Research note

The Egg Model

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Abstract

The "Egg Model" is a synthetic reservoir model consisting of an ensemble of 101 relatively small three-dimensional realizations of a channelized reservoir produced under water flooding conditions with eight water injectors and four producers. It has been used in numerous publications to demonstrate a variety of aspects related to computer-assisted flooding optimization and history matching. Unfortunately the details of the parameters settings are not always identical and not always fully documented in several of these publications. We present a "standard version" of the Egg Model which is meant to serve as a test case in future publications, and a data set of 100 permeability realizations in addition to the permeability field used for the standard model. We implemented and tested the model in four reservoir simulators: Dynamo/Mores (Shell), Eclipse (Schlumberger), AD-GPRS (Stanford University) and MRST (Sintef), which produced near-identical output. This note describes the input parameters of the standard model. Together with the input files for the various simulators, it has been be uploaded in the 3TU.Datacentrum repository with free access to external users.

Model description

The Egg Model was developed as part of the PhD thesis work of Maarten Zandvliet and Gijs van Essen. The first publication that refers to it appears to be reference [1] in which only a single, deterministic reservoir model was used. Thereafter, an ensemble version has been used in several publications; see e.g. references [2] to [4], while also the deterministic version has been used frequently to test algorithms for computer–assisted flooding optimization, history matching or, in combination, closed-loop reservoir management; see e.g. references [5] to [9]. Moreover, a recent version, with the same reservoir shape but an entirely different permeability field has been presented in reference [10]. The original stochastic model used in references [2] to [4] consists of an ensemble of 100 realizations of a channelized reservoir in the form of discrete permeability fields modeled with $60 \times 60 \times 7 = 25.200$ grid cells of which 18.553 cells are active. The non-active cells are all at the outside of the model, leaving an-egg-shaped model of active cells. Each of the permeability fields in each of the seven layers has been hand-drawn using a simple computer-assisted drawing program. The realizations displays a clear channel orientation with a typical channel distance and sinuosity. The permeability values have not been conditioned on the wells, while the porosity is assumed to be constant. The seven layers have a strong vertical correlation, such that the permeability fields are almost two-dimensional. A sample of six realizations is displayed in Figure 1. The combination of the deterministic model and the ensemble result in an ensemble of 101 models which together form the “standard model” as described in this note.

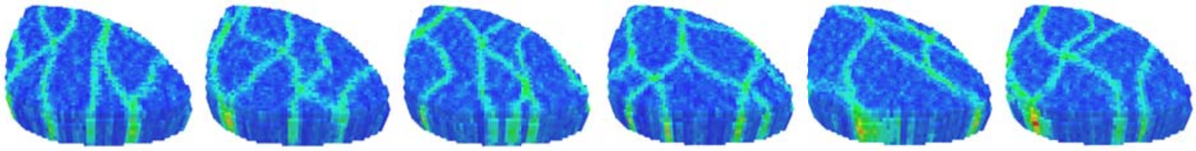

Figure 1: Six randomly chosen realizations, displaying the typical structure of high-permeability meandering channels in a low-permeability background.

In all publications the Egg Model has been used to simulate two-phase (oil-water) flow. Because the model has no aquifer and no gas cap, primary production is almost negligible, and the production mechanism is water flooding with the aid of eight injection wells and four production wells, see Figure 2.

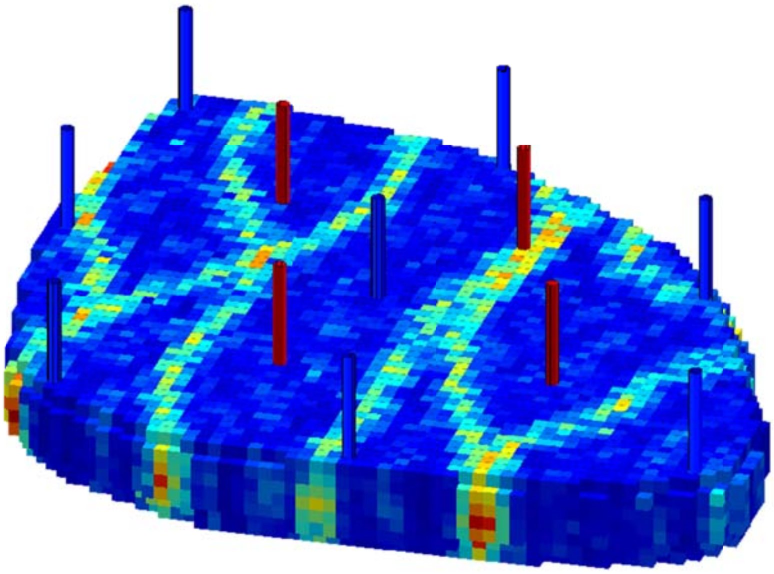

Figure 2: Reservoir model displaying the position of the injectors (blue) and producers (red).

