Simulating Naturally Fractured Reservoirs: Comparing Discrete Fracture Network Models to the Upscaled Equivalents*

By

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Search and Discovery Article #40323 (2008)
Posted November 3, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, Texas, April 20-23, 2008

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Abstract

Naturally-fractured reservoirs are an important, but difficult to manage, worldwide reservoir type. Complex, difficult-to-define, fracture networks yield complex reservoir systems with significant uncertainty regarding their ability to aid, or impair production. Despite the key role of fracture networks in production performance, reservoir simulations typically use equivalent, porous medium properties to represent the aggregate impact of fracture networks. A series of simulations performed for two idealized, fractured basement reservoirs provide a basis for comparing results obtained using: 1) a discrete 3-D fracture network (DFN) simulator, and 2) two different equivalent porous media simulators. The two reservoir cases illustrate the possible impact of geologic uncertainty in assessing the characteristics of subsurface fracture networks. Results obtained using both single- and dual- porosity simulation methods are also compared.

Three-phase, black-oil simulators used in this study include the conventional reservoir simulators ECLIPSE and IMEX and the upstream transmissibility weighted control volume finite element DFN simulator developed at the University of Utah. The geometry-based Oda method is used to upscale permeability tensors initially defined in the discrete fracture network. Volumetric fracture intensity is calculated in each grid block to represent the upscaled porosity. Upscaling with a series of different grid block sizes (ranging from 10 to 200 ft cubes) in a 1000 by 1000 by 200 ft reservoir volume reveals that the upscaled results depend strongly on the relationship between grid block size, fracture network geometry, and simulator type. A portfolio of comparative simulation results are helping us to better understand the level of uncertainty that might be introduced when using equivalent property, multi-phase simulators to represent fractured reservoir systems.

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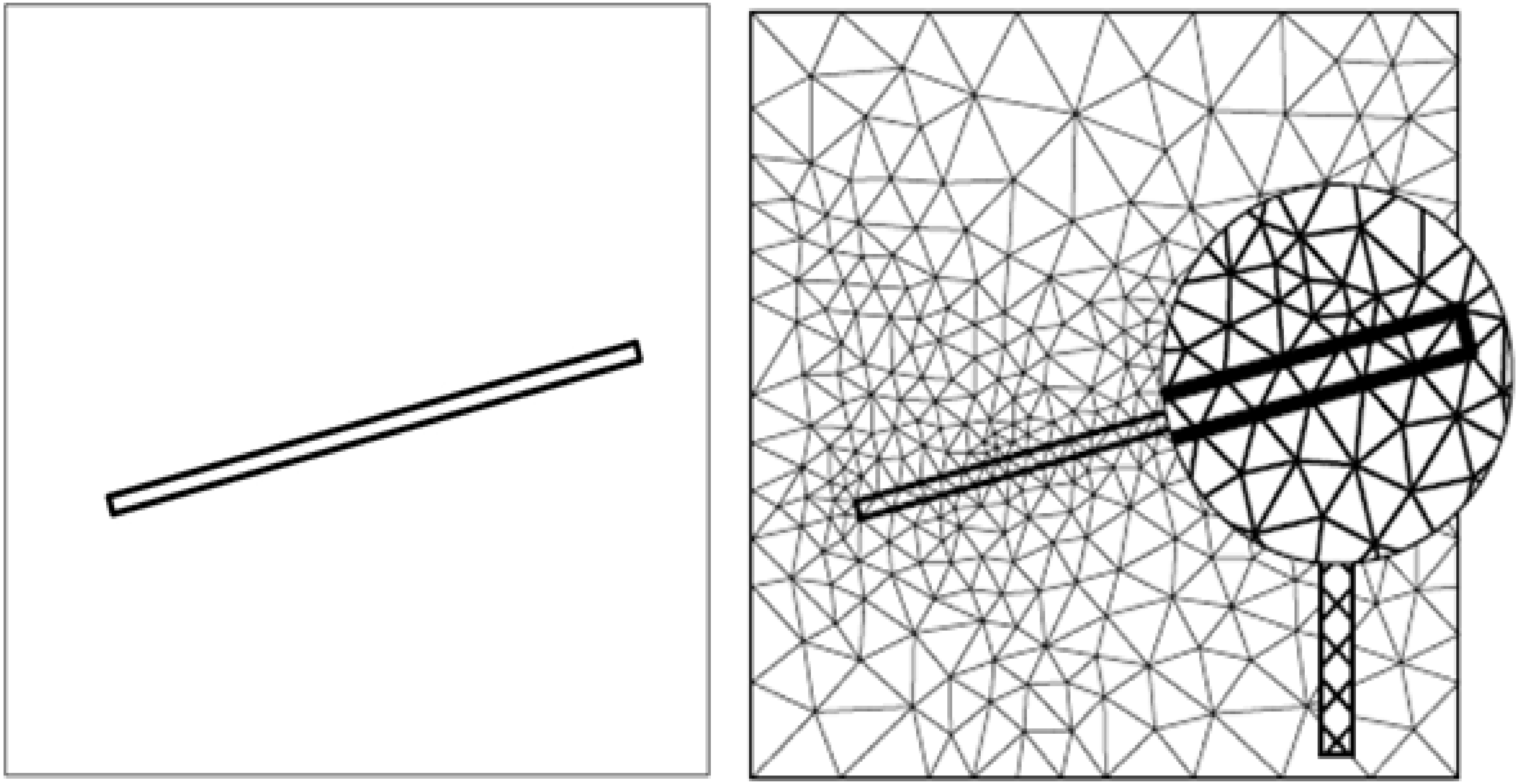
❑Outline

- Background
- Simulator verification
- Fracture properties homogenization
- Case studies (multi-phase)
- Summary

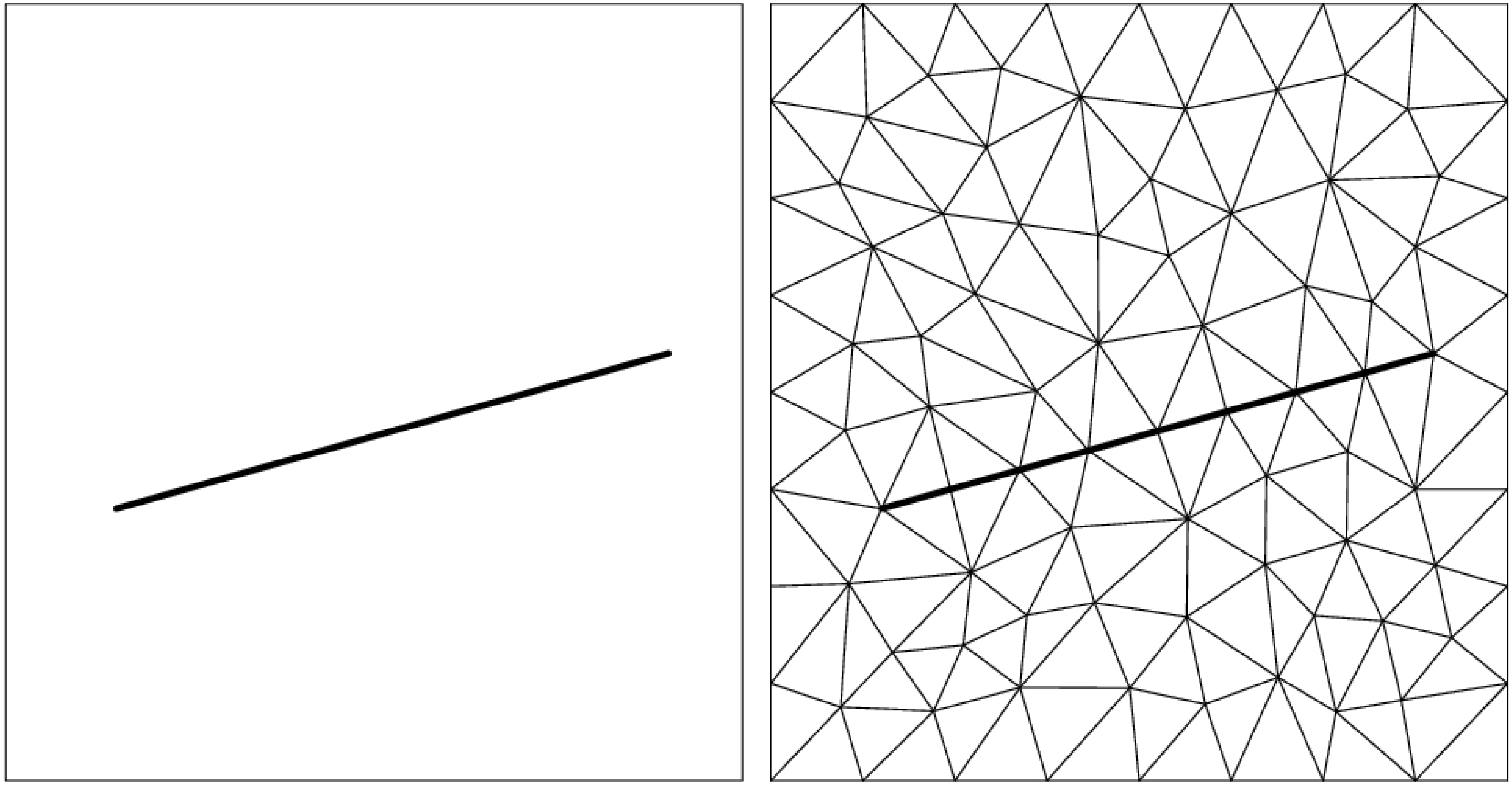
❑Background – Modeling fractures in reservoir simulation

