A Comparison of Discrete Fracture Models for Single Phase Flow in Porous Media by COMSOL Multiphysics® Software

C. A. Romano-Perez[1], M. A. Diaz-Viera[2]

1. Universidad Nacional Autónoma de México, Facultad de Ingeniería, Ciudad de México, D.F., México;
2. Instituto Mexicano del Petróleo, Ingeniería de Recuperación Adicional, Ciudad de México, D.F., México.

Introduction: A comparison of discrete fracture and explicit fracture models for single-phase flow in fractured porous media using COMSOL Multiphysics® is presented to understand the contribution of each individual fracture to fluid flow, and the exchange between fracture and surrounding medium at a scale such that the fractures could be modeled explicitly.

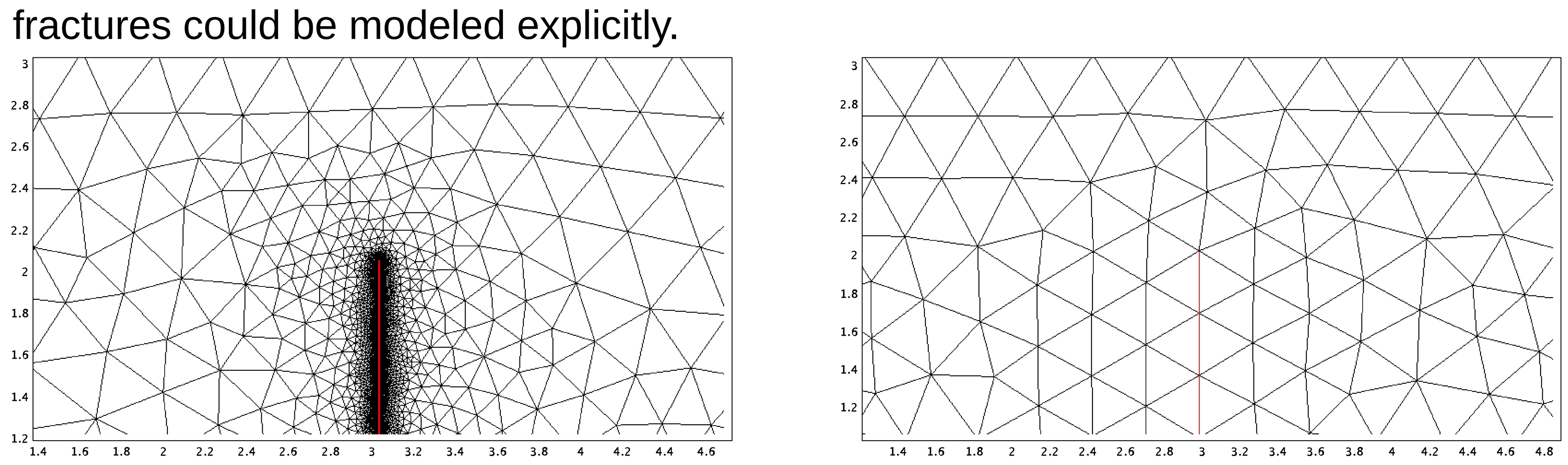

Figure 1. Gridding of the fractured media with a single fracture. From left to right: Explicit fracture model and Embedded fracture approach.

Single Phase Flow Model in a Porous Medium: A single phase flow model in a homogeneous and isotropic porous medium for a slightly compressible fluid is obtained by a fluid mass balance equation in terms of the pressure as follows

$$\phi c_t \frac{\partial p}{\partial t} - \nabla \cdot \left(\frac{\underline{\underline{k}}}{\mu} \cdot \nabla p \right) = q; \qquad \underline{u} = -\frac{\underline{\underline{k}}}{\mu} \cdot \nabla p$$

Explicit Fracture Flow Model: In this model two different porous media, represented in separated subdomains, are considered. One of them is a fracture and the other one is a porous matrix, as are schematically presented in the Figure 2.