Unfortunately the details of the parameters settings in the publications listed above are not always identical. Differences concern fluid parameters, grid cell sizes, well operating constraints, and production periods. In addition, the parameter setting have not always been fully documented which sometimes makes it difficult, or even impossible, to reproduce the numerical results of those publications. Therefore, in this note we present a "standard version" of the Egg Model which is meant to serve as a standard test case in future publications. The parameters of the standard model have been listed in in Table 1. The 101 permeability fields are available in Eclipse format (ASCII text files) as supplementary material to this note. Figure 3 displays the relative permeabilities and the associated fractional flow and Buckley-Leverett solution.

Implementation

We implemented the standard Egg Model in four different reservoir simulators: 1) Dynamo/MoReS, the proprietary Shell simulator that was used to generate the original Egg Model, 2) Eclipse 100, the commercial black oil simulator developed by Schlumberger [11], 3) AD-GPRS, the academic General Purpose Research Simulator developed by Stanford University [12], and 4) the Matlab Reservoir Simulation Toolbox (MRST), an open-source simulator developed by Sintef [13], [14]. The four simulators require slightly different parameter settings for e.g. time stepping and solver performance. Moreover, MRST requires user-written code to compute e.g. phase rates from the total rates as computed in the standard implementation. In all simulators the input was chosen as prescribed rates in the injectors and prescribed bottom-hole pressures in the producers. Additional pressure constraints in the injectors and rate constraints in the producers (if required by the simulator) where chosen so high that they were never encountered during the simulations. The exact input files for the four simulators, including the user-written code, are available as supplementary material to this note and have been uploaded in the 3TU.Datacentrum [15]. The results obtained with the four simulators are almost identical, as illustrated by the phase rates in the four producers displayed in Figure 4.

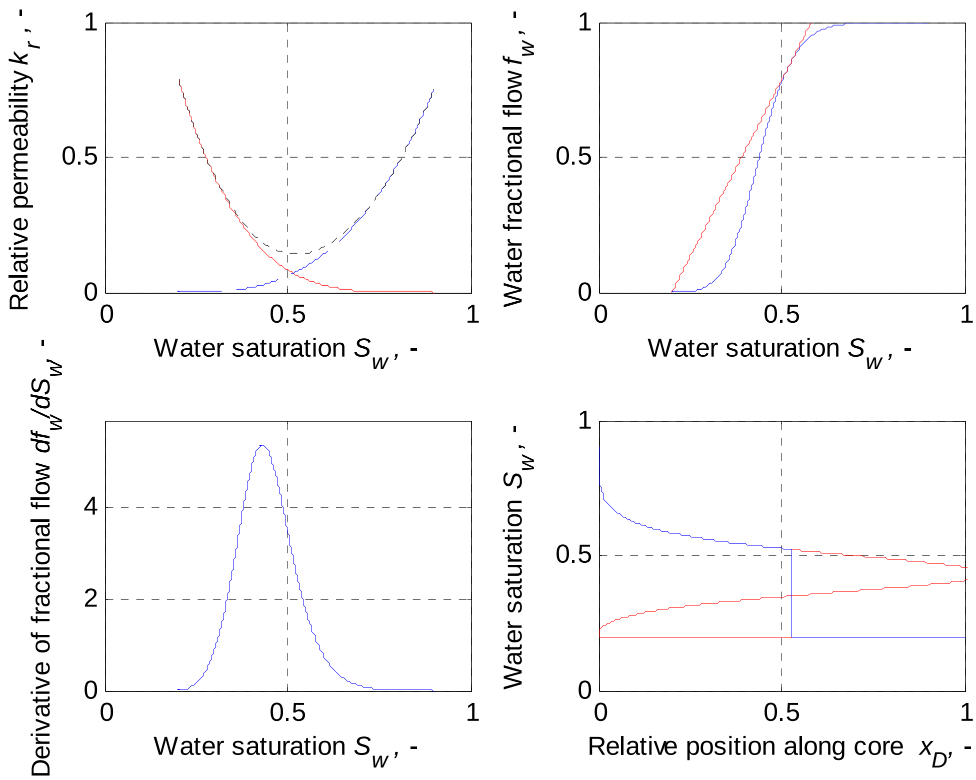

Figure 3: Relative permeabilities (top-left), fractional flow (top-right), derivative of fractional flow (bottom-left) and Buckley-Leverett solution (bottom-right).

