Research Summary

Interference Test Analysis with Two Fractured Horizontal Wells

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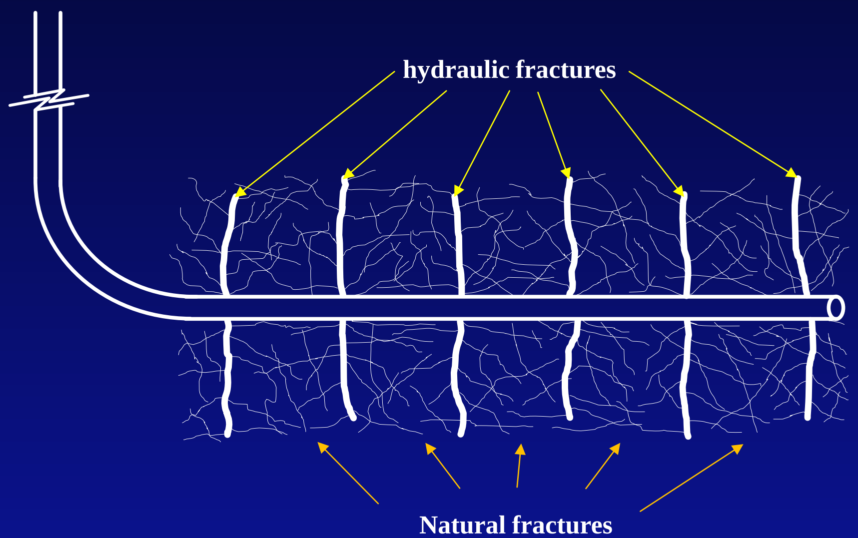
Overview

- Fractured horizontal wells in low-permeability reservoirs
- As high-conductivity paths.
- Advantages:
  - ✓ Increase contact area
  - ✓ Improve project economics
- Physical mechanism → **still limited** → interference test

