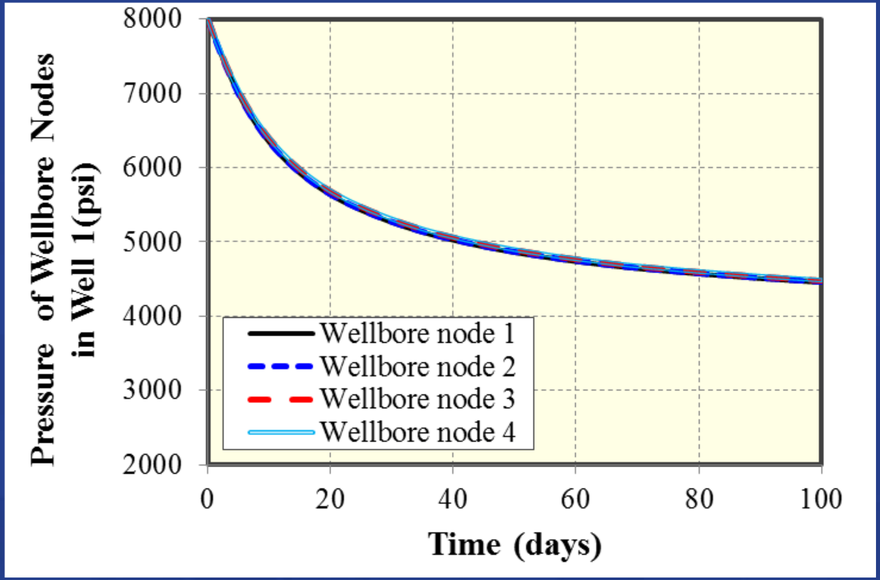
Pressure Distribution and Streamline





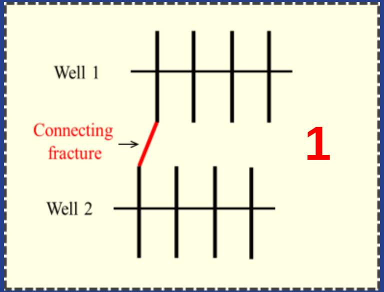
Multiple Slanted Fracture Hits

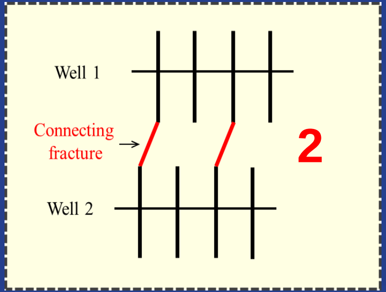


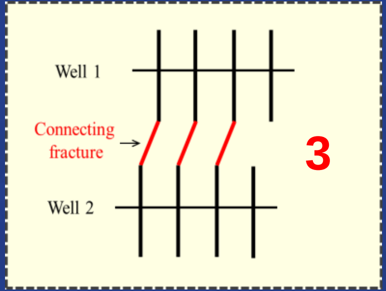


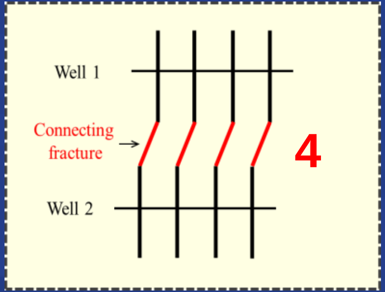
Pressure response of four wellbore nodes