- **Single Porosity**
- Discrete Fracture Network (DFN)
- Dual Porosity



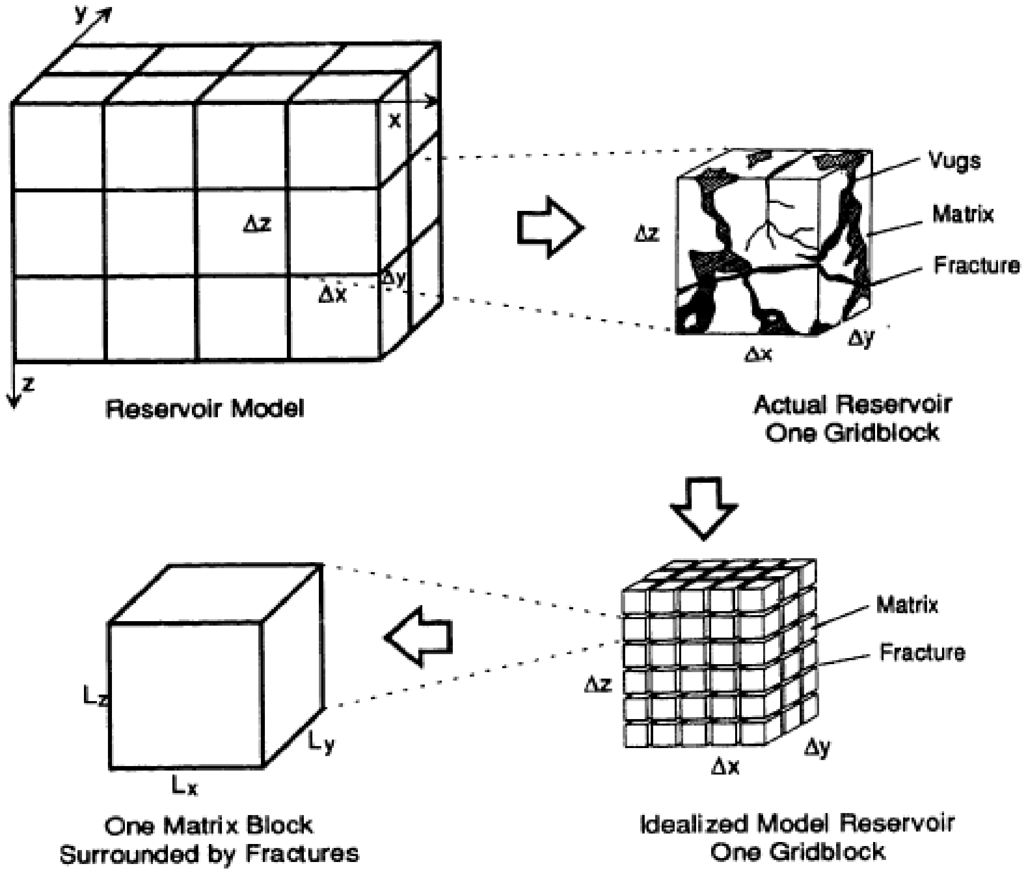
Background – Modeling fractures in reservoir simulation

- Single Porosity
- **Discrete Fracture Network (DFN)**
- Dual Porosity



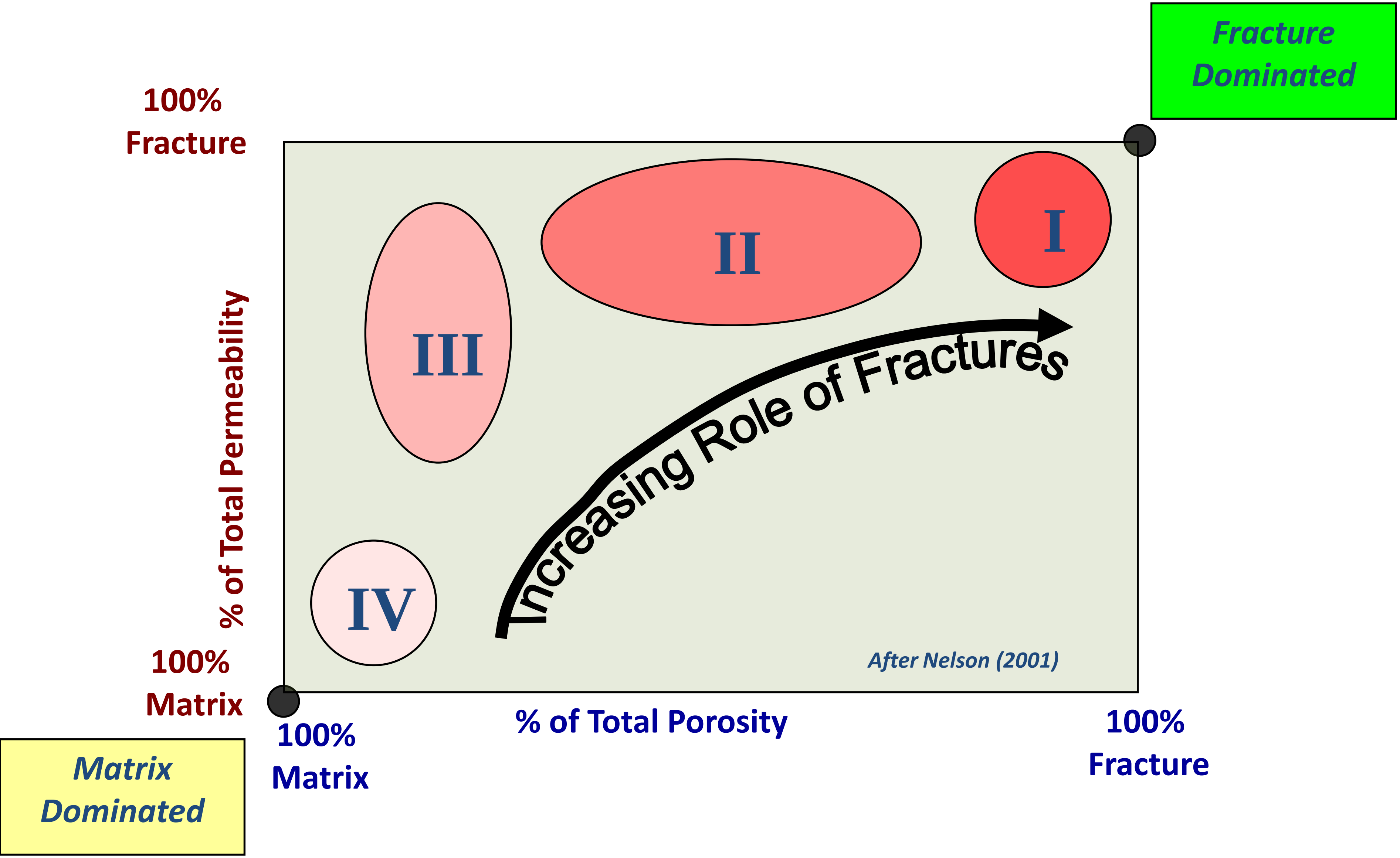
Background – Modeling fractures in reservoir simulation

- Single Porosity
- Discrete Fracture Network (DFN)
- **Dual Porosity**



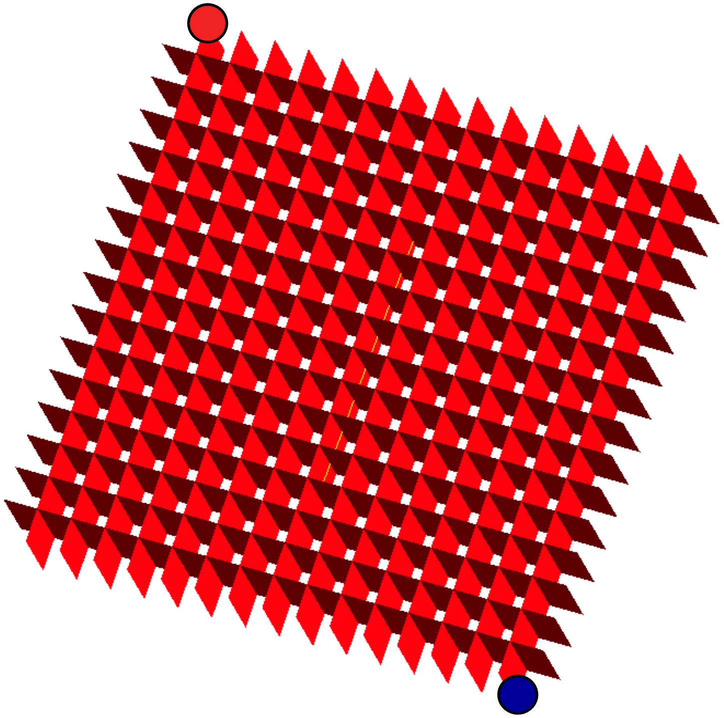
(Warren and Root, 1963)

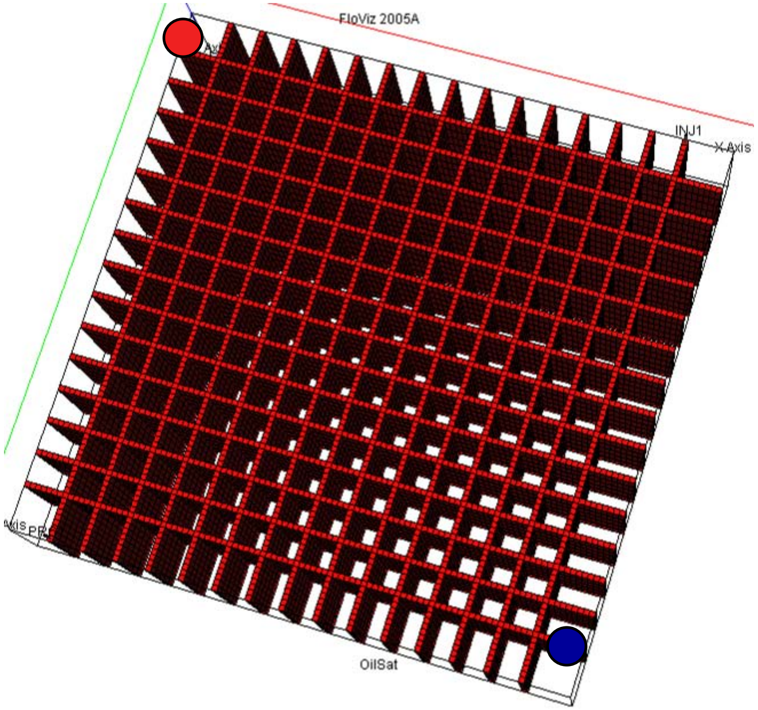
❑Background - Fractured reservoir classifications