Domain Decomposition Approach: The model consist in two separated subdomains divided by an internal boundary. Each subdomain represents a porous media and the internal boundary represents a fracture, as can be seen in the Figure

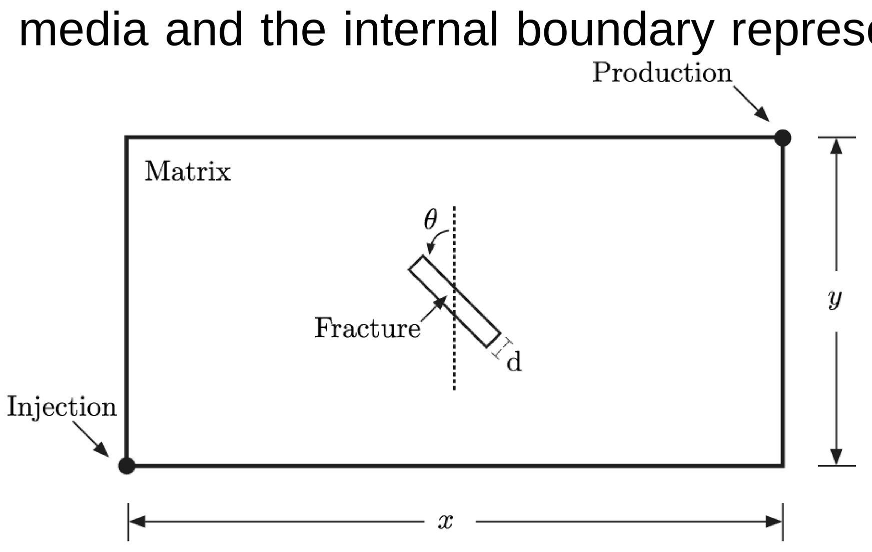

Figure 2. Schematic representation of the geometrical configuration of the explicit fracture model.

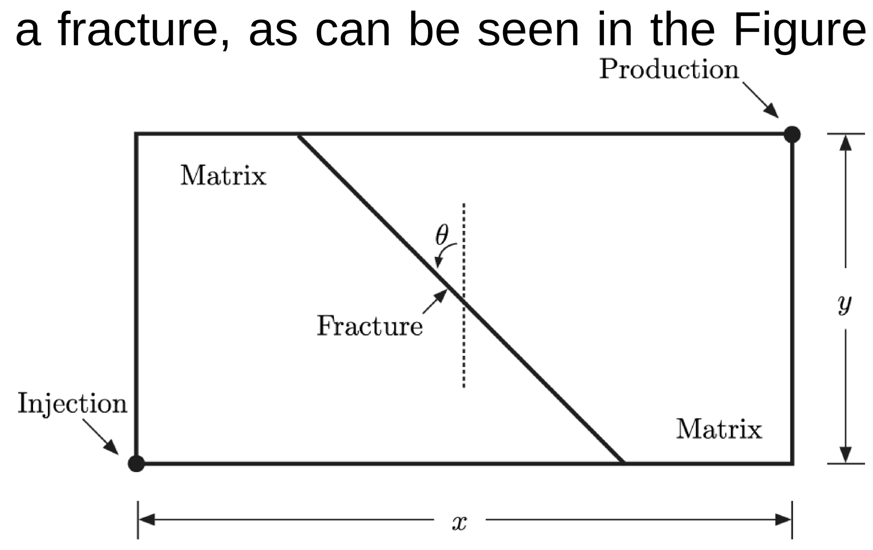

Figure 3. Schematic representation of the geometrical configuration of the domain decomposition approach.

Governing equations

$$d\phi^f c_t^f \frac{\partial P^f}{\partial t} + \nabla_\tau \cdot \left(\underline{U}^f \right) = \left(\underline{u}^1 - \underline{u}^2 \right) \cdot \underline{n} + Q_{fr}; \qquad \underline{U}^f = -\frac{d}{\mu} \underline{\underline{k}}_\tau^f \cdot \nabla_\tau P^f$$

$$Q^f = \int_{-d/2}^{d/2} q^f d\underline{n}; \qquad P^f = \tfrac{1}{d} \int_{-d/2}^{d/2} p^f d\underline{n}$$

Internal Boundary conditions

$$-\frac{1}{2}\left(\underline{u}^1 \cdot \underline{n}_1 \right)\Big|_{\Sigma_1} + \alpha^f p^1\Big|_{\Sigma_1} = -\frac{1}{2}\left(\underline{u}^2 \cdot \underline{n}_2 \right)\Big|_{\Sigma_2} + \alpha^f P^f$$

$$-\frac{1}{2}\left(\underline{u}^2 \cdot \underline{n}_2 \right)\Big|_{\Sigma_2} + \alpha^f p^2\Big|_{\Sigma_2} = -\frac{1}{2}\left(\underline{u}^1 \cdot \underline{n}_1 \right)\Big|_{\Sigma_1} + \alpha^f P^f$$

$$\alpha^f = \frac{2\underline{\underline{k}}_n^{fr}}{\mu d}$$

Embedded Fracture Approach: This embedded fracture approach is very similar to the domain decomposition approach. The main difference is that there is a single porous matrix domain in which the fracture is embedded, as can be seen in the Figure 4.