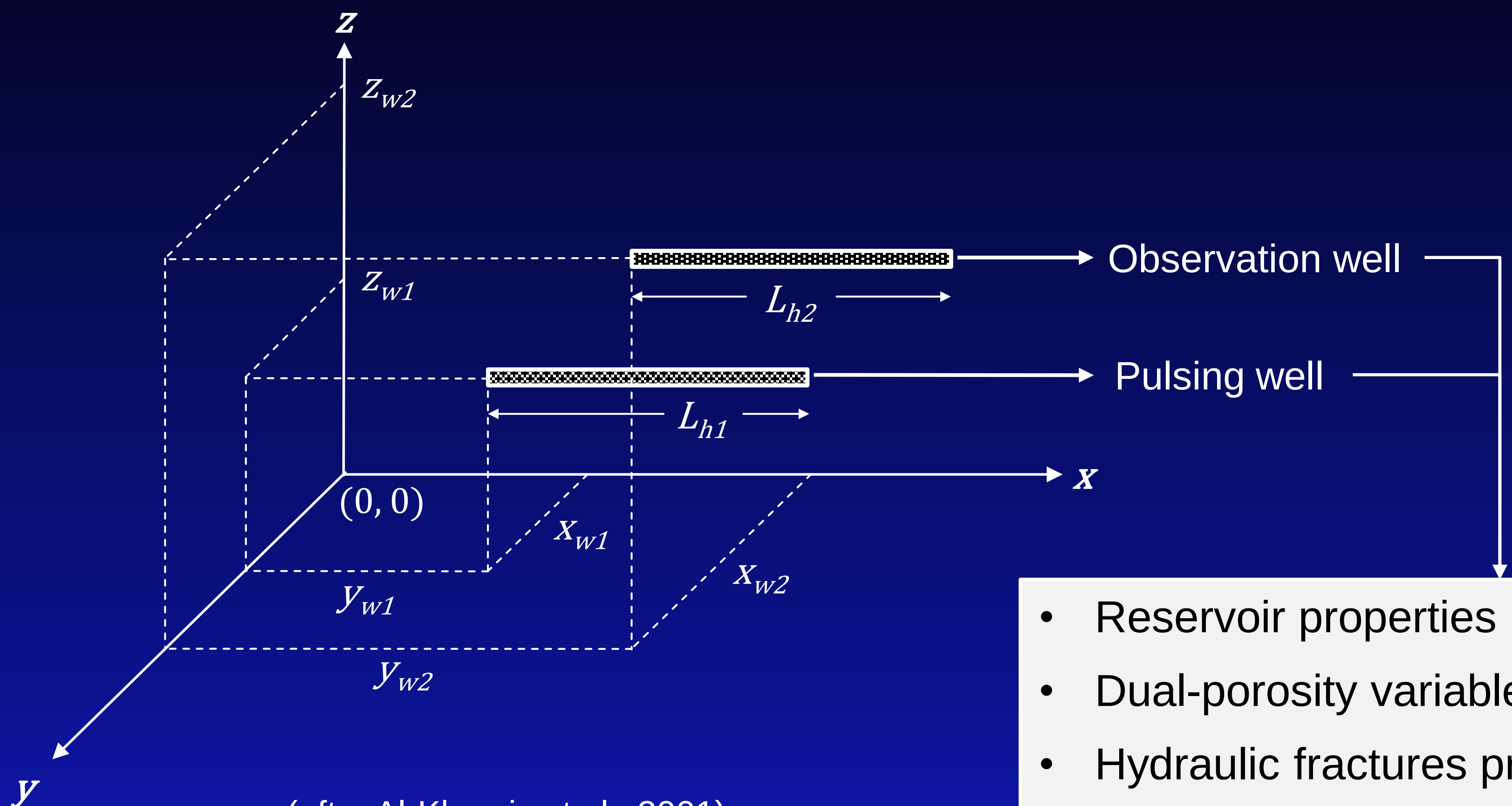
Fractured Horizontal Well



(after Torcuk et al., 2013)

What is Interference Test?

At least two wells (points) are involved



