The egg model - a geological ensemble for reservoir simulation

DOI:
10.1002/gdj3.21

Document status and date:
Published: 01/01/2014

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

RMetS Royal Meteorological Society
Geoscience Data Journal
Open Access

The egg model – a geological ensemble for reservoir simulation

J. D. Jansen[1,*], R. M. Fonseca[1], S. Kahrobaei[1], M. M. Siraj[2], G. M. Van Essen[1] and P. M. J. Van den Hof[2]

[1]*Department of Geoscience and Engineering, TU Delft, Delft, The Netherlands*
[2]*Department of Electrical Engineering, TU Eindhoven, Eindhoven, The Netherlands*

**Correspondence: J. D. Jansen, Delft University of Technology, Department of Geoscience and Engineering, Stevinweg 1, 2628 CN Delft, The Netherlands, E-mail: j.d.jansen@tudelft.nl*

The research presented in this paper was partly funded by the Integrated Systems Approach to Petroleum Production (ISAPP) and Recovery Factory (RF) projects.

The 'Egg Model' is a synthetic reservoir model consisting of an ensemble of 101 relatively small three-dimensional realizations of a channelized oil reservoir produced under water flooding conditions with eight water injectors and four oil 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 parameter 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 dataset 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 article 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.

Geosci. Data J. ***1***: *192–195 (2014), doi: 10.1002/gdj3.21*

Received: 2 December 2013, revised: 18 September 2014, accepted: 15 October 2014

Key words: reservoir, simulation, channelized, geological, ensemble

Dataset

Identifier: doi:10.4121/uuid:916c86cd-3558-4672-829a-105c62985ab2
Creator: Jansen J. D., R. M. Fonseca, S. Kahrobaei, M. M. Siraj, G. M. Van Essen, and P. M. J. Van den Hof
Title: The Egg Model – data files
Publisher: 3TU.Datacentrum, The Netherlands
Publication year: 2013
Version: 1.0

Introduction

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 Zandvliet *et al.* (2007) in which only a single, deterministic reservoir model was used. Thereafter, an ensemble version has been used in several publications; see, e.g. Van Essen *et al.* (2009), 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. The original 'stochastic' model consists of an ensemble of 100 realizations of a channelized reservoir in the form of discrete permeability fields modelled 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 high-permeability channels in a low-permeable background represent typical meandering river patterns as encountered in fluvial environments. Each field is unique, and, as a result, the permeability in each of the cell locations can be described with a probability distribution. However, there exists no underlying mathematical model to create additional permeability fields. The fields display 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

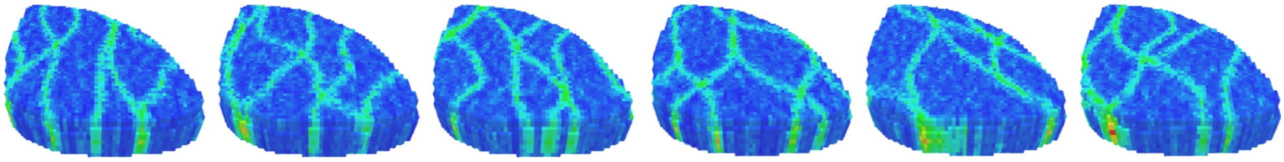

Figure 1. Six randomly chosen realizations, displaying the typical structure of high-permeability meandering channels in a low-permeability background. The vertical scale is exaggerated with a factor two.

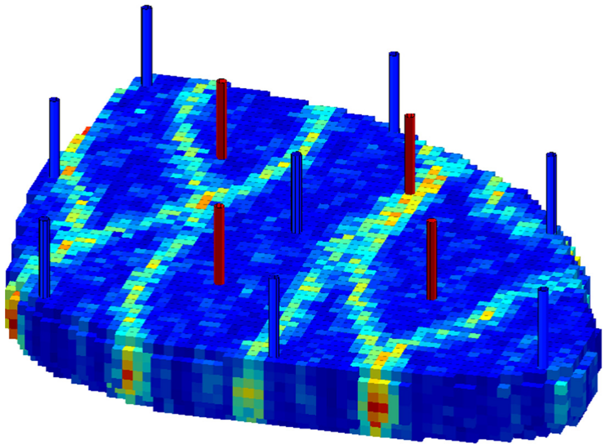

Figure 2. Reservoir model displaying the position of the injectors (blue) and producers (red). The vertical scale is exaggerated with a factor two.

fields are almost two dimensional. A sample of six realizations (each consisting of seven layers) is displayed in Figure 1. The combination of the deterministic and the 'stochastic' model results in an ensemble of 101 permeability realizations which, together with the other reservoir and fluid properties, forms the 'standard Egg Model' as described in this article.