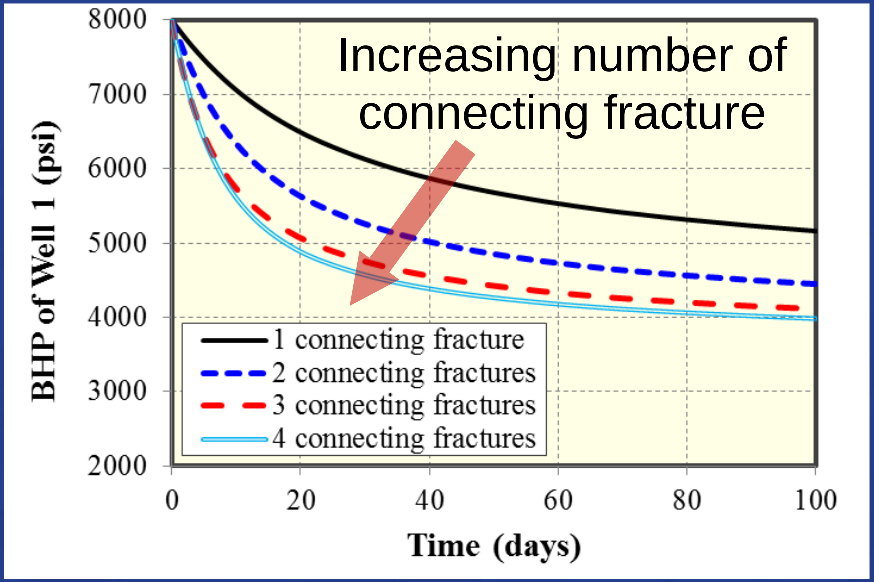
Multiple Slanted Fracture Hits





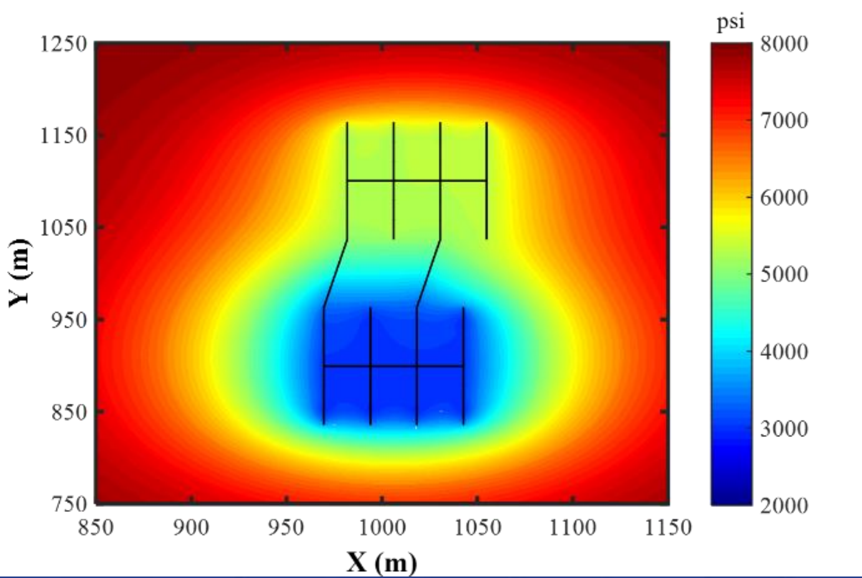




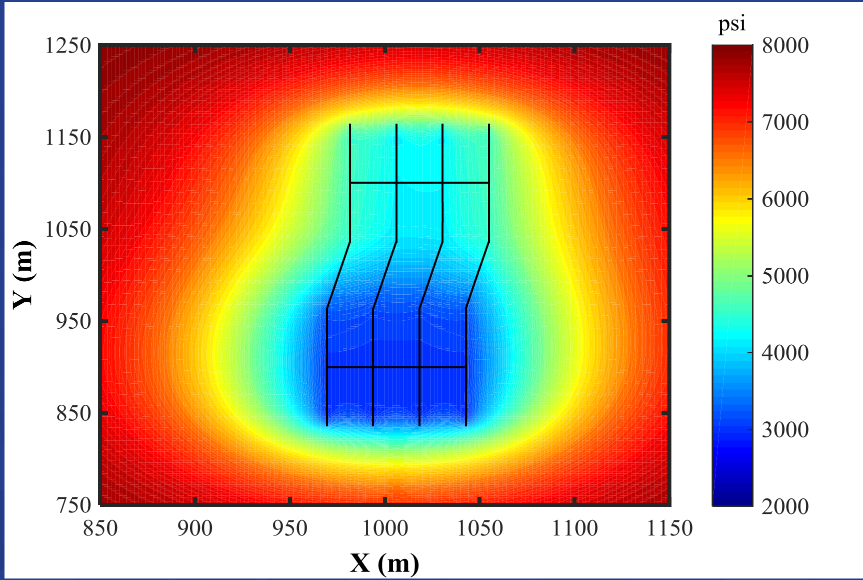


Effect of number of connecting fracture

Multiple Slanted Fracture Hits



2 connecting fractures

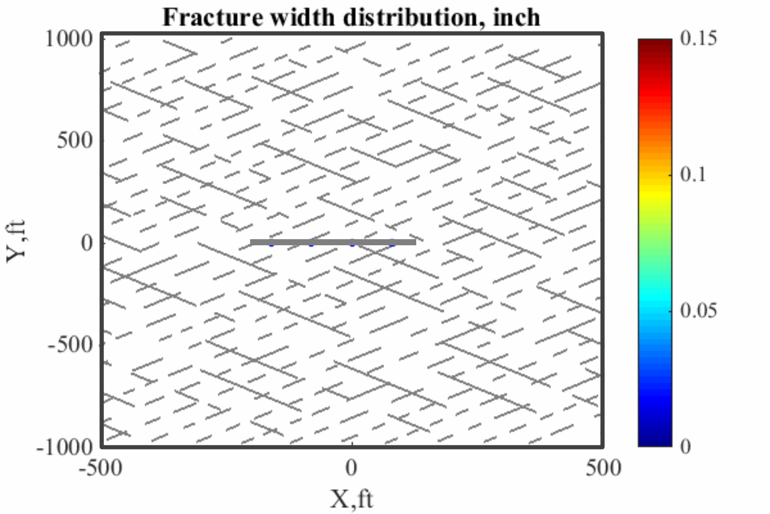


4 connecting fractures

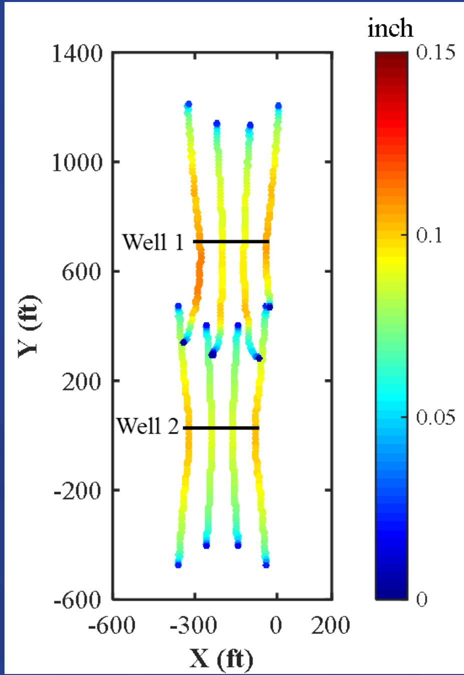