(after Al-Khamis et al., 2001)

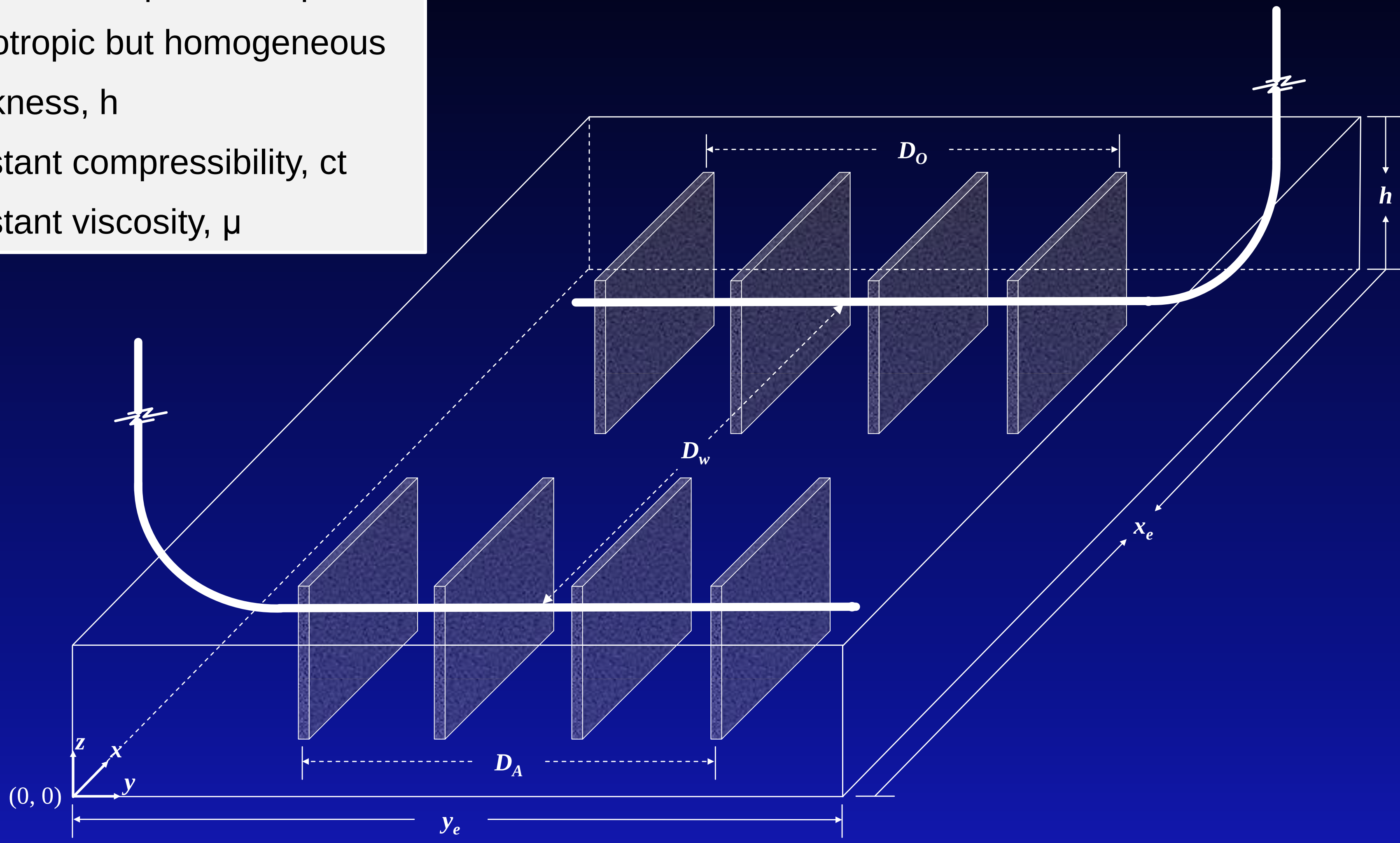
- Reservoir properties
- Dual-porosity variables
- Hydraulic fractures properties
- Reservoir connectivity