After Nelson (2001)

❑CVFE simulator verification – Regular basement domain

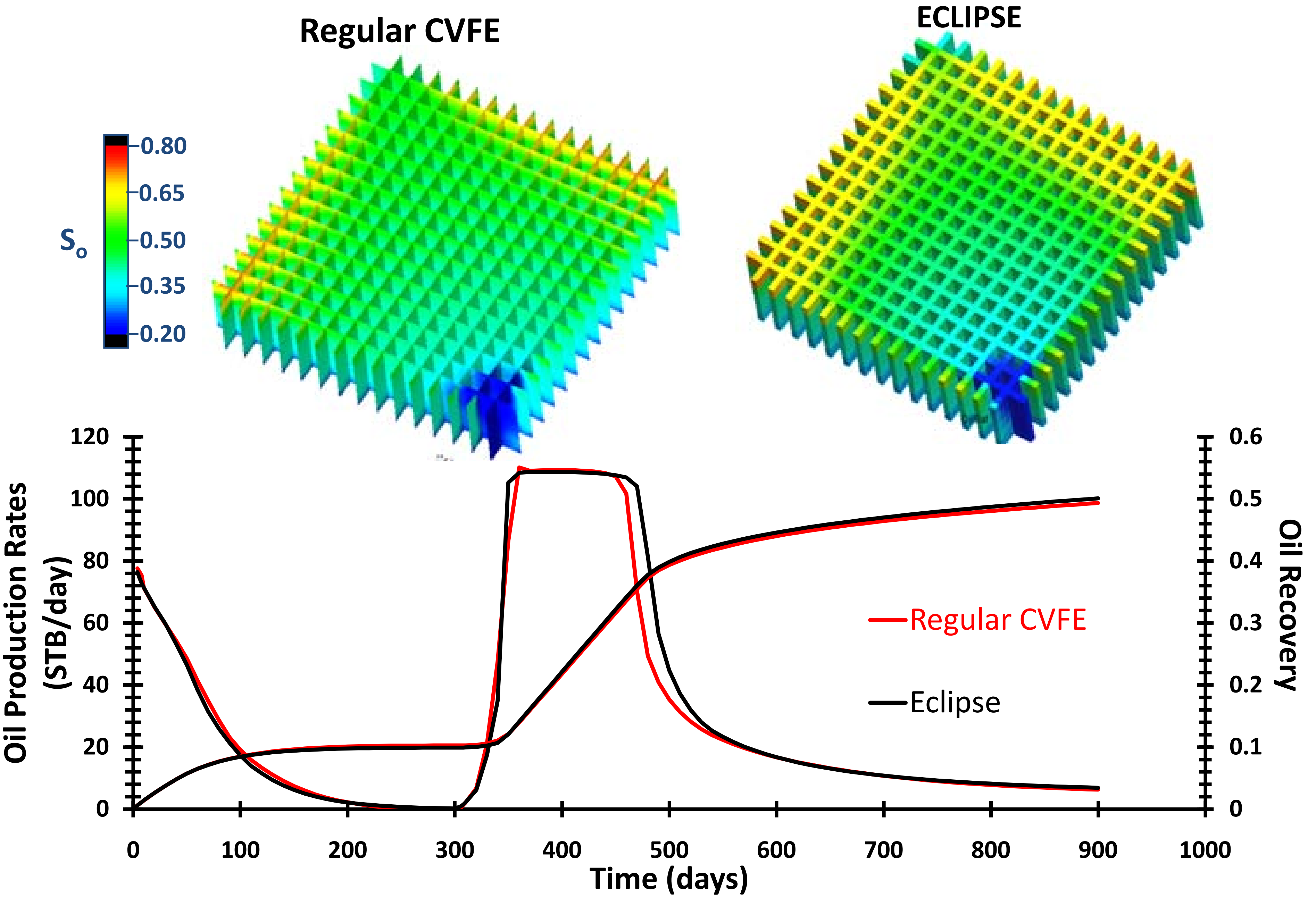




Common Model Properties

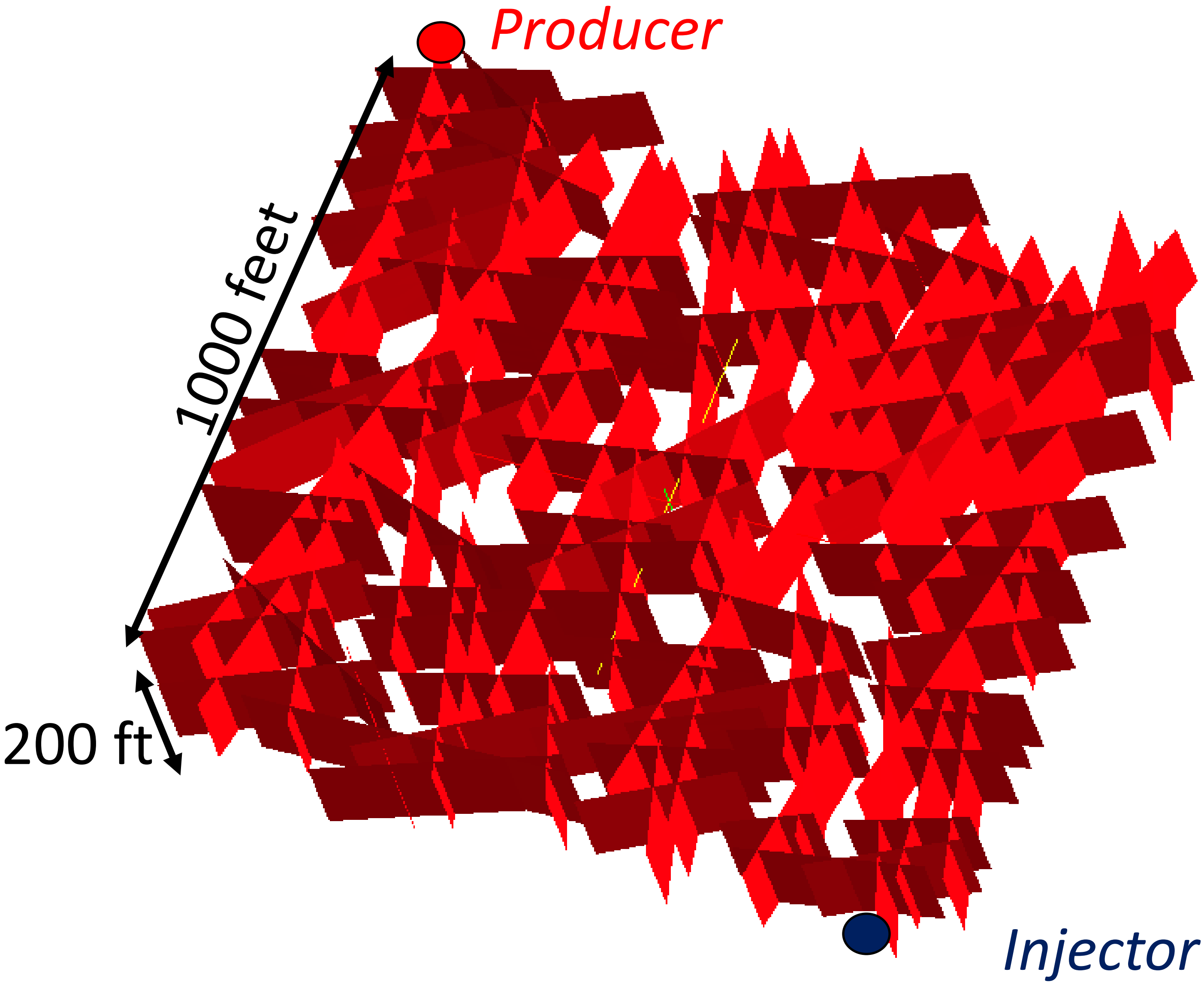
- Impermeable matrix with *f* = 0 (Type I, basement reservoir system)
- Domain = 1,000 ft by 1,000 ft by 200 feet deep
- Total feature length = 30,000 feet
- Reference Case: Feature *k* = 1,000 md, *f* = 14 %, width = 0.5 feet
- OOIP = 53,580 STB
- Injection Pressure = 4,300 psi
- ●Injection Well ●Production Well

