POD-based deflation method for reservoir simulation

PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof.ir. K.C.A.M. Luyben,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op
vrijdag 2 februari 2018 om 17:47 uur

door

Gabriela Berenice DIAZ CORTES
MSc

geboren te Mexico

Dit proefschrift is goedgekeurd door de promotor Prof. dr. ir. J.D. Jansen
Prof. dr. ir. C. Vuik

Samenstelling promotiecommissie:

Prof. dr. ir. C. Vuik
Prof. dr. ir. J.D. Jansen

POD-based deflation method for reservoir simulation
Dissertation at Delft University of Technology.

ISBN Please define ISBN

Contents

Samenvatting

Summary

Chapter 1

Introduction

1.1 Reservoir simulation

Petroleum reservoirs are layers of sedimentary rock, which vary in terms of grain size, mineral and clay contents. Reservoir simulation is a way to analyze and predict the fluid behavior inside a reservoir through the analysis of a model, which can be a geological or a mathematical model.

The geological model describes the reservoir, i.e., the rock formation. For this description, a set of petrophysical properties are defined. The main properties are: the *rock porosity*, ϕ, defined as the fraction of void space inside the rock and the *rock permeability*, $\mathbf{K}$, that determines the rock's ability to transmit a fluid through the reservoir. The rock permeability in general is a tensor where each entry $\mathbf{K}_{ij}$ represents the flow rate in one direction (i) caused by the pressure drop in the same (i) or in a perpendicular (j) direction.

For the mathematical modeling, we describe the flow through porous media making use of the principle of mass conservation and Darcy's law, corresponding to the momentum conservation. The mass balance equation for a fluid phase α is given by:

$$\frac{\partial(\phi\rho_\alpha S_\alpha)}{\partial t} + \nabla\cdot(\rho_\alpha \mathbf{v}_\alpha) = \rho_\alpha q_\alpha, \tag{1.1}$$

and the Darcy's law reads:

$$\mathbf{v}_\alpha = -\frac{\mathbf{K}_\alpha}{\mu_\alpha}(\nabla p_\alpha - \rho_\alpha g \nabla d), \tag{1.2}$$

where, ρ_α, μ_α and p_α are the density, viscosity, and pressure of the fluid; g is the gravity constant, d is the depth of the reservoir and q_α are sources, usually, fluids injected into the reservoir. The saturation of a phase (S_α), is the fraction of void space filled with that phase in the medium, where a zero saturation indicates that the phase is not present. Fluids inside a reservoir are usually filling completely the empty space, this property is expressed by the following relation:

$$\sum_\alpha S_\alpha = 1. \tag{1.3}$$

If our system consists in more than one fluid phase, the permeability of each fluid phase, α, will be affected by the presence of the other phase. Therefore, the effective permeability $\mathbf{K}_\alpha$ has to be used instead of the absolute permeability $\mathbf{K}$. The absolute and effective permeabilities are related via the saturation-dependent relative permeability:

$$\mathbf{K}_\alpha = k_{r\alpha}(S_\alpha)\mathbf{K}.$$

The fluid density $\rho_\alpha = \rho_\alpha(p)$ and the rock porosity $\phi = \phi(p)$ can be pressure dependent. The dependence is given by the *rock compressibility*, c_r,

$$c_r = \frac{1}{\phi}\frac{d\phi}{dp} = \frac{d(ln(\phi))}{dp}, \tag{1.4}$$

for the porosity, and the *fluid compressibility*, c_f,

$$c_f = \frac{1}{\rho_\alpha}\frac{d\rho_\alpha}{dp} = \frac{d(ln(\rho_\alpha))}{dp}, \tag{1.5}$$

for the density.

1.1.1 Single-phase flow

1.1.2 Two-phase flow

Chapter 2

Numerical methods

Chapter 3

Single-phase flow

Chapter 4

Two-phase flow

Conclusions

Appendix 1

List of notation

Symbol	Quantity	Unit
ϕ	Rock porosity	
α	Fluid phase	
$\mathbf{K}$	Rock permeability	$Darcy\ (D)$
$\mathbf{K}_\alpha$	Effective permeability	$Darcy\ (D)$
$\mathbf{k}_{r\alpha}$	Relative permeability	
μ_α	Fluid viscosity	$Pa \cdot s$
S_α	Saturation	
ρ_α	Fluid density	kg/m^3
$\mathbf{v}_\alpha$	Darcy's velocity	m/d
q_α	Sources	
c_r	Rock compressibility	Pa^{-1}
c_f	Fluid compressibility	Pa^{-1}
g	Gravity	m/s^2
d	Reservoir depth	
λ_α	Fluid mobilities	$D/(Pa \cdot s)$
p	Pressure	Pa
p_c	Capillary pressure	Pa

Table 1: Notation

My 2 Appendix

My 3 Appendix