Background

- No analytical (or semi-analytical) solution.
- To develop the mathematical model:
  - Finite-conductivity fracture (Cinco-Ley and Meng, 1988)
  - Fractured horizontal well:
    - *Infinite reservoir (Raghavan et al., 1997)*
    - *Closed rectangular reservoir (Chen and Raghavan, 1997)*
  - Open horizontal section (Ozkan, 1988)
  - Superposition theorem application

Schematic Model

- Uniform initial pressure, pi
- Anisotropic but homogeneous
- Thickness, h
- Constant compressibility, ct
- Constant viscosity, μ



Mathematical Model

Finite-conductivity fracture

$$\bar{p}_{wD} - \frac{1}{2x_{fD}} \int_{-x_{fD}}^{+x_{fD}} \bar{q}_{fD}(\alpha,s) K_0\left[\sqrt{(x_D - x_{wD} - \alpha)^2 + (y_D - y_{wD})^2}\sqrt{u}\right] d\alpha + \frac{\pi}{C_{fD}} \int_{x_{wD}}^{x_D} \int_{x_{wD}}^{x_D'} \bar{q}_{fD}(x_D'') dx_D'' dx_D' = \frac{\pi x_D}{C_{fD} s}$$

$$= \bar{p}_{fD}$$

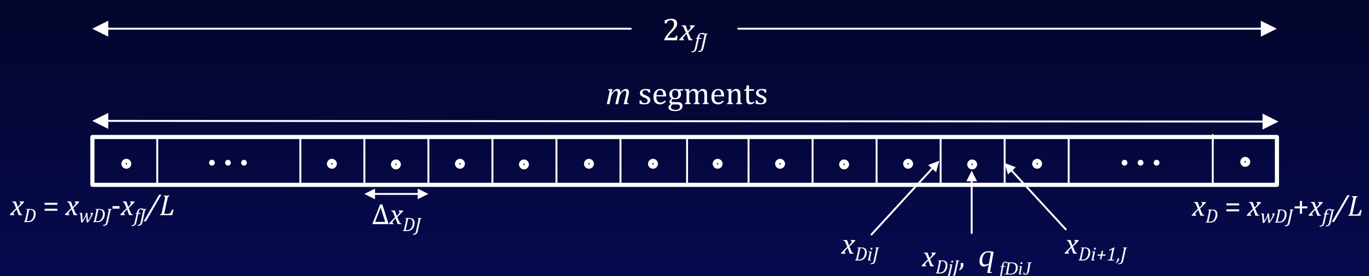
Closed rectangular – single-fracture system solution

$$\bar{p}_{fD}(x_D, y_D) = \frac{\pi}{x_{eD}} \int_{-x_{fD}}^{+x_{fD}} \bar{q}_{fD}(\alpha,s) \left\{ \frac{\left[\cosh\left(\sqrt{u}\, y_{eD1}\right) + \cosh\left(\sqrt{u}\, y_{eD2}\right)\right]}{\in} + \frac{2x_{eD}}{\pi x_{fD}} \right.$$