Table 1: Reservoir and fluid properties			
Symbol	*Variable*	*Value*	*SI units*
h	Grid-block height	4	m
Δx, Δy	Grid-block length/width	8	m
ϕ	Porosity	0.2	-
c_o	Oil compressibility	1.0×10^{-10}	Pa^{-1}
c_r	Rock compressibility	0	Pa^{-1}
c_w	Water compressibility	1.0×10^{-10}	Pa^{-1}
μ_o	Oil dynamic viscosity	5.0×10^{-3}	Pa s
μ_w	Water dynamic viscosity	1.0×10^{-3}	Pa s
k_{ro}^0	End-point relative permeability, oil	0.8	–
k_{rw}^0	End-point relative permeability, water	0.75	–
n_o	Corey exponent, oil	4.0	–
n_w	Corey exponent, water	3.0	–
S_{or}	Residual-oil saturation	0.1	–
S_{wc}	Connate-water saturation	0.2	–
p_c	Capillary pressure	0.0	Pa
$\breve{p}_R$	Initial reservoir pressure (top layer)	40×10^6	Pa
$S_{w,0}$	Initial water saturation	0.1	–
q_{wi}	Water injection rates, per well	79.5	m^3/d
p_{bh}	Production well bottom hole pressures	39.5×10^6	Pa
r_{well}	Well-bore radius	0.1	M
T	Simulation time	3600	d

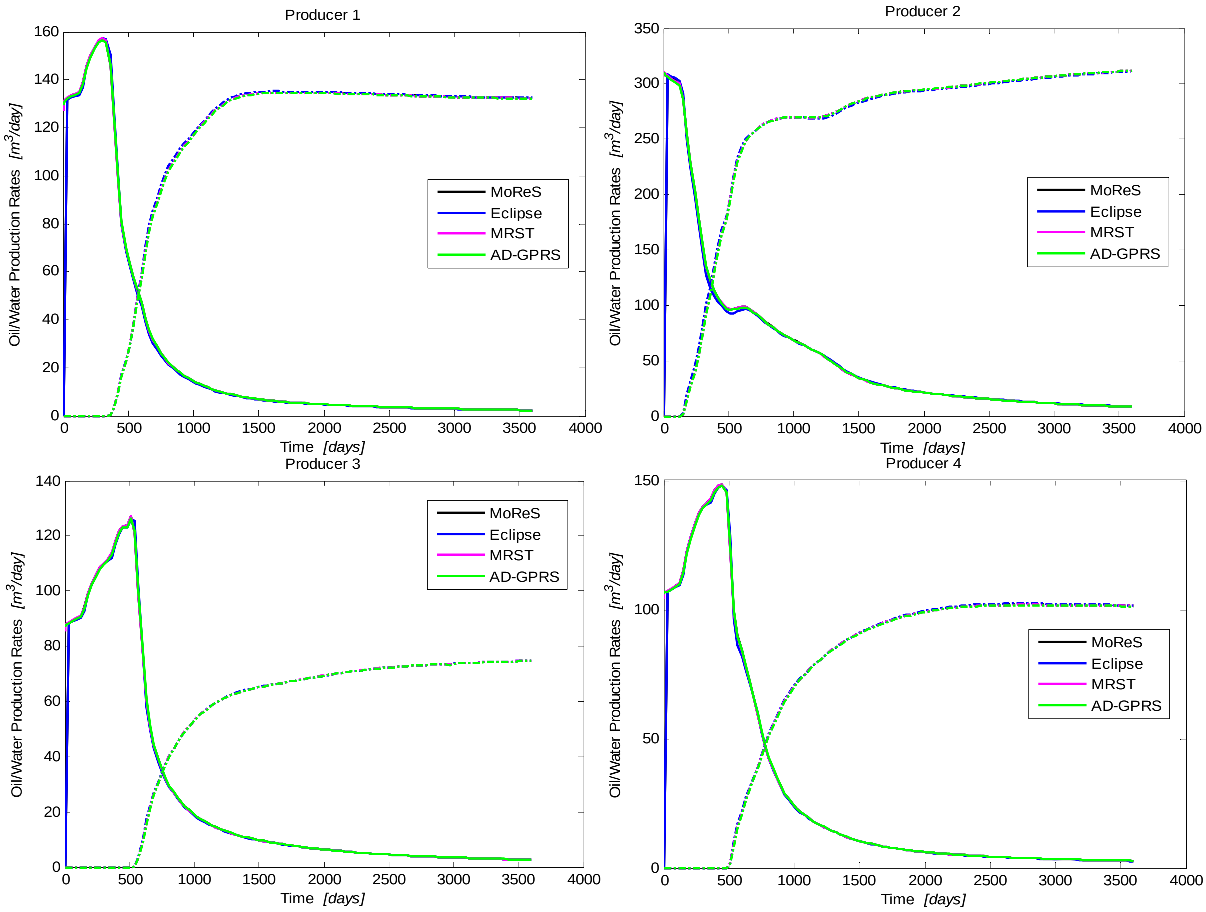

Figure 4: Well flow rates (oil and water) in the four producers for the four simulators. The curves for the various simulators are nearly identical.

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