❑CVFE simulator verification - Model comparisons at 900 days

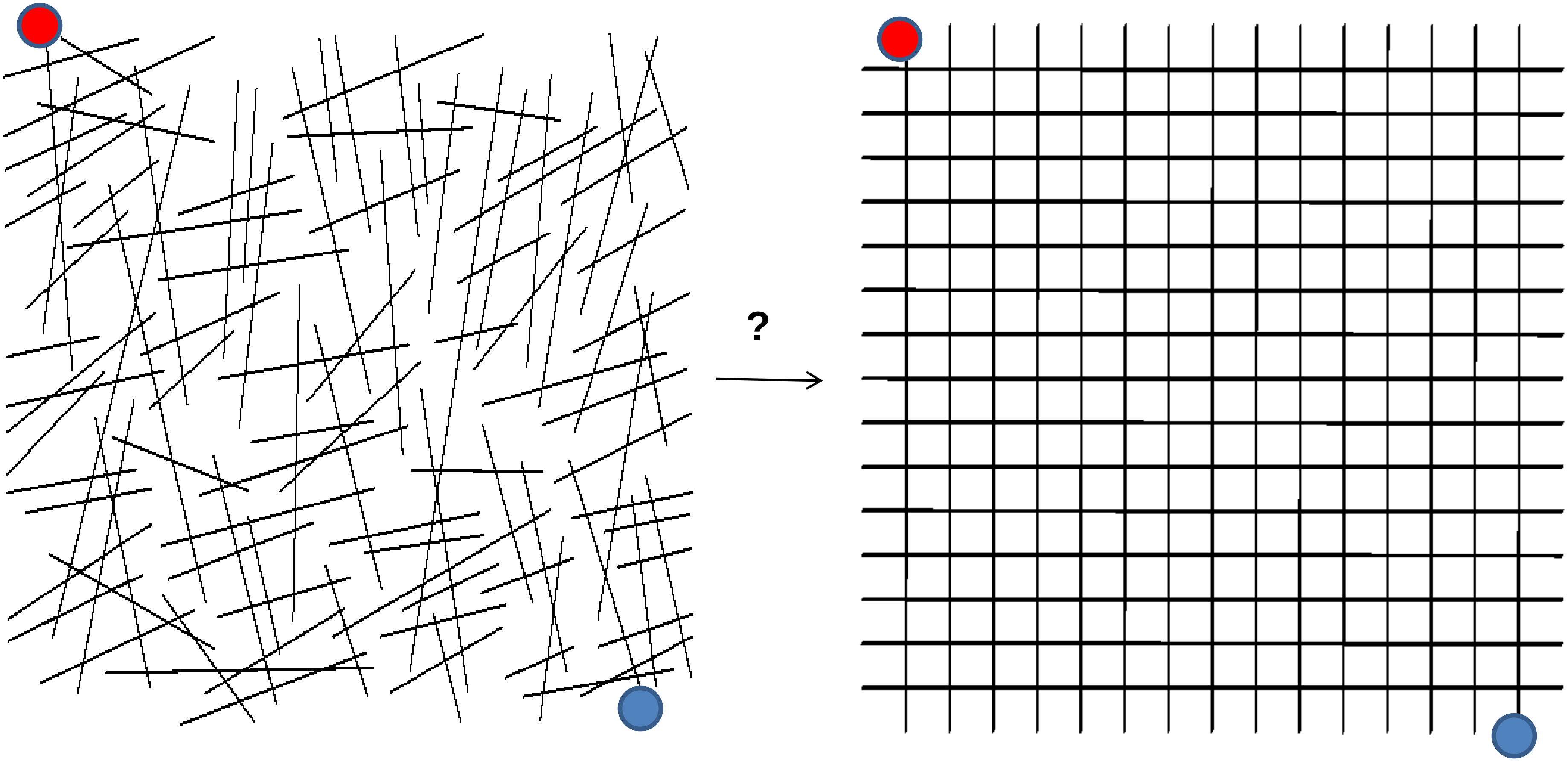


❑Consider “real” discrete fracture networks

k = 1000 md, f = 14 %, width = 0.5 feet



Can “real” system be represented by “ideal” system?



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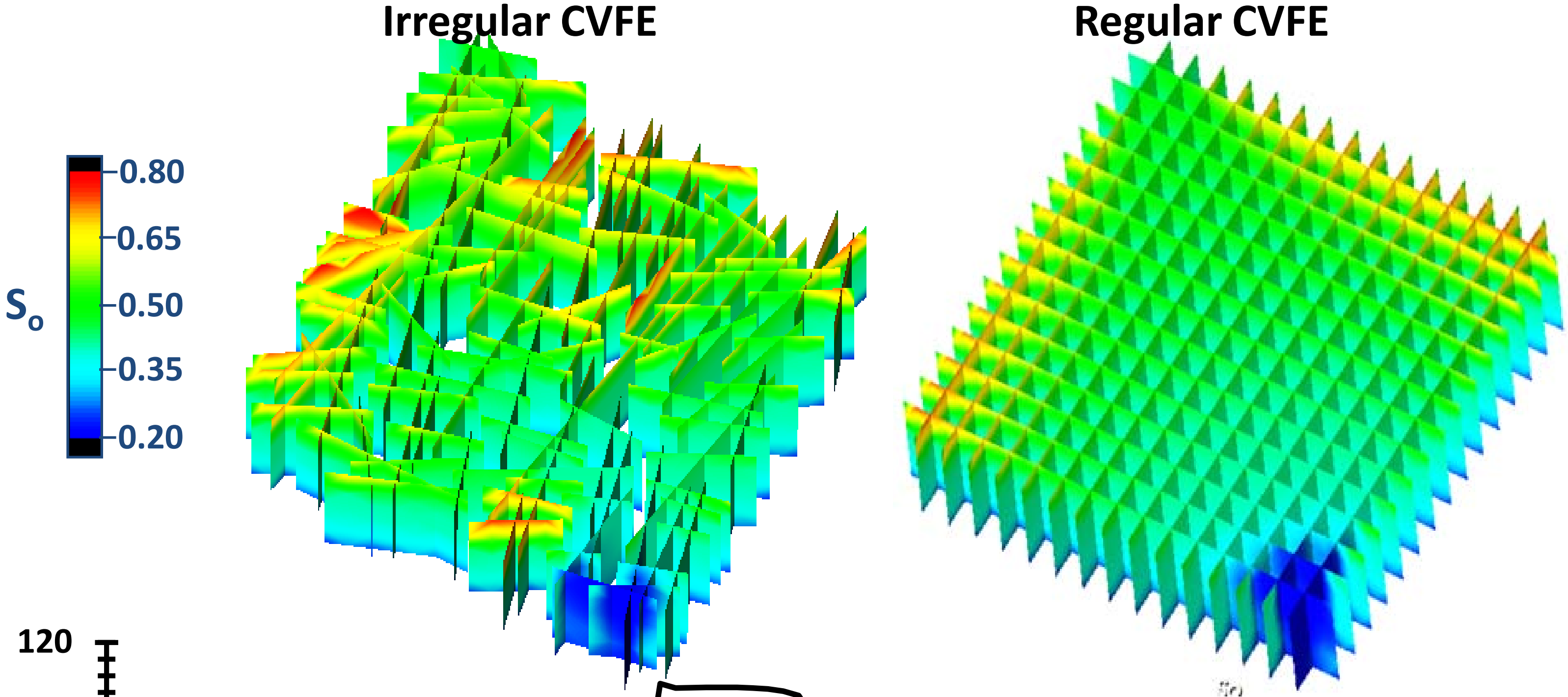
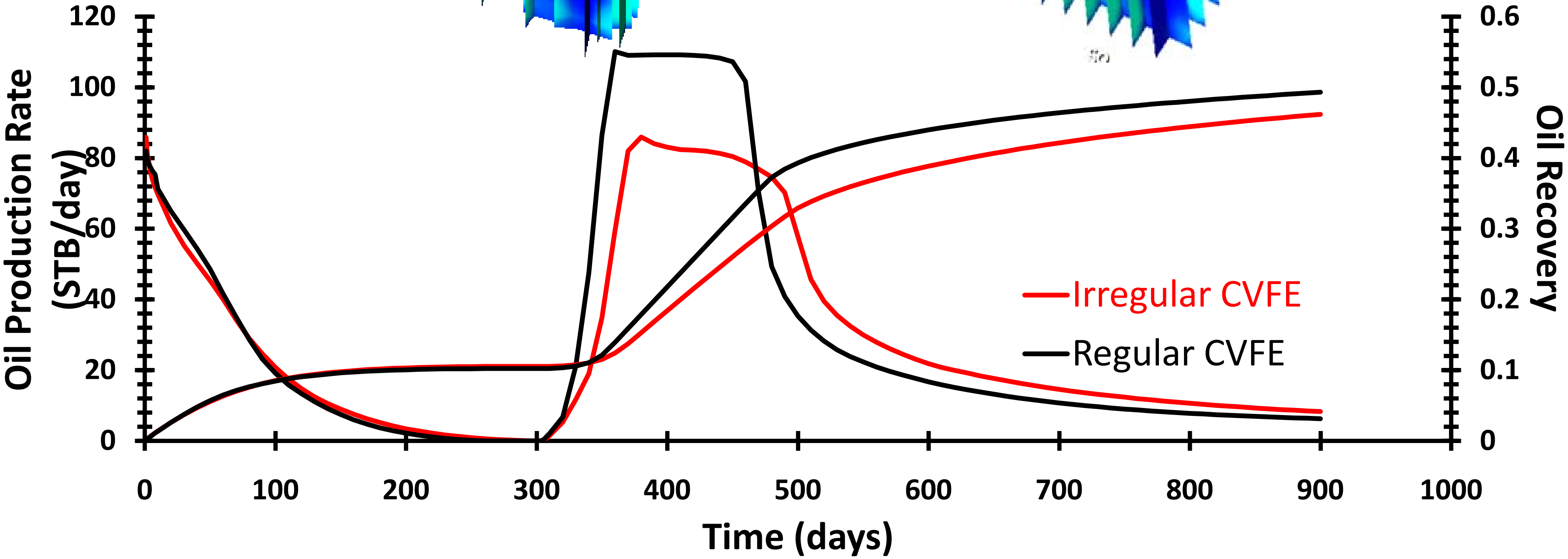
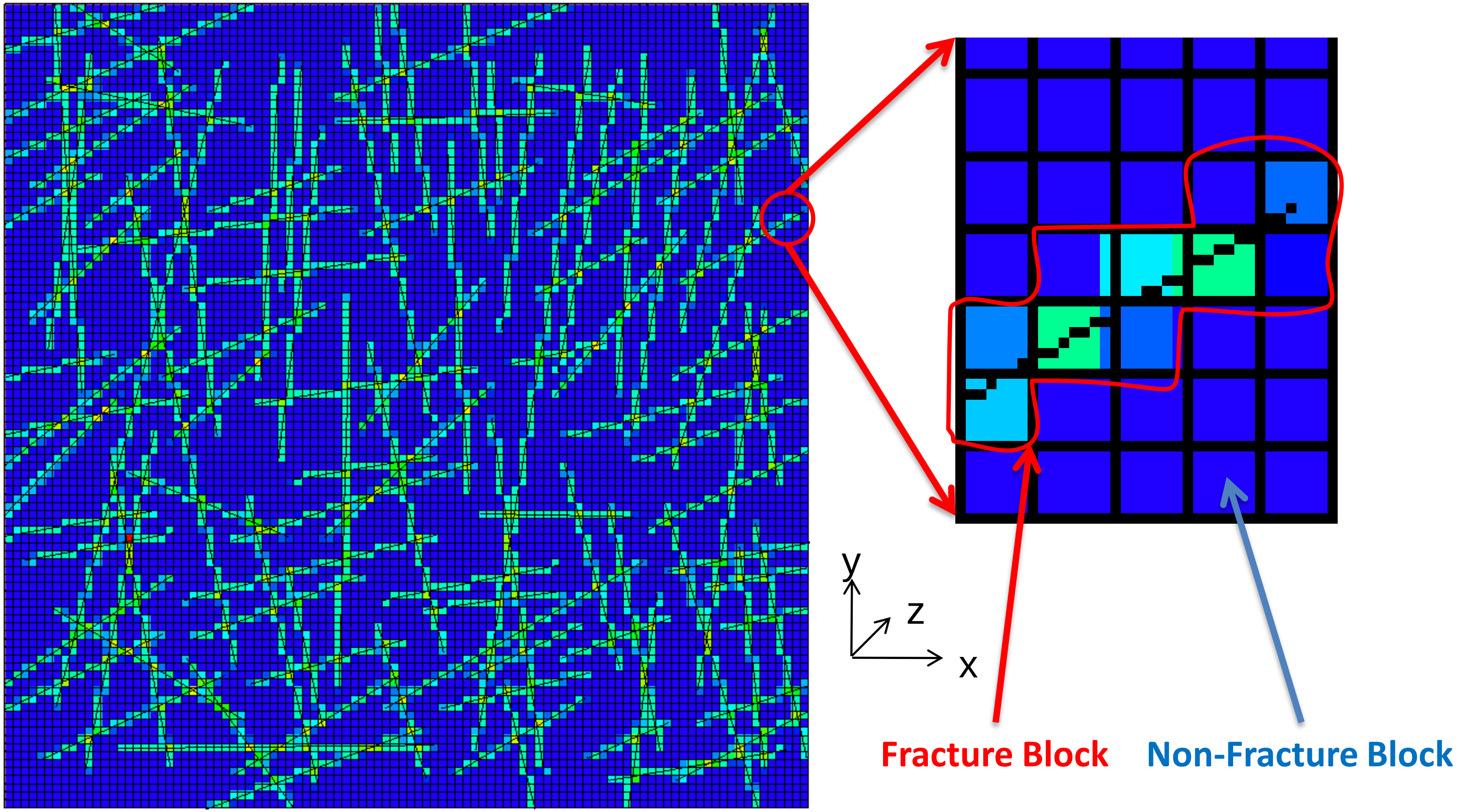