$$\left. \sum_{k=1}^{\infty} \frac{1}{k} \sin\left(k\pi \frac{x_{fD}}{x_{eD}}\right) \cos\left(k\pi \frac{x_{wD}}{x_{eD}}\right) \cos\left(k\pi \frac{x_D}{x_{eD}}\right) \frac{\left[\cosh\left(\in_k y_{eD1}\right) + \cosh\left(\in_k y_{eD2}\right)\right]}{\in_k} \right\} d\alpha$$

Semi-Analytical Solution

fracture discretization:



total flux equation:

$$\sum_{i=1}^{m} \bar{q}_{fDi} = \frac{m}{s}$$

$$\begin{bmatrix} a_{1,1} & a_{1,2} & . & . & . & a_{1,m+1} & 1 \\ a_{2,1} & a_{2,2} & . & . & . & a_{2,m+1} & 1 \\ a_{3,1} & a_{3,2} & . & . & . & a_{3,m+1} & 1 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ a_{m,1} & a_{m,2} & . & . & . & a_{m,m+1} & 1 \\ 1 & 1 & . & . & . & 1 & 0 \end{bmatrix} \times \begin{bmatrix} \bar{q}_{fD1}(s) \\ \bar{q}_{fD2}(s) \\ \bar{q}_{fD2}(s) \\ . \\ . \\ \bar{q}_{fD(M-1)}(s) \\ \bar{p}_{wD}(s) \end{bmatrix} = \begin{bmatrix} \pi x_{D1}/C_{fD}s \\ \pi x_{D2}/C_{fD}s \\ \pi x_{D3}/C_{fD}s \\ . \\ . \\ \pi x_{Dm}/C_{fD}s \\ m/s \end{bmatrix}$$

Matrix Equation for Interference Test

$$[A]\cdot\{x\}=\{B\}$$

Superposition Theorem:

$$\bar{p}_D=\bar{p}_{DA}+\bar{p}_{DO}$$

Inf. cond. wellbore:

$$\bar{p}_{wDA}=\bar{p}_{wDAj}$$

$$\bar{p}_{wDO}=\bar{p}_{wDOj}$$

Total flux equation:

$$\sum_{k=1}^{n_A}\sum_{i=1}^{m_A}\bar{q}_{fDi,kA}=\frac{m_A}{s}$$

$$\sum_{k=1}^{n_O}\sum_{i=1}^{m_O}\bar{q}_{fDi,kO}=0$$

Pressure convolution:

$$\bar{p}_{wDA}=\sum_{k=1}^{n_A}s\bar{q}_{DkA}\,\bar{p}_{wDAj,k}$$

$$\bar{p}_{wDO}=\sum_{k=1}^{n_O}s\bar{q}_{DkO}\,\bar{p}_{wDOj,k}$$

$$A=\begin{bmatrix}
a_{1,1} & a_{1,2} & . & . & a_{1,m_A*n_A} & b_{1,1} & b_{1,2} & . & . & b_{1,m_O*n_O} & 1 & 0\\
a_{2,1} & a_{2,2} & . & . & a_{2,m_A*n_A} & b_{2,1} & b_{2,2} & . & . & b_{2,m_O*n_O} & 1 & 0\\
. & . & . & . & . & . & . & . & . & . & . & .\\
. & . & . & . & . & . & . & . & . & . & . & .\\
a_{m_A*n_A,1} & a_{m_A*n_A,2} & . & . & a_{m_A*n_A,m_A*n_A} & b_{m_O*n_O,1} & b_{m_O*n_O,2} & . & . & b_{m_O*n_O,m_O*n_O} & 1 & 0\\
c_{1,1} & c_{1,2} & . & . & c_{1,m_A*n_A} & d_{1,1} & d_{1,2} & . & . & d_{1,m_O*n_O} & 0 & 1\\
c_{2,1} & c_{2,2} & . & . & c_{2,m_A*n_A} & d_{2,1} & d_{2,2} & . & . & d_{2,m_O*n_O} & 0 & 1\\
. & . & . & . & . & . & . & . & . & . & . & .\\
. & . & . & . & . & . & . & . & . & . & . & .\\
c_{m_A*n_A,1} & c_{m_A*n_A,2} & . & . & c_{m_A*n_A,m_A*n_A} & d_{m_O*n_O,1} & d_{m_O*n_O,2} & . & . & d_{m_O*n_O,m_O*n_O} & 0 & 1\\
1 & 1 & . & . & 1 & 0 & 0 & . & . & 0 & 0 & 0\\
0 & 0 & . & . & 0 & 1 & 1 & . & . & 1 & 0 & 0
\end{bmatrix}$$

