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COUPLED FLOW– AND ROCK MECHANICS SIMULATION: OPTIMIZING THE COUPLING TERM FOR FASTER AND ACCURATE COMPUTATION

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Abstract. Coupled flow– and rock mechanics simulations are necessary to achieve sufficient understanding and reliable production forecasts in many reservoirs, especially those containing weak or moderate strength rock. Unfortunately these runs are in general significantly more demanding with respect to computing times than stand-alone flow simulations. A scheme is presented whereby the number of needed rock mechanics simulations in such a setting can be reduced to a minimum. The scheme is based on constructing optimal input for flow simulations from a few rock mechanics runs. Results obtained with the scheme are at least as accurate as traditional coupled runs, but computations are considerably faster, often as much as two orders of magnitude.

Key Words. Reservoir simulation, Coupled simulation, Rock mechanics, Compaction

1. Introduction

Production forecasts in petroleum reservoirs are most often computed by reservoir simulators, based on numerical solution of the equations for flow in porous media. In most or many reservoirs the compaction of the porous rock will have strong influence on pressure development and flow pattern, and as such is an important parameter to model reliably. In the flow equations, fluid pressure is the only present parameter that these compaction computations can be based on. In reality, however, compaction depends on reservoir rock behaviour, which may be nonlinear poro-elasto-plastic, depending on stress path, temperature, and possibly water content [8]. Hence it is widely accepted in the community that rock-mechanics simulations, preferably coupled flow– and rock mechanics simulations are necessary when accurate compaction computation is required, which is the case for most reservoirs, possibly excluding reservoirs comprised solely of strong or hard rock.

An example of results obtained by employing different strategies for compaction computation is shown in Figure 1, where simulated oil production and water cut (fraction of produced water to total liquid production) from a producing well in a fluvial reservoir is depicted for the three different cases, i) assuming permeability k does not change under compaction, ii) assuming k is a function of fluid pressure, $k = k(p_f)$, and iii) the correct formulation, k is a function of stress (in this case mean effective stress p'), $k = k(p')$.

From the figure it can be clearly seen that the choice of compaction model can have large consequences for e.g. production predictions. The stress distribution in the reservoir is dependent on properties in the surrounding rock as well as within the reservoir, and hence is distributed in a manner which cannot be caught by

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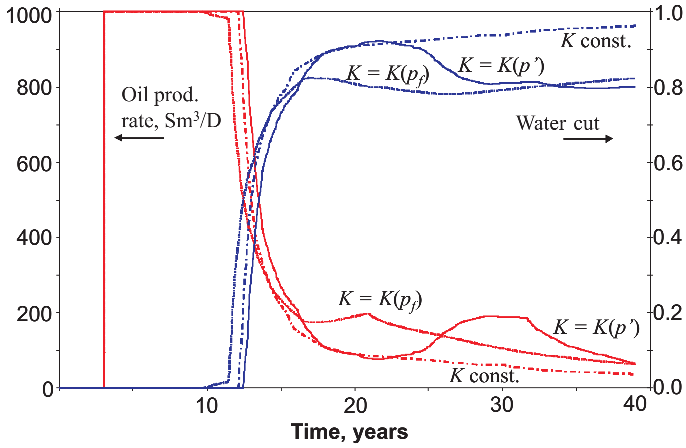

FIGURE 1. Oil and water production in one well; three different models for how permeability varies with load

the pressure state alone. An example is shown in Figure 2, where (simulated) permeability multipliers (ratio of current to initial permeability) are shown in a reservoir cross section transverse to a system of initially high-permeability channels in a relatively strong background material. Figure 2a shows the multipliers when modelled as functions of fluid pressure, while Fig. 2b shows the more accurate distribution when modelled as a function of stress, and clearly shows how the channel compaction influences larger parts of the reservoir cross section (internal stress arching). In general the rock mechanics boundary conditions have large impact on the compaction distribution in the reservoir, which is a major reason that the compaction cannot be a function of the pressure only.

During the last few decades there has been a growing awareness that a complete understanding of reservoir dynamics frequently also requires understanding of the interaction between fluid flow and rock mechanics. One example is the change of porosity and permeability due to the deformation of reservoir rock, which is a consequence of the changing stress field within and surrounding the reservoir, and how these altered conditions influence the fluid flow in the porous medium. As the coupling between these mechanisms is strong the full coupled system (Eqns. 1–5 below) should ideally be solved simultaneously. The main reasons for seeking alternatives to such a scheme are, i) The simultaneous solving of the coupled system can be prohibitively expensive (in terms of computing time), and ii) Commercial flow simulators offer a rich set of options for reservoir management, and in the same manner commercial stress simulators offer a multitude of rock behaviour models. No existing fully coupled simulators include all the options that "specialist" users need and do not wish to sacrifice for the benefit of using a single simulator. Hence alternative coupling schemes have been sought. In order of increasing complexity these include, one-way coupling, one-way coupling with feedback, two-way coupling, and two-way coupling with pore volume iterations [3, 4, 5, 6, 7, 8, 9, 13, 14, 15, 17]. For a relatively complete description, see [11] and the references herein.

The focus in this paper is on the coupling mechanism, and especially how the coupling term can be modified to achieve fast and accurate solutions. The coupling term was discussed by e.g. Gutierrez [4], Dean et *al.* [2], and Mainguy and Longuemare [9]. In the latter paper it was noted that the term was not important