In most 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. Unfortunately, the details of the parameter settings in the various publications using the Egg Model are not always identical. Differences concern fluid parameters, grid cell sizes, well operating constraints, and production periods. In addition, the parameter settings 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 article 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 Table 1. Figure 3 displays the relative permeabilities and the associated fractional flow curve.

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/day
p_{bh}	Production well bottom-hole pressures	39.5×10^6	Pa
r_{well}	Well-bore radius	0.1	m
T	Simulation time	3600	day

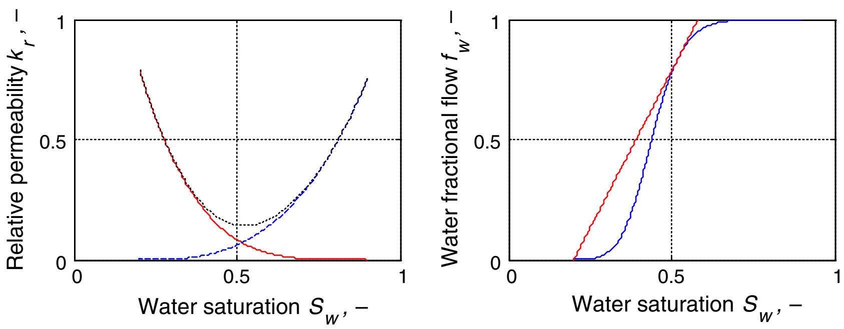

Figure 3. Left: Relative permeabilities (blue dashed: water; red solid: oil; black dotted: total). Right: fractional flow curve (blue: fractional flow; red: tangent indicating the shock saturation).

1. 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 (ECLIPSE, 2013), (3) AD-GPRS, the academic General Purpose Research Simulator developed by Stanford University (AD-GPRS, 2013), and (4) the Matlab Reservoir Simulation Toolbox, an open-source simulator developed by Sintef (Lie *et al.*, 2012; MRST, 2013). 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 com-