Internal Boundary conditions

$$p^2\Big|_{\Sigma_2} - p^1\Big|_{\Sigma_1} = \frac{\mu d}{2\underline{\underline{k}}_n^f}\left(\left(\underline{u}^2 \cdot \underline{n}_2 \right)\Big|_{\Sigma_2} - \left(\underline{u}^1 \cdot \underline{n}_1 \right)\Big|_{\Sigma_1} \right); \qquad p^2\Big|_{\Sigma_2} + p^1\Big|_{\Sigma_1} = 2P^f$$

Results: Discrete fracture models compared to explicit fracture model have the advantage that for the same order of accuracy the number of elements in the mesh are reduced significantly and, consequently, they have a better computational performance since it involves fewer degrees of freedom (unknowns). The number of mesh elements for each configuration of the fracture is presented in Table 1.

θ	Explicit fracture	Discrete fracture	
		Domain decomposition	Embedded fracture
0 °	8,300	346	336
45 °	8,048	342	338
90 °	8,048	332	332
-45 °	8,160	338	338

Table 1. Number of triangular elements for the discrete fracture and explicit fracture models; Single fracture configuration.

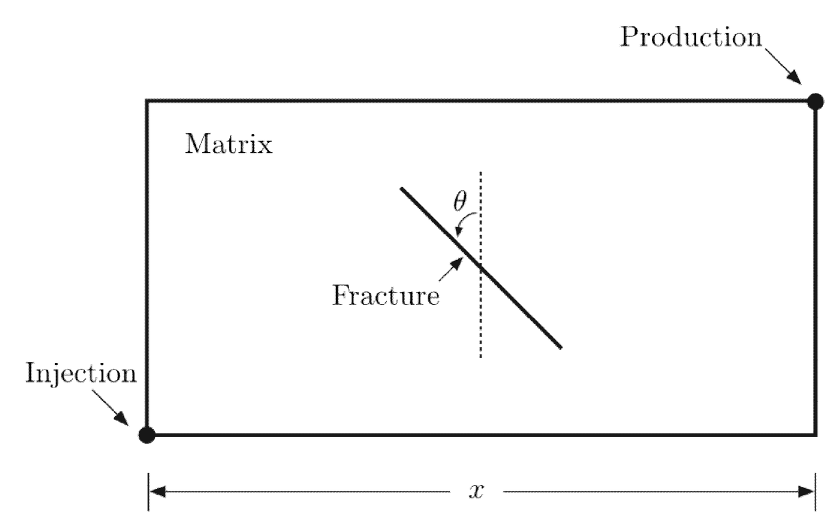

Figure 4. Schematic representation of the geometrical configuration of the embedded fracture approach.

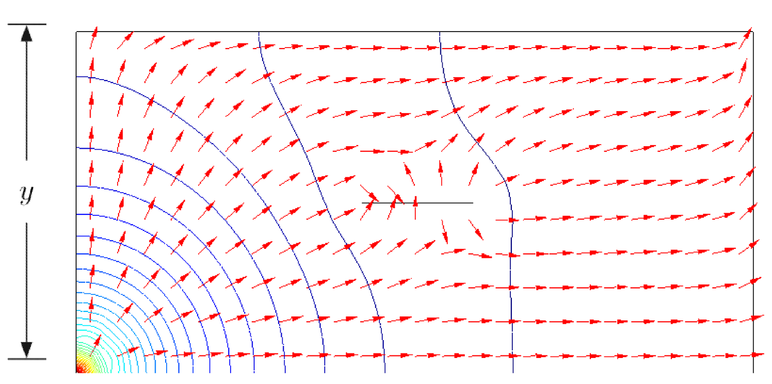

Figure 5. Pressure and fluid velocity at 120 seconds of fluid injection-production considering a single horizontal fracture more permeable than the porous medium (θ=90º).

