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Numerical Modelling of Coupled Ssingle Phase Fluid Flow, Mass Transport and Mechanical Fields Analysis for Well Injectivity Decline Assessment

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SUMMARY

Introduction

Formation permeability damage is recognized as one of the major source of declines in both injectivity and productivity of wells. During injection, the development of the external and internal filter cake are the most common causes for well impairment. The external filtration occurs on the interface between wellbore/formation via accumulated particles, while the internal filtration occurs due to retention of particles within the formation. Pang and Sharma (1997), categorizes the type of the injection decline curves observed in core flow experiments, and successfully reproduced them by use of a deep-bed filtration model.

As utilized in a number of previous works (Aji 2014, Bedrikovetsky et al. 2011, Herzig et al. 1970, Khatib 1994 and Wennberg and Sharma 1997), in order to evaluate the fines migration including its retention and entrainment, the most common approach is to solve the mass transport balance equation, which may be expressed by advection-diffusion partial differential formula. In this study, the approach adopts the mass transport field and is coupled with the seepage flow and mechanical fields in the 3D Finite Element package, ELFEN Wellbore. This approach enables assessment of injectivity declines resulting from the formation permeability damage. The assessment of the well injectivity requires three stages of the analysis: 1) wellbore excavation; 2) completion; 3) injection/production. Including all three stages is important, since mechanical deformations at any stage may result in the non-radial flow path. Throughout all the stages, permeability damage is considered in the mass transport field by considering deposition of fines under the fluid velocity computed from the fluid flow field. A simple deep bed filtration theory is utilized to compute the deposition of fines. This study concentrates on the impact of the internal filtration on the fluid injectivity, and leaves the external filtration impact to future studies.

Modelling methodology

ELFEN Wellbore package is designed to conduct the well-life modelling of near wellbore processes by 3D FE method including: 1) wellbore excavation; 2) completion; 3) injection.

The wellbore excavation process is analysed based on the given wellbore geometry (inclination and azimuth), in-situ stresses and pore fluid pressure, and designed drilling fluid mud weight. During this stage the formation may be mechanically damaged resulting in either breakout or breakdown near wellbore. The leak-off ratio of the drilling fluid also has an impact on the stresses, pore fluid pressure and permeability damage near wellbore. After the excavation, the wellbore completion process is analysed by activating a desired system such as open-hole with gravel pack or expandable sand screen, or leaving as an open hole. Removable of drilling overpressure after well completion may induce further mechanical damage near wellbore even with completion systems in place. Finally scheduled injection/production process is analysed. The injection process is modelled by specifying the injection fluid flow rate, while the production process is modelled by specifying the BHP. Fines migration with deposition and mobilization mechanisms have significant role for the injectivity/production efficiency. The fluid flow path reflects the formation mechanical damage induced in the previous processes (i.e. wellbore excavation and completion) and may cause reservoir compaction (due to depletion) and fracture propagation (due to injected fluid).

Multi fields coupling method

The geomechanical coupled model considered in this study assumes a fully saturated single phase flow condition. The mass transport balance equation is represented by the advection-conduction equation with the sink term of mass depositions and the source term for entrainment.

During the coupling process, all the necessary variables are transferred across the three fields. A variable transferred from one field is used to update another parameter in the received field: pore pressure from the seepage field is used to compute effective stress in the mechanical field; fluid velocity from the seepage field is used to compute mass deposition and mobilization in the mass field;

mass deposition from the mass field is used to compute permeability in the seepage field; porosity from the mechanical field is used to compute permeability in the seepage field and mass deposition in the mass field. This coupling process is schematically summarized in Fig. 1. In this study, the mass transport field represents the fines migration, which are assumed not to contribute the mechanical properties of the formation. Thus there are no direct data transfer from the mass transport field to the mechanical field.

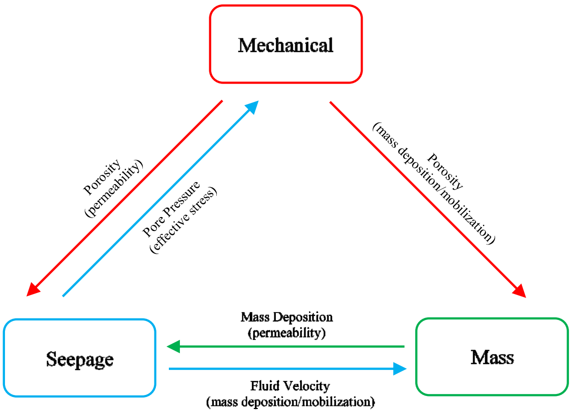

Figure 1 *Three fields coupled process.*

Geomechanical model

To model the near wellbore response of the formation over the whole well life ranging from the drilling to injection, it is essential to capture the various mechanical damage mechanisms including tensile failure (Mode-I), shear dilation and compaction. The geomechanical constitutive model utilized for this study is the base type of the Rockfield Soft Rock-3 (SR3) hierarchical constitutive model (Crook et al. 2006), which is a rate independent non-associated flow model and presented in Fig. 2. This SR3 constitutive model extends the Cam Clay critical state model in a number of ways to represent the experimentally observed rock formations and its main features are listed below:

- The non-linear elastic behavior inclusion to augment the elastic law;
- Flexibility of the shape of yield surface so that the observed experimental results are fitted over a wide range of stress state;
- Non-associative flow rule;
- Pressure dependent hardening/softening law.