A Hydraulic Fracture Propagation Model

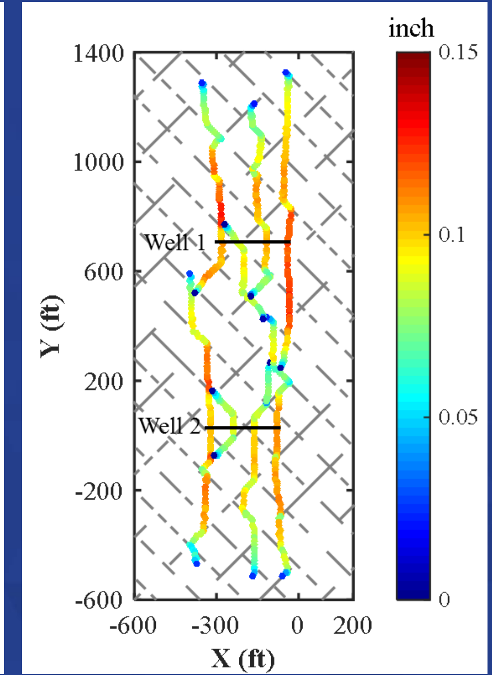
XFRAC: CompleX hydraulic FRACture development model (Wu and Olson, 2015)

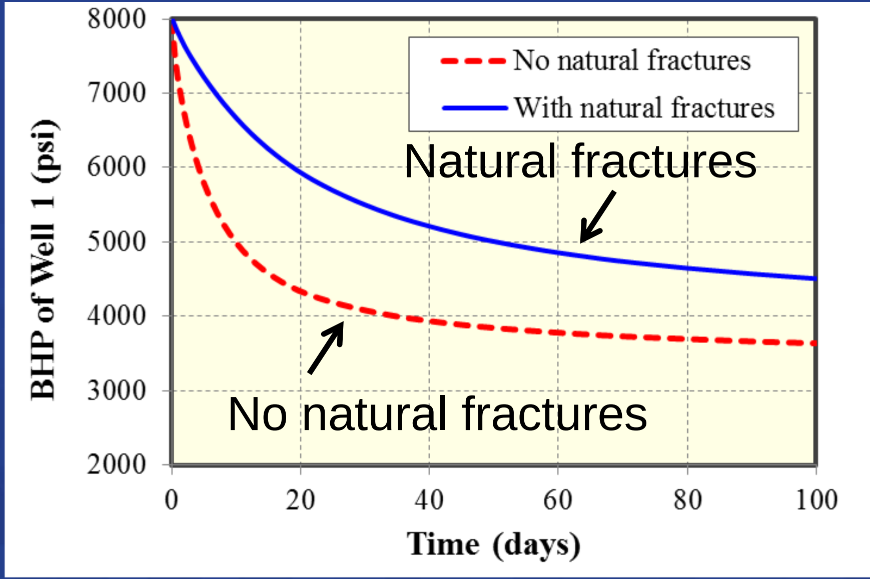
- Couple rock deformation and fluid flow
- Incorporate physical mechanisms
- ✓ Stress shadow effects
- ✓ Dynamic fluid rate distribution
- ✓ Interaction of HF and NF
- High computational efficiency