Fine grid for conventional finite-difference simulator



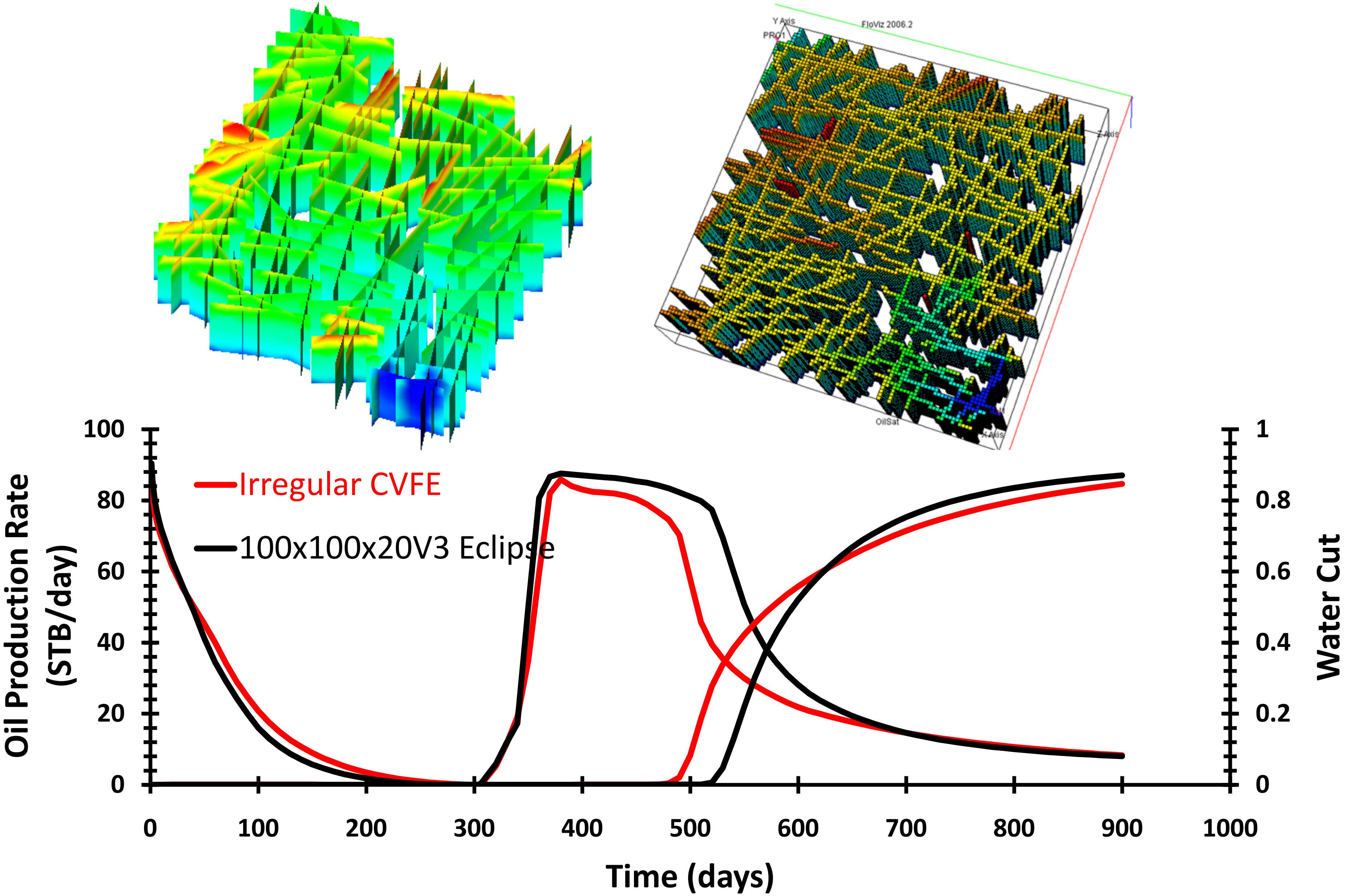
Fracture Block **Non-Fracture Block**

$$\Phi_{GridBlock} = \frac{V_{DFN}}{V_{GridBlock}} = \frac{\sum (A_{DFN} \cdot e)}{V_{GridBlock}} = P_{32} \cdot e$$

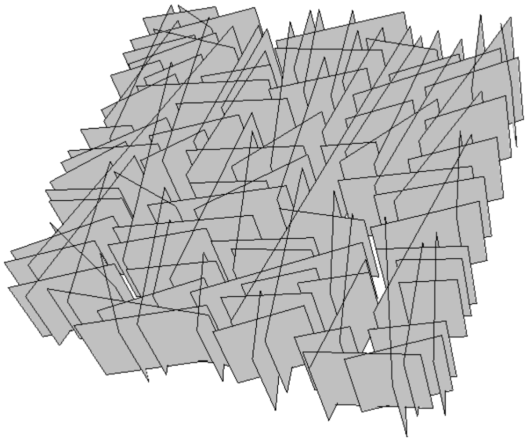
☐ Fine grid for conventional finite-difference simulator