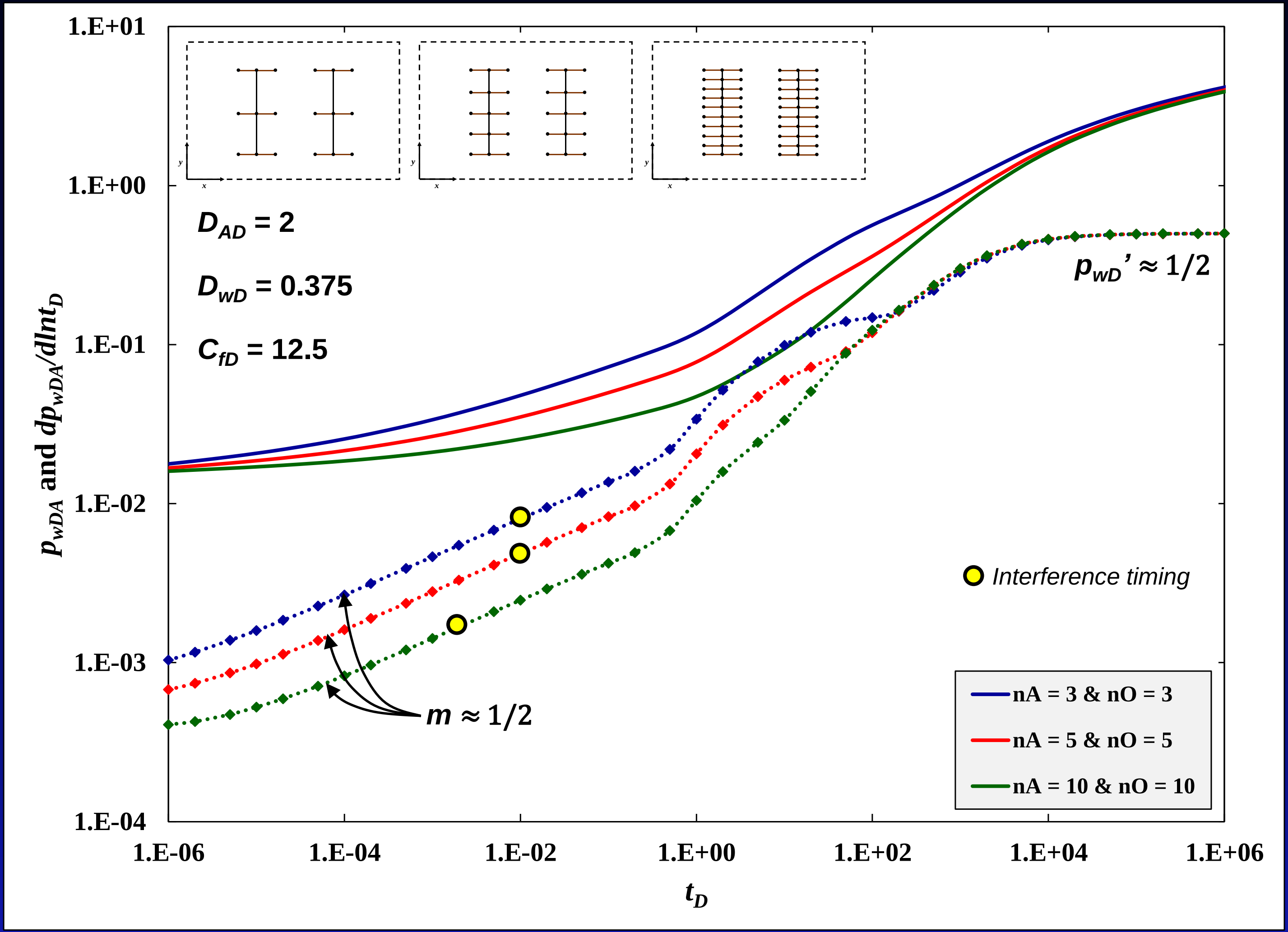
$$x=\begin{bmatrix}\bar{q}_{fDA1,1}(s) & \bar{q}_{fDA1,2}(s) & . & . & . & \bar{q}_{fDO1,1}(s) & \bar{q}_{fDAO1,2}(s) & . & . & . & \bar{p}_{wDA}(s) & \bar{p}_{wDO}(s)\end{bmatrix}$$