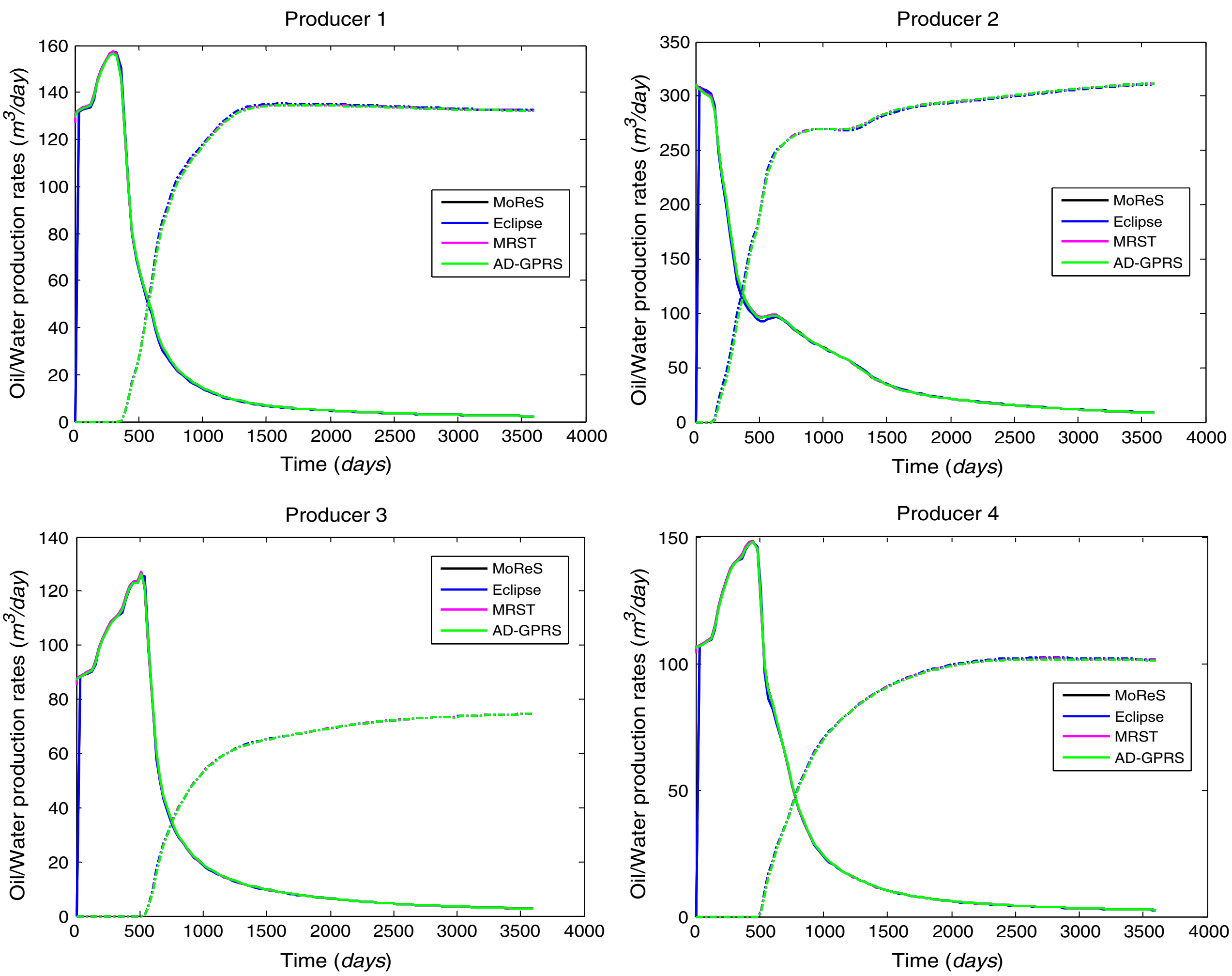

Figure 4. Well flow rates (oil and water) in the four producers for the four simulators. The curves for the various simulators are nearly identical.

puted 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) were chosen so high that they were never encountered during the simulations. The exact input files for the four simulators, including the user-written code, have been uploaded in the 3TU.Datacentrum. The results obtained with the four simulators are almost identical, as illustrated by the phase rates in the four producers displayed in Figure 4.

File format

The Egg Model dataset consists of a single zip file containing five directories. Four of these contain input files for the reservoir simulators Dynamo/MoReS (Shell), Eclipse (Schlumberger), AD-GPRS (Stanford University) and MRST (Sintef), all in the form of ASCII files. The fourth directory contains 100 additional permeability realizations in Eclipse input format (ASCII files).

Acknowledgements

The research presented in this article was performed as part of the Integrated Systems Approach to Petroleum Production (ISAPP) and Recovery Factory (RF) projects. ISAPP is a joint project between Delft University of Technology (TU Delft), the Netherlands Organization for Applied Scientific Research (TNO), Eni, Statoil, and Petrobras. RF is a joint project between Shell and TU Delft in cooperation with the Eindhoven University of Technology (TU Eindhoven). We acknowledge Schlumberger for the use of the Eclipse simulator under an academic license. We acknowledge Shell for the use of the Dynamo/MoReS simulator as part of the RF project. We acknowledge Stanford University, in particular Hamdi Tchelepi for the use of AD-GPRS and Drosos Kourounis (now with USI Lugano) for implementing an earlier version of the egg model in that simulator, and Sintef, in particular Stein Krogstad, for assistance in running MRST.

References

AD-GPRS. 2013. General Purpose Research Simulator. https://pangea.stanford.edu/researchgroups/supri-b/research/research-areas/gprs (accessed 4 November 2014).

ECLIPSE. 2013. ECLIPSE Industry Reference Reservoir Simulator. http://www.software.slb.com/products/foundation/pages/eclipse.aspx (accessed 4 November 2014).

Jansen JD, Fonseca RM, Kahrobaei S, Siraj MM, Van Essen G, Van den Hof PMJ. 2013. The egg model – data files. Version 1.0. 3TU.Datacentrum, The Netherlands, doi:10.4121/uuid:916c86cd-3558-4672-829a-105c62985ab2

Lie KA, Krogstad S, Ligaarden IS, Natvig JR, Nilsen HM, Skaflestad B. 2012. Open source MATLAB implementation of consistent discretisations on complex grids. *Computational Geoscience* **16**(2): 297–322, doi:10.1007/s10596-011-9244-4.

MRST. 2013. MATLAB Reservoir Simulation Toolbox. http://www.sintef.no/Projectweb/MRST/ (accessed 4 November 2014)

Van Essen GM, Zandvliet MJ, Van den Hof PMJ, Bosgra OH, Jansen JD. 2009. Robust water flooding optimization of multiple geological scenarios. *SPE Journal* **14** (1): 202–210, doi:10.2118/102913-PA.

Zandvliet MJ, Bosgra OH, Van den Hof PMJ, Jansen JD, Kraaijevanger JFBM. 2007. Bang-bang control and singular arcs in reservoir flooding. *Journal of Petroleum Science and Engineering* **58**: 186–200, doi:10.1016/j.petrol.2006.12.008.