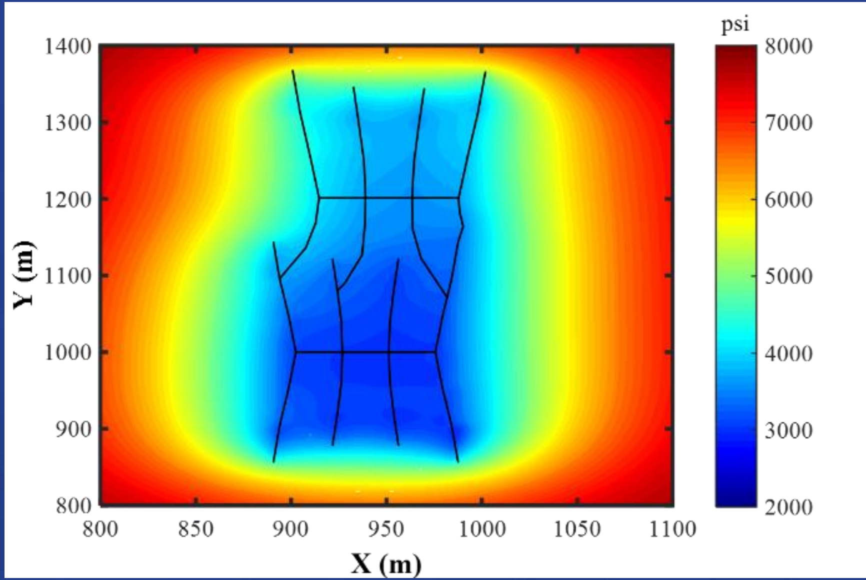
Multiple Complex Fracture Hits



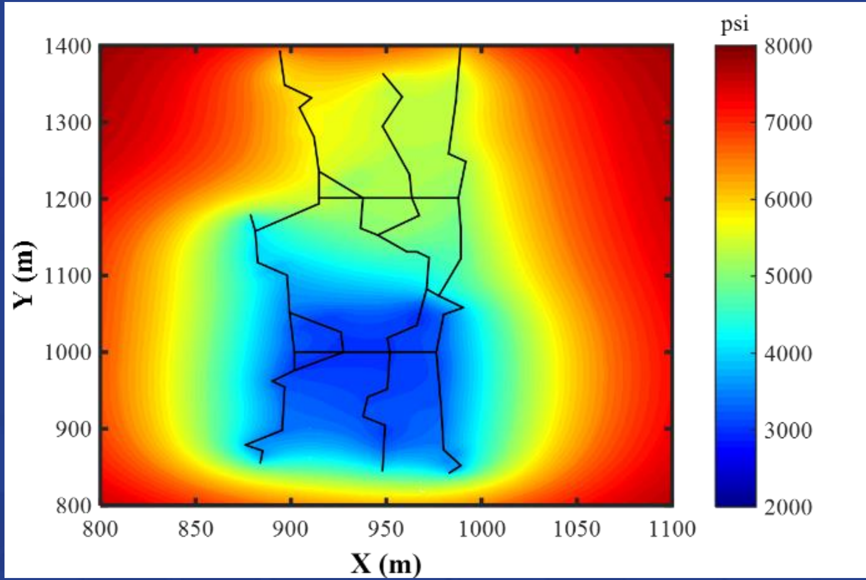




Multiple Complex Fracture Hits



No natural fractures



With natural fractures

Conclusions

- A good match between semi-analytical model and numerical model is obtained
- Pressure drop of shut-in well increases with the increasing connecting fracture conductivity, primary hydraulic fracture conductivity, and number of connecting fractures
- Pressure drop of shut-in well decreases with the increasing matrix permeability
- Pressure decline of shut-in well is larger without natural fractures than that with natural fractures

Thank You!