Proceeding Series of the Brazilian Society of Applied and Computational Mathematics, Vol. 5, N. 1, 2017.

Trabalho apresentado no CNMAC, Gramado - RS, 2016.

Proceeding Series of the Brazilian Society of Computational and Applied Mathematics

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Creeping Flow Simulation of Salt Layers in a Sedimentary Basin

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In sedimentary basins, large oil reservoirs are found beneath layers of salt, called subsalt. The salt found in such basins is an extraordinarily fluid material compared to other rocks. These properties of salt present unique challenges for drilling and completion. Drillers have to address factors that cause openhole instability and accompanying problems, including borehole walls weakened by incompatible muds, restrictions, and undergauge hole caused by salt creep. During the life of a well, salt movement can displace wellbore tubulars, possibly causing either failure or restricted access.

There are at least two ways to describe the creep behavior of salt. In the context of structural mechanics, the flow of salt is generally considered as a problem for the evolutionary displacement, which leads to the equations for the displacement. In the context of fluid dynamics [2], the creep behavior is considered as a problem of steady incompressible flow with low Reynolds number. We propose a model to describe the creeping of rock salt as an inertialess flow of a viscoelastic fluid of Oldroyd-B type. The governing equations for the problem can be written as [3]

$$\nabla \cdot \mathbf{v} = 0, \tag{1}$$

$$-\eta_s \nabla^2 \mathbf{v} + \nabla p = \nabla \cdot \boldsymbol{\tau}, \tag{2}$$

$$\boldsymbol{\tau} + \lambda_1 (\tau)^{\nabla} = \eta_p \dot{\gamma}, \tag{3}$$

where $\mathbf{v}$ is the velocity vector, p is isotropic pressure, $\boldsymbol{\tau}$ is the elastic stress tensor, $-\eta_s$ and $-\eta_p$ are the solvent and polymeric viscosities, respectively. The operator $(*)^{\nabla}$ represents the covariant derivative of a tensor, and is given by

$$(*)^{\nabla} = \frac{D}{Dt}(*) - \left\{ (*) \cdot \nabla \mathbf{v} + (\nabla \mathbf{v})^{\mathrm{T}} \cdot (*) \right\} \tag{4}$$

The above system of equations (1)-(3) has been solved using the Element-Based Finite-Volume Method [1, 4], which enables using an unstructured hybrid grid (constituted by

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triangular and quadrilateral elements) of cell-vertex type (Figure 1). Coupled mass and momentum conservation equations were solved using the interpolation function of the finite element differential scheme (FIELDS) [5]. Such interpolation function avoided the checkerboard pressure problem, which arises from the collocated arrangement of the variables in the computational grid. Furthermore, this interpolation function also promoted the inclusion of the pressure and stress terms in the mass conservation equation. The presence of nodal pressure values in the interpolation of velocity avoid any decoupling between velocity and pressure fields. Elastic components of the stress has been computed by solving constitutive equation using either the single point upstream (SPU) or skew upwind difference scheme-node (SUDS-NO). The resulting linear systems has been solved using both the GMRES and BiCGSTAB methods provided by the PETSc library with an ILU preconditioner.

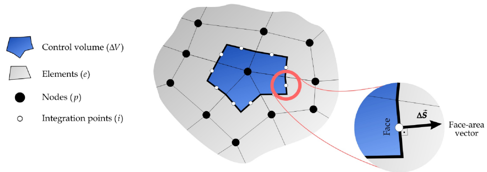

Figure 1: Main geometrical entities on the element-based finite-volume method

At first, the start-up of planar Poiseuille flow between two parallel plates has been tackled. For Oldroyd-B model there exist analytical solution making it possible to evaluate exactly the discretization errors of the numerical method. Excellent agreement has been found between the present numerical results and those analytical solutions.

The follow up step, is to apply the method to the 4:1 planar contraction benchmark problem, in order to investigate the influence of the viscosity effects on the flow, and results has been compared with those found in the literature for creeping Oldroyd-B flow, for a range of Weissenberg numbers. The algorithm is able to capture latest trends reported in the literature.

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