In addition to the SR3 constitutive model, the Rankine tensile criterion is also considered to represent the tensile failure of the material (Mode-I). This combination of the SR3 and Rankine tensile criterion enables the material model to represent the various type of damage mechanisms including tensile failure (Mode-I), shear dilation and compaction as shown in Fig. 2.

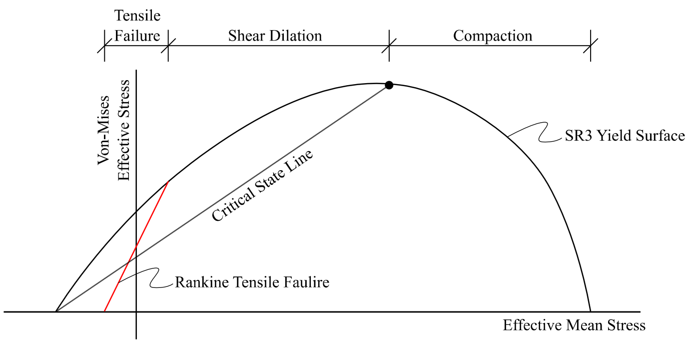

Figure 2 *SR3 with Rankine Tensile Failure Model with Various Damage Modes.*

Permeability damage model

The permeability can be damaged by both the mechanical deformation and the fines deposition within the pore space (Fig. 3). Here D_{mech} is the permeability damage factor due to mechanical deformation, which may vary as a function of porosity, strain or stress. Also D_{mass} is the permeability damage factor governed by the deposited fines concentration. This study adopts the Kozeny-Carmon type model (Civan 2007) for mechanically induced permeability damage D_{mech}, with permeability increasing for the dilation and reducing for the compaction. The fines deposition induced permeability damage, D_{mass}, is computed as a function of the volumetric fraction of fines deposition, which is similar to the one proposed by Pang and Sharma (1997), and validated against 1D core flow experimental test conducted by Todd et al (1990).

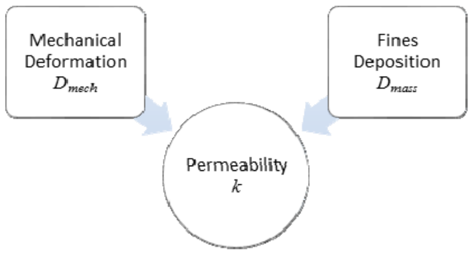

Figure 3 *Permeability Update within Three Fields Coupled Process.*

Fines injection to vertical wellbore model – effects of fines concentration

The open-hole vertical wellbore model is constructed in the form of a coupled fluid flow, mass transport and mechanical analysis. The main objective of this model is to investigate the impact of permeability change invoked both by mechanical damage and fines migration on the fluid injectivity. A total of three cases are simulated:

- **(i)** Coupled seepage-mass-mechanical analysis with no fines injection (clean water).
- **(ii)** Coupled seepage-mass-mechanical analysis with 50 ppm fines injection.
- **(iii)** Coupled seepage-mass-mechanical analysis with 85 ppm fines injection.

All three cases assume no in-situ fines in the formation. The results are compared to each other in terms of normalized permeability and injectivity decline as shown in Fig. 4. Note that normalized permeability is the ratio of the damaged permeability to the intact permeability and injectivity decline is the inverse of dimensionless differential pressure increase (Pang and Sharma, 1997).

For all cases, the permeability increases near wellbore at pre-injection status reflecting the formation shear damage induced by the well excavation. Subsequently, the permeability decreases during injection due to the fines deposition as shown in case 1 and case 2 results. The difference in permeability reduction between case 1 and case 2 is invoked by the injected fines concentration. This impacts of fines concentration can be also observed in the injectivity decline curve.

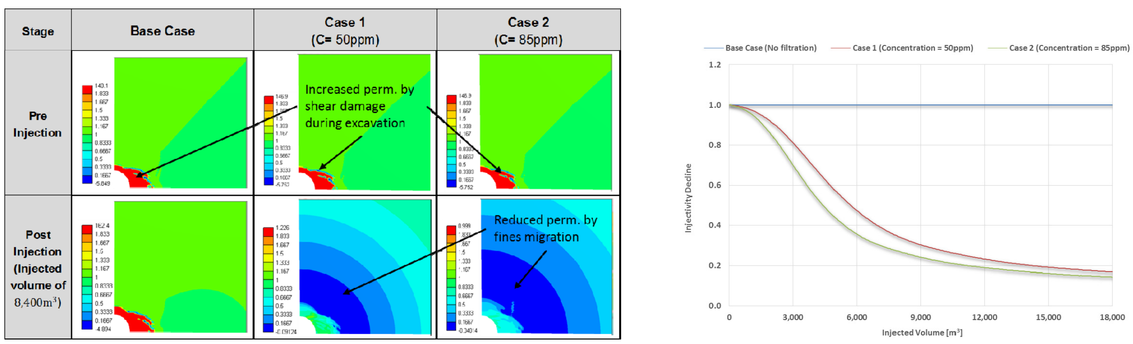

Figure 4 *(Left) Normalized Permeability at Pre and Post Injection; (Right) Injectivity Decline vs. Injected Fluid Volume*

Conclusions

A series of analyses have been conducted with a coupled field method for injection well models. The numerical results have shown the capability to capture the injectivity decline induced by the permeability change due to both mechanical damage and fines deposition.

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