CVFE: 27 min

ECLIPSE: 3158 min

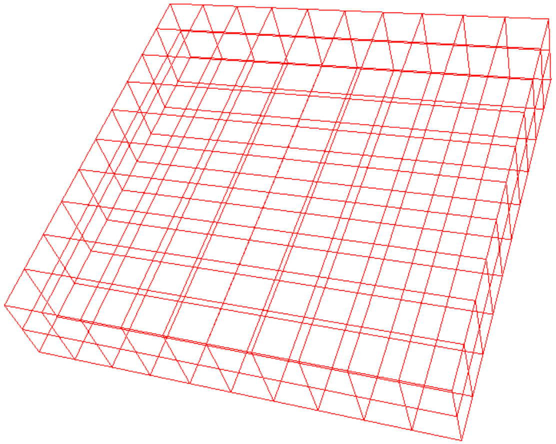


❑Fracture properties homogenization – porosity



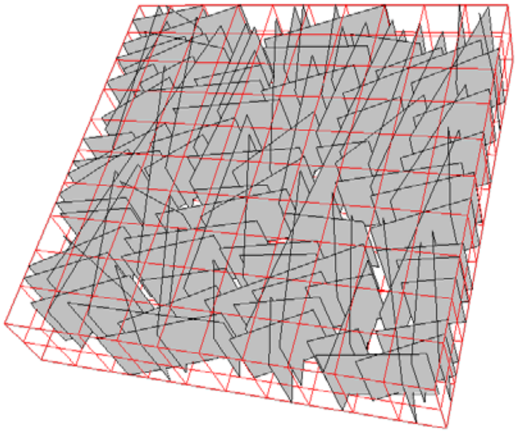
Fracture Network

+



Gridblocks

=



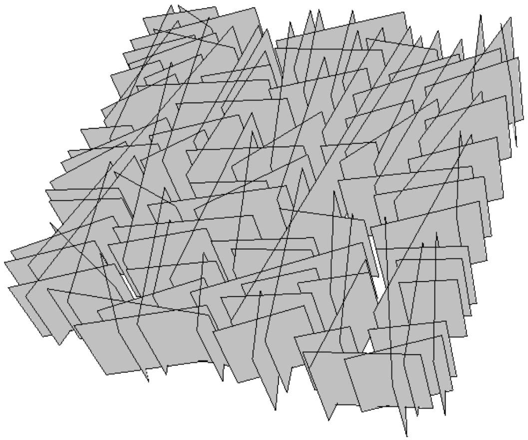
Equivalent Continuum

- **Porosity Homogenization**:

$$\Phi_{GridBlock} = \frac{V_{DFN}}{V_{GridBlock}} = \frac{\sum (A_{DFN} \cdot e)}{V_{GridBlock}} = P_{32} \cdot e$$

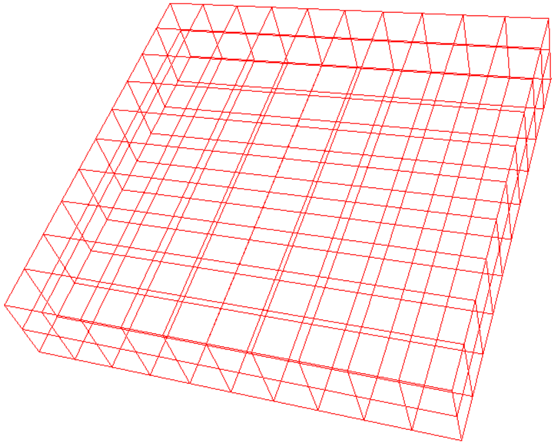
(Dershowitz et.al., 2000)

❑Fracture properties homogenization – Permeability



Fracture Network

+



Gridblocks

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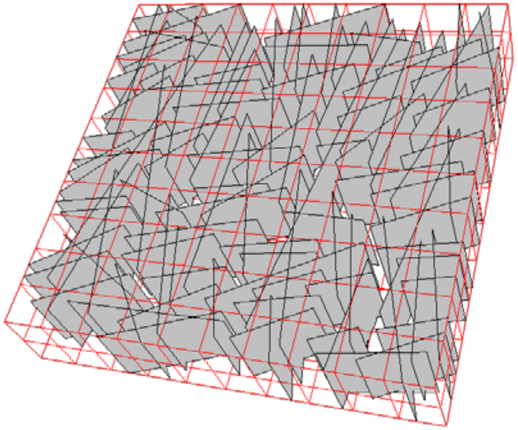
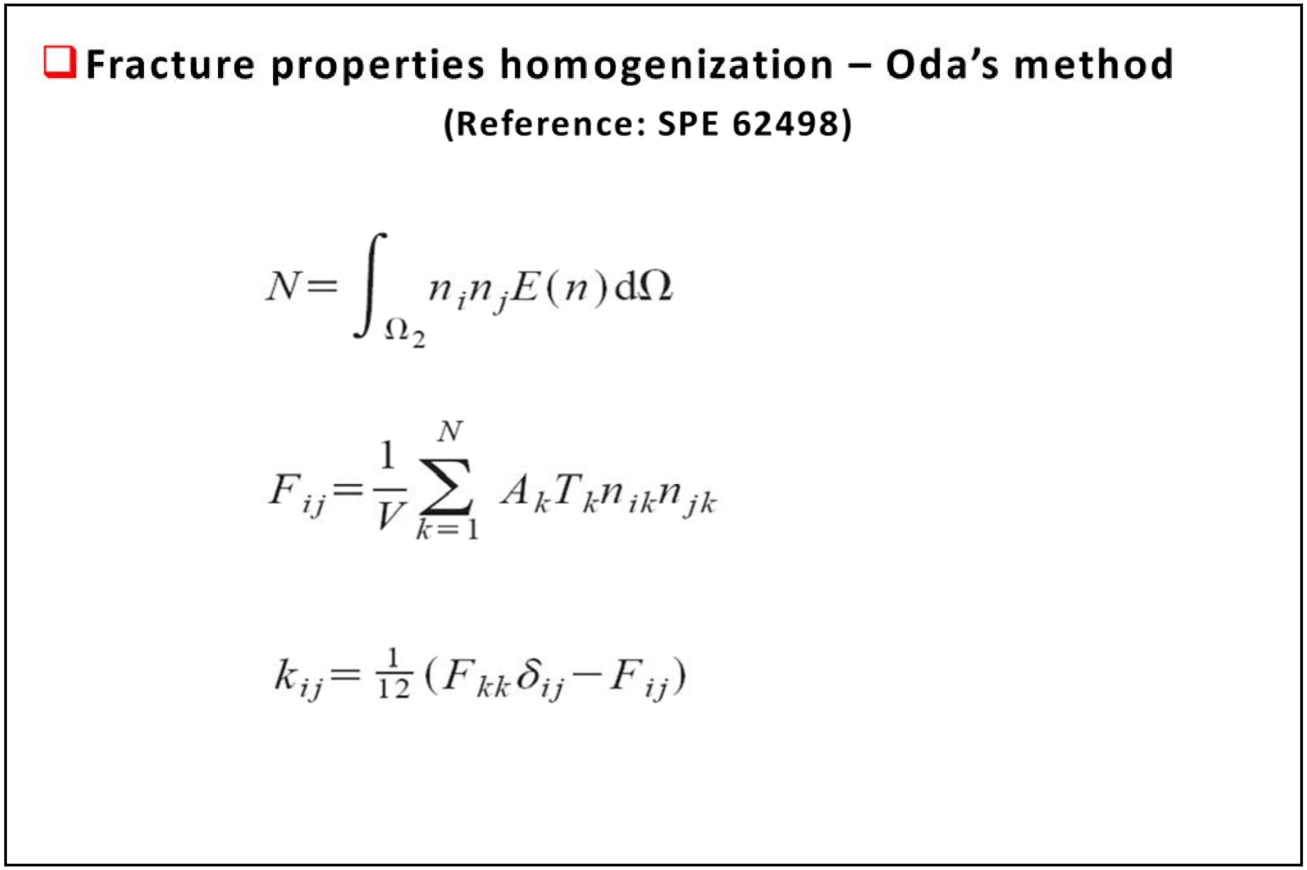


Equivalent Continuum

- **Permeability Homogenization:**
  - Geometric based: Oda Method
  - Flow based: block “K” method



❑ Fracture properties homogenization – Oda’s method

(Reference: SPE 62498)