$$B=\begin{bmatrix}\dfrac{\pi x_{DjA1}}{C_{fDA}s} & \dfrac{\pi x_{DjA2}}{C_{fDA}s} & . & . & \dfrac{\pi x_{DjAn_A}}{C_{fDA}s} & 0 & 0 & . & . & 0 & \dfrac{m_A}{s} & 0\end{bmatrix}$$

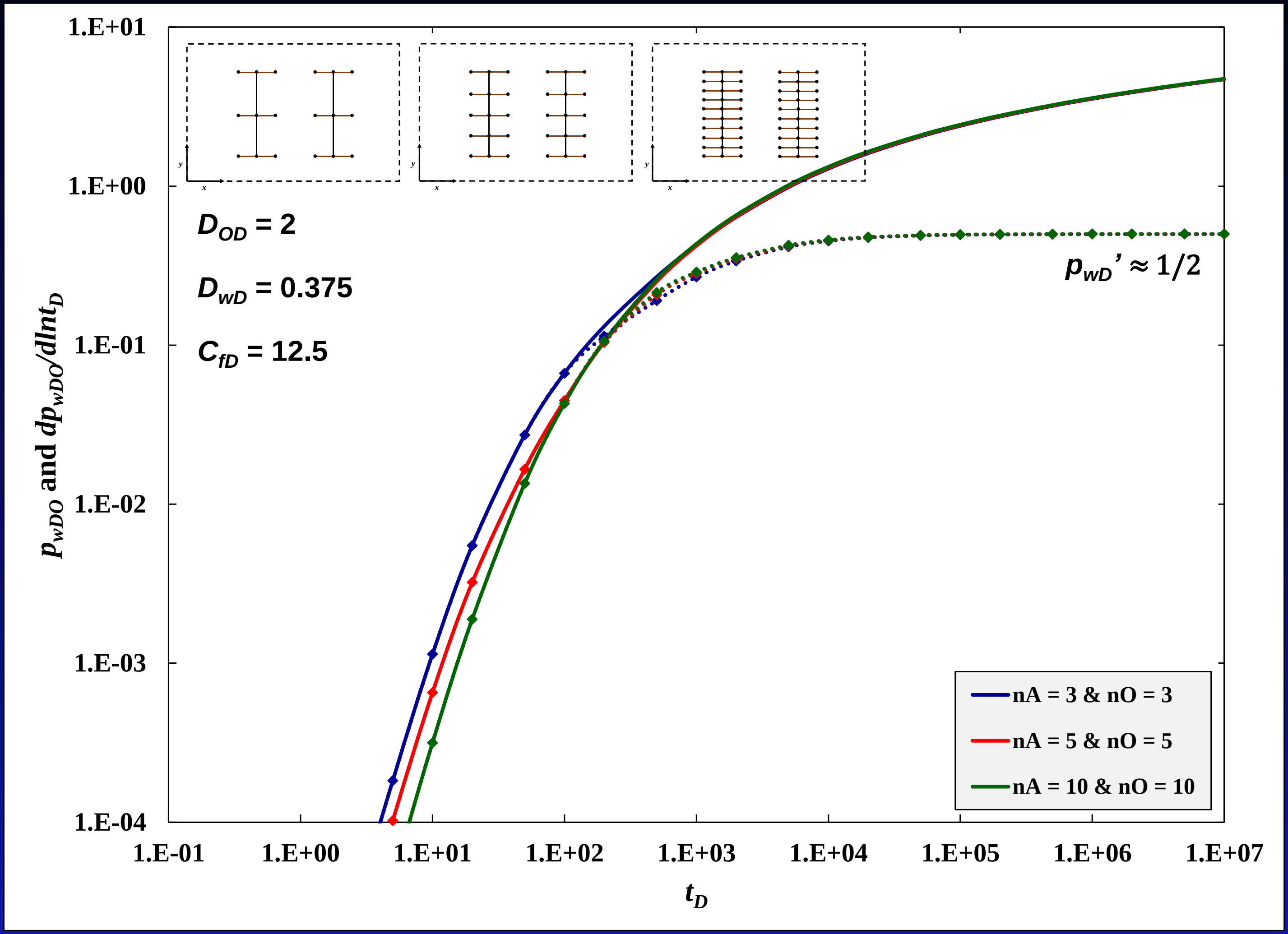
Preliminary Results

- Two fractured horizontal wells in an infinite reservoir (base case)
- Zipper well configuration
- Fractured horizontal well intercepted by a stand-alone fracture

