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MODELLING OF FLUID FLOW IN HYDROCARBON RESERVOIRS CROSSED BY SEALING FAULTS USING FINITE ELEMENTS WITH EMBEDDED DISCONTINUITIES IN PRESSURE FIELD

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The fault is in general understood as the slide between two sides of the formation across a friction contact. Sealing faults are structures of great importance for the hydrocarbon trapping in the generation and migration processes. Due to its low permeability, fluid flow in reservoir is not allowed through the fault as well as oil migration to other permeable zones of the geological formation is prevented

To simulate the behavior of the production of hydrocarbons in reservoirs crossed by sealing faults, a technique of finite elements with embedded strong discontinuity, proposed by [1] has been implemented for the hydraulic problem, incorporating the discontinuities of pore pressure field due to a band with lower permeability (sealing fault) than the surrounding porous media.

This approach has been proved as efficient for the simulation of crack propagation in brittle materials, making it unnecessary to use interface elements or remeshing techniques. This technique is consistent with the principles of continuum mechanics; in addition it can reduce the computational effort and simplify the discretization of the dominium, as the discontinuity is embedded in the element mesh crossing the elements. For the hydraulic problem, the discontinuity of the pore pressure field has been treated similarly to the displacement field in the mechanical problem.

It is assumed that the pore pressure field becomes discontinuous. The jump in the pore pressure, [[P]], can lead to the following expression to calculate the pressure of the continuous media:

$$P = \hat{P} - N_1[\![P]\!] + H[\![P]\!]$$

where $\hat{P}$ is the approximation of pore pressure field on the regular part of the element, obtained by interpolation of nodal values of the pressure through the standard finite elements. N_1 is the shape function of the isolated node and H is a Heaviside function. The gradient of the pore pressure can be defined by:

$$\nabla P = \nabla \hat{P} - \nabla N_1 \left[\left[P\right]\right] + \delta\, \mathbf{n} \left[\left[P\right]\right]$$

where δ is the Dirac delta distribution. The fluid flow in the continuous portion is given by:

$$\mathbf{q}_\Omega = -\mathbf{K}_\Omega \left[\nabla \hat{P} - \nabla N_1 [\![P]\!]\right]$$

and the fluid flow in discontinuity is given by:

$$\mathbf{q}_S = -\mathbf{K}_S \left[\nabla \hat{P} + \left(-\nabla N_1 + \frac{\mathbf{n}}{k}\right)[\![P]\!]\right]$$

the fluid flow continuity is ensured by the condition:

$$\mathbf{n}^T \cdot \left(\mathbf{q}_{\Omega/S} - \mathbf{q}_S\right) = 0$$

It is possible to calculate the jump of the pore pressure,

$$[\![P]\!] = \mathbf{n}^T \left(\mathbf{K}_S - \mathbf{K}_\Omega\right) \cdot \nabla \hat{P} \cdot \left[\mathbf{n}^T \mathbf{K}_\Omega \nabla N_1 + \mathbf{n}^T \mathbf{K}_S \left(-\nabla N_1 + \frac{\mathbf{n}}{k}\right)\right]^{-1}$$

the fluid flow in the continuous portion of an element crossed by a discontinuity can be obtained:

$$\mathbf{q}_\Omega = \underbrace{-\mathbf{K}_\Omega \left[\mathbf{I} - \frac{\nabla N_1 \mathbf{n}^T \left(\mathbf{K}_S - \mathbf{K}_\Omega\right)}{\mathbf{n}^T \left(\mathbf{K}_S - \mathbf{K}_\Omega\right) \nabla N_1 - \mathbf{n}^T \mathbf{K}_S \dfrac{\mathbf{n}}{k}}\right]}_{\mathbf{K}_{ef}} \nabla \hat{P}$$

Finally, an effective permeability tensor, $\mathbf{K}_{ef}$, was obtained for the elements with embedded discontinuity. This approach has proved to be able to model the mechanism of production of hydrocarbons in reservoirs crossed by sealing faults avoiding the pathological mesh-size dependence or undesired exceeding discretization observed in classical numerical implementations [2].

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