$$N = \int_{\Omega_2} n_i n_j E(n)\, \mathrm{d}\Omega$$

$$F_{ij} = \frac{1}{V} \sum_{k=1}^{N} A_k T_k n_{ik} n_{jk}$$

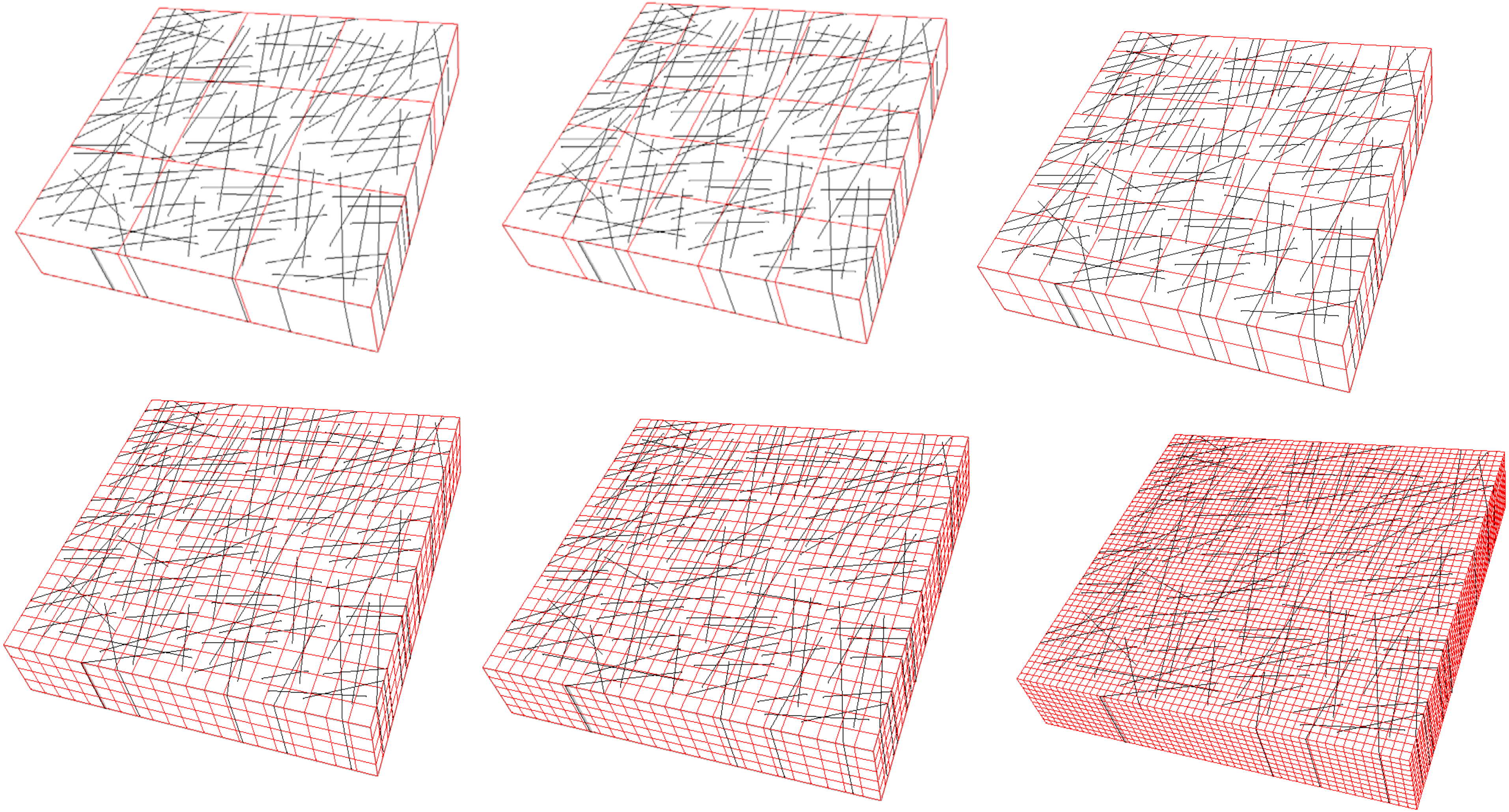
$$k_{ij} = \tfrac{1}{12}\left(F_{kk}\delta_{ij} - F_{ij}\right)$$

Oda’s method begins by considering the orientation of the fractures in a grid cell, expressed as a unit normal vector n, integrating the fractures over all of the unit normals N; Oda obtained the mass moment of inertia of fracture normals distributed over a unit sphere.

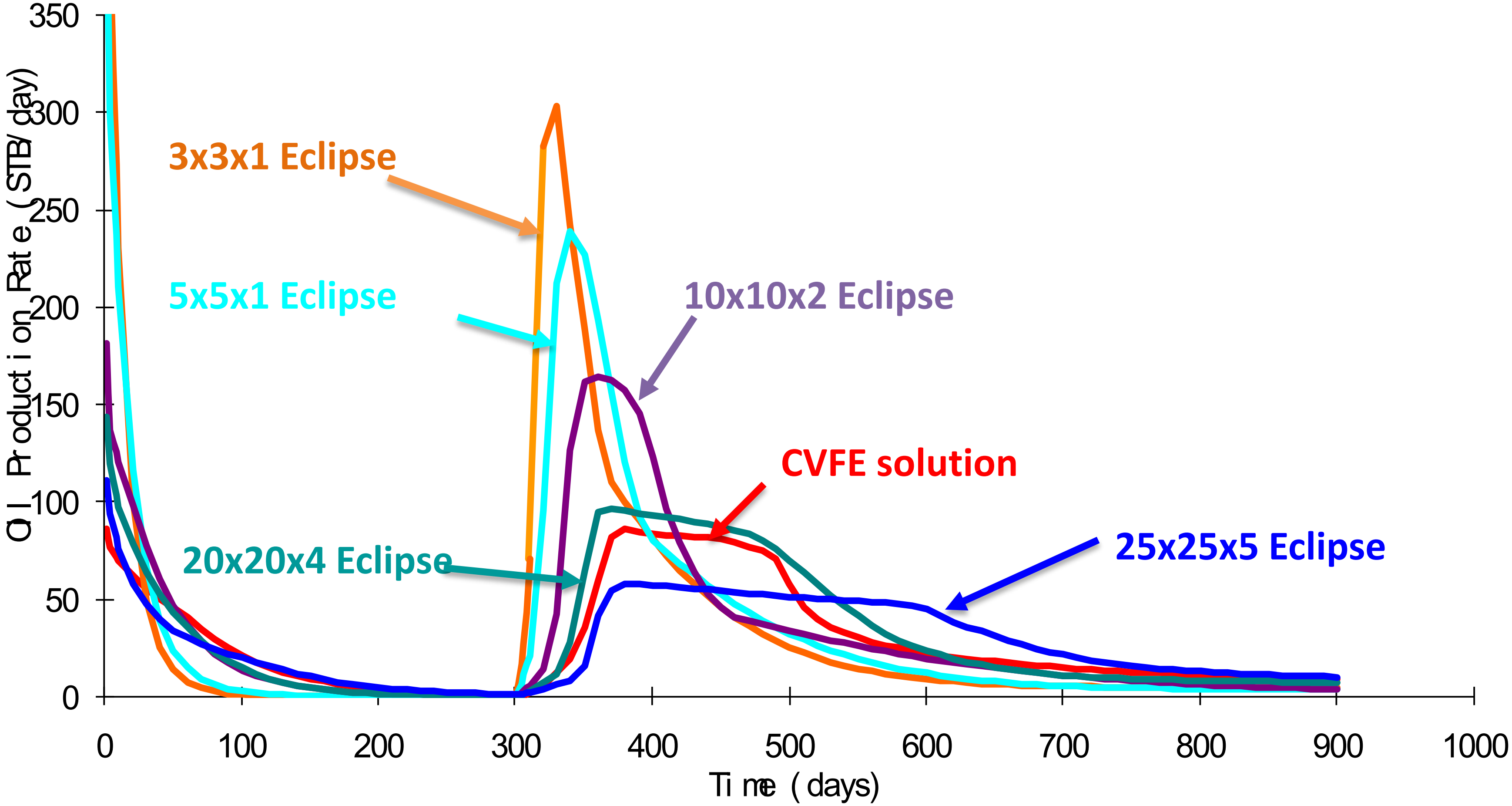
For a specific grid cell with known fracture areas A_k and transmissivities Tk, obtained from the DFN model, an empirical fracture tensor can be calculated by adding the individual fractures weighted by their area and transmissivity.

Oda’s permeability tensor is derived from Fij by assuming that Fij expresses fracture flow as a vector along the fracture’s unit normal. Assuming that fractures are impermeable in a direction parallel to their unit normal, Fij must be rotated into the planes of permeability.

Grid block size sensitivity study: The finer, the better?