The discrete fracture model using the embedded fracture approach is much more simple and flexible to implement in comparison with the domain decomposition approach. This approach can represent properly the flow if the fracture is more permeable than the porous medium but not in the opposite case (see Figure 6). And its accuracy is better when the main flow direction is parallel to the fracture plane (see Figures 5 and 7).

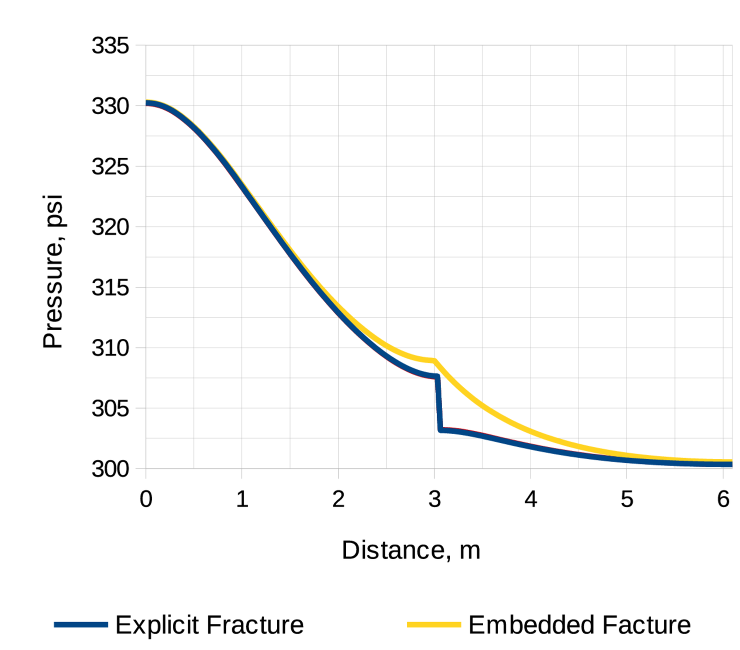

Figure 6. Pressure profile at 120 seconds of fluid injection-production considering a single vertical fracture less permeable than the porous medium (θ=0º).

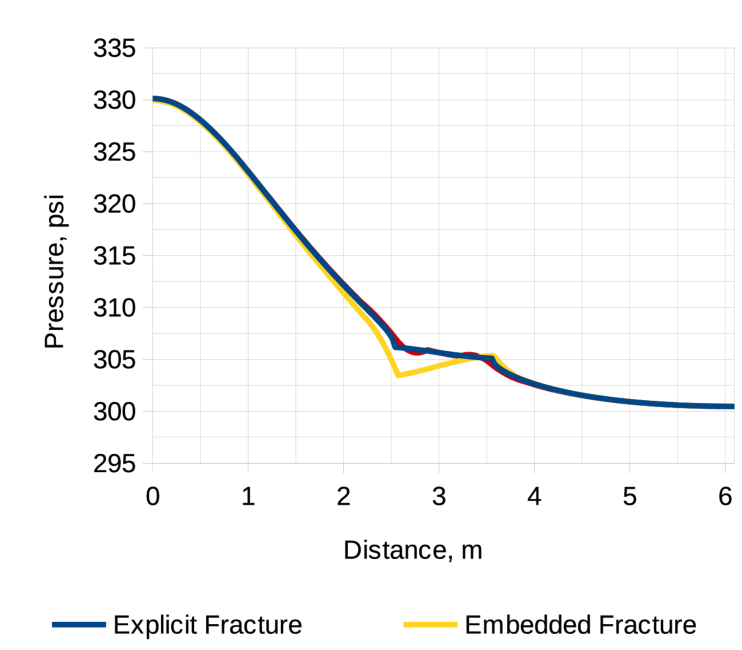

Figure 7. Pressure profile at 120 seconds of fluid injection-production considering a single horizontal fracture more permeable than the porous medium (θ=90º).

Conclusions: Since in oil recovery process modeling, the case where the fracture has a higher permeability than the surrounding porous medium usually is more significant than the case where the fracture has lower permeability, the embedded fracture approach could represent a viable alternative to model flow through a discrete fracture network in porous media.

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