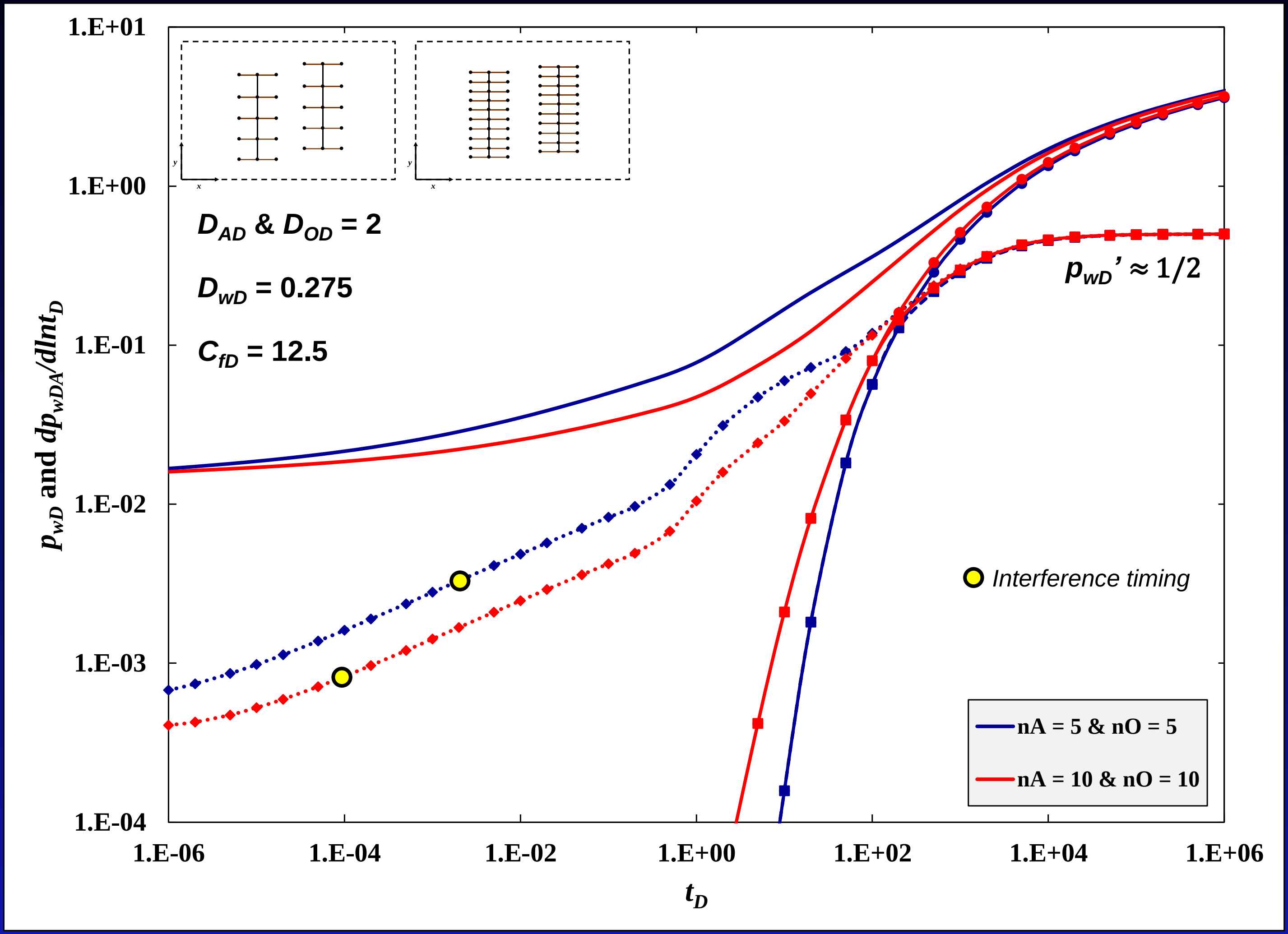
Base Case – Active Well



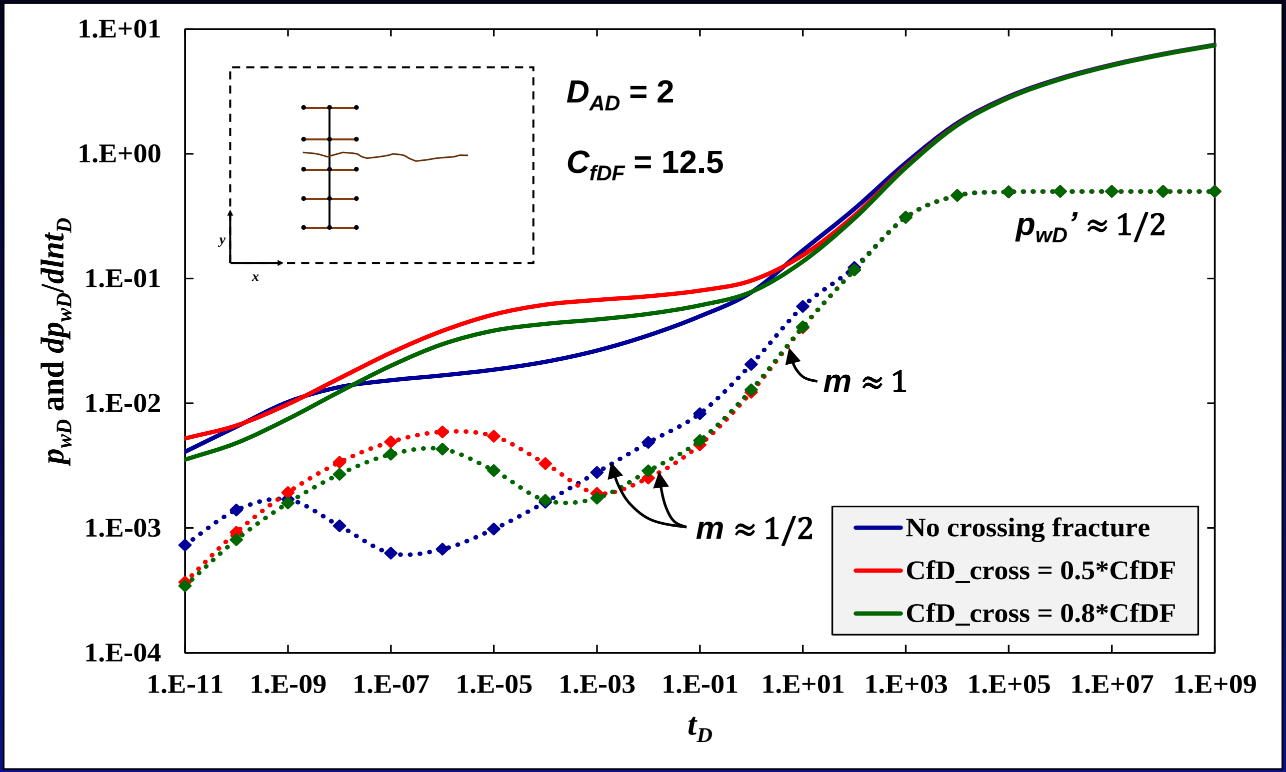
Base Case – Observation Well



Zipper Well Configurations



Frac. Hz. Well with a Stand-Alone Fracture (n_F = 5)



This model will be used for interference test with a stand-alone (crossing) finite-conductivity fracture

Ongoing Works

- Discussions on the distribution of multiple-fracture fluxes, pressure-transient responses, and boundary effects.
- Effect of:
  - Horizontal and vertical separation (zipper and non-zipper)
  - Open horizontal sections
  - Permeability anisotropy
  - Stand-alone fracture crossing both active and observation wells

Thank you…