❑ Grid block sensitivity study – Three phase simulation



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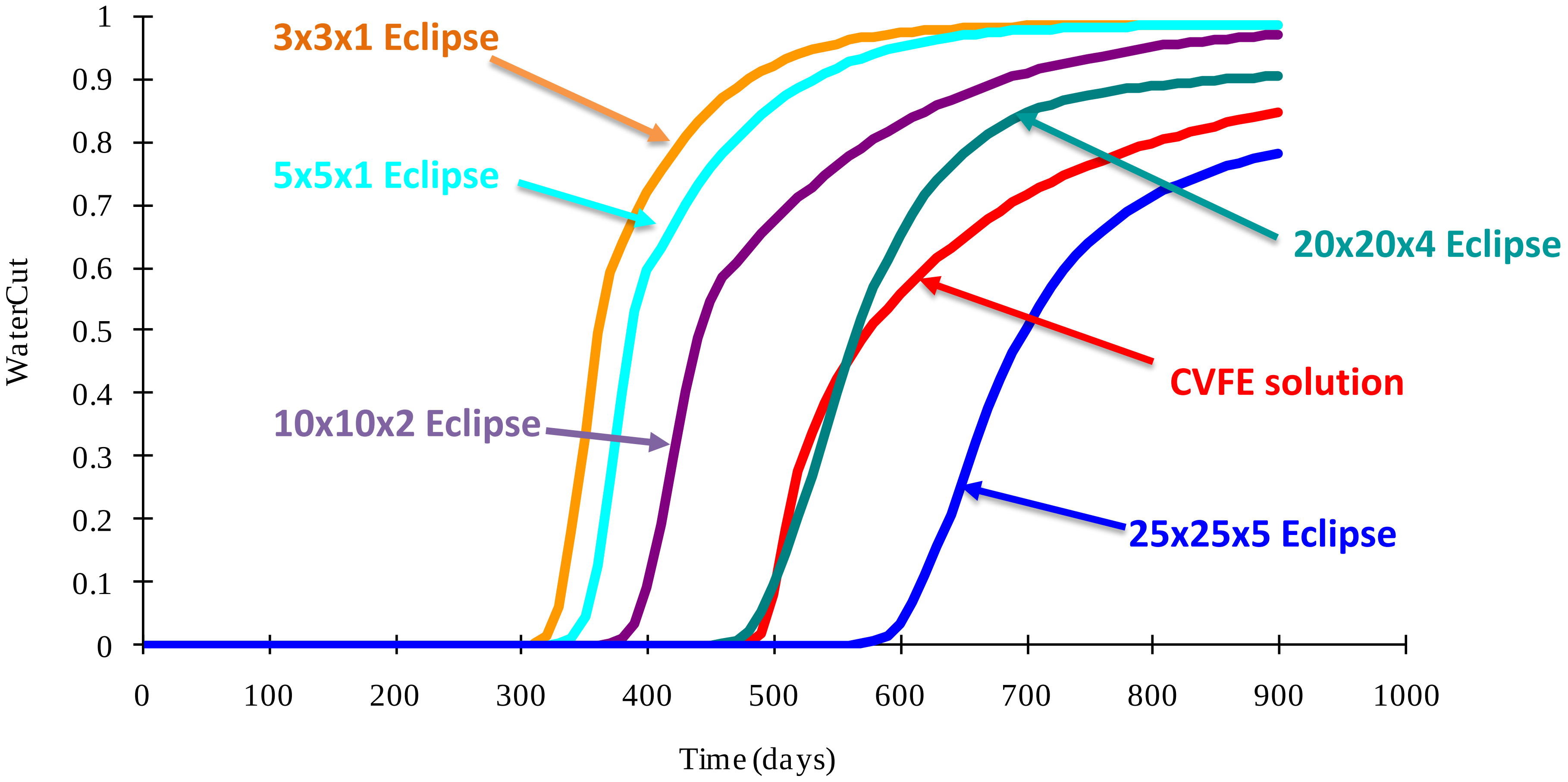
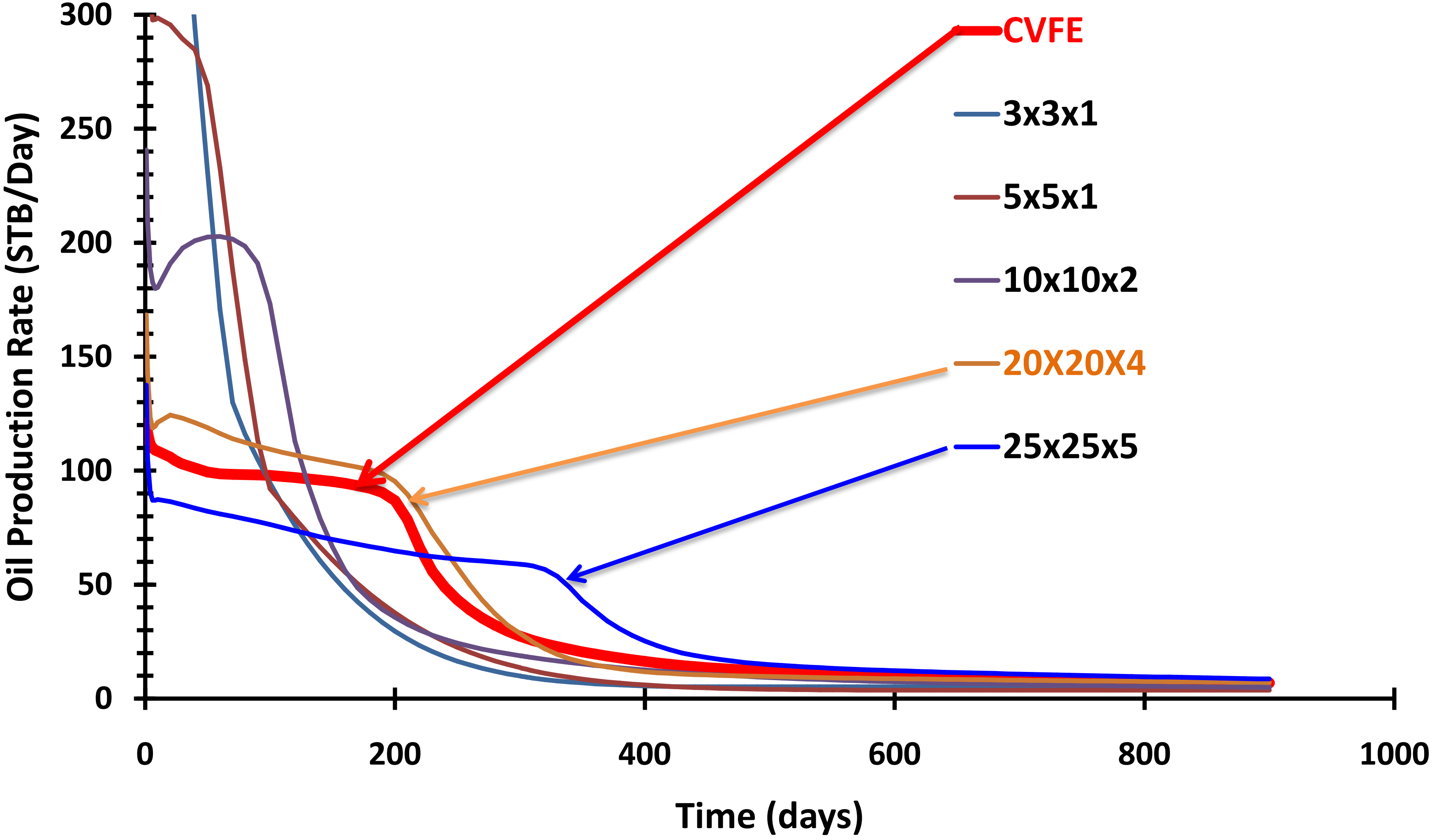
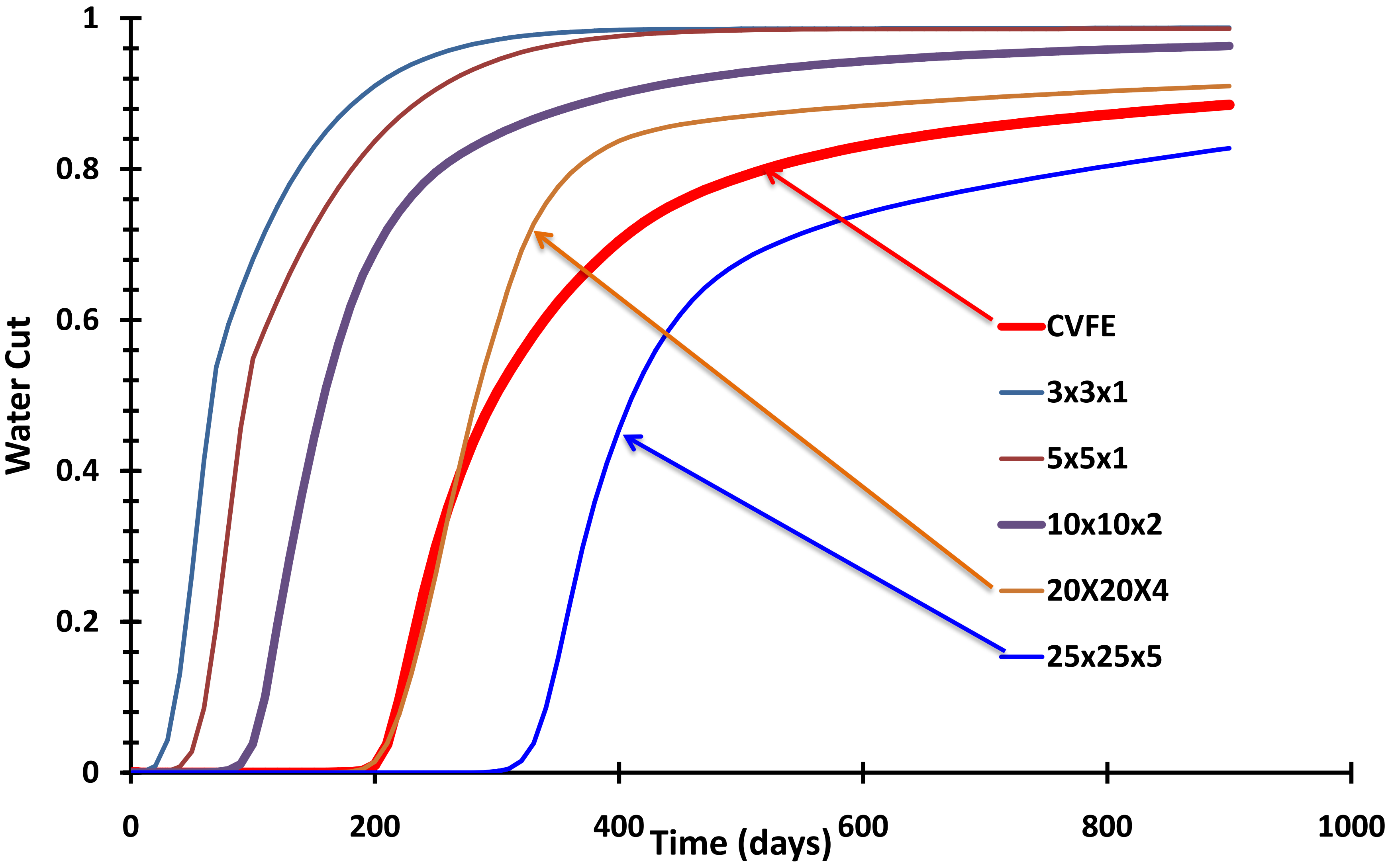


❑ Grid block sensitivity study – Two phase simulation



❑Grid block sensitivity study – Two phase simulation



❑Summary

- ❑A new CVFE reservoir simulator successfully presents its capability to handle multi-phase fluid flow through naturally fractured networks.

- ❑Oda’s permeability tensor is sensitive on grid block sizes.

- ❑CVFE simulator could be a good choice helping decide equivalent grid block sizes for multi-phase flow purpose.

Acknowledgements

- U.S. DOE Contract DE-FC26-04NT15531 through the National Energy Technology Laboratory.
- Schlumberger Inc. – Eclipse academic license
- Golder Associates. – FracMan academic license
- Sandia National Laboratories – CUBIT license
- Argonne National Laboratory – PETSc
- Our team at University of Utah

References

Dershowitz, B., P. Lapointe, T. Eiben, and L. Wei, 1998, Integration of discrete feature network methods with conventional simulator approaches: SPE paper no. 62498, presented at the 1998 SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana, Sept 27-30.

Oda, M., 1985, Permeability tensor for discontinuous rock masses: Geotechnique, v. 35, p. 483.

Thank you for your attention!