

University of Groningen

Numerical simulation of two-phase flow in offshore environments

Wemmenhove, Rik

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:
2008

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Wemmenhove, R. (2008). Numerical simulation of two-phase flow in offshore environments s.n.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Numerical Simulation of Two-Phase Flow in Offshore Environments

Rik Wemmenhove

This research was financially supported by the Dutch Technology Foundation STW (GWI.6433).

RIJKSUNIVERSITEIT GRONINGEN

Numerical Simulation of Two-Phase Flow in Offshore Environments

Proefschrift

ter verkrijging van het doctoraat in de
Wiskunde en Natuurwetenschappen
aan de Rijksuniversiteit Groningen
op gezag van de
Rector Magnificus, dr. F. Zwarts,
in het openbaar te verdedigen op
vrijdag 16 mei 2008
om 16.15 uur

door

Rik Wemmenhove

geboren op 3 juni 1982
te Den Ham

Promotor: Prof. dr. A. E. P. Veldman

Copromotor: Dr. ir. R. Luppes

Beoordelingscommissie: Prof. dr. ir. H. W. M. Hoeijmakers
Prof. dr. ir. R. H. M. Huijsmans
Prof. dr. ir. B. Koren

ISBN 978-90-367-3427-1

Contents

1	Introduction	1
1.1	Hydrodynamic wave loading	1
1.2	Air entrapment and air entrainment	2
1.3	Experimental validation	5
1.4	Simulation method	6
1.4.1	Discretisation	7
1.4.2	Free surface and density	7
1.4.3	Compressible air	9
1.4.4	Boundary treatment	9
1.5	Outline	10
2	Mathematical model	11
2.1	Governing equations	11
2.1.1	Equations of fluid dynamics	11
2.1.2	Free surface	13
2.2	Energy conservation	13
2.2.1	Kinetic energy balance	13
2.2.2	Symmetry properties in the energy balance	16
3	Numerical model	19
3.1	Continuity equation	19
3.2	Momentum equation	20
3.2.1	Conservative or nonconservative?	21
3.2.2	Sequence of variable calculation	22
3.2.3	Density and mass flux positioning	22
3.3	Discretisation of convection	25
3.3.1	First-order upwind discretisation	26
3.3.2	Second-order upwind discretisation	29
3.3.3	Symmetry properties of convection and B3	31
3.3.4	Density ratio in the convection	32
3.4	Discretisation of diffusion, pressure and gravity	34
3.4.1	Diffusive term	34

3.4.2	Pressure term	36
3.4.3	External force - Gravity term	36
3.5	Discretisation in time	37
3.5.1	Formulation of the Poisson equation	37
3.5.2	Time integration method	40
4	Free surface & density	45
4.1	Cell labeling	45
4.1.1	Geometry labeling	45
4.1.2	Free surface labeling	46
4.2	Compressibility in the Poisson equation	46
4.2.1	Reduction of unsteady and density gradient terms	47
4.2.2	Equation of state	48
4.2.3	Linearization of unsteady density term	49
4.2.4	Density gradient and convective density term	51
4.2.5	Treatment of negative pressures	51
4.3	Gas pressure and gas density	52
4.3.1	Phase conservation in closed domains	53
4.3.2	Gas pressure in surface cells	54
4.4	Density averaging method	57
4.4.1	Density in cell centers	57
4.4.2	Density averaging at cell edges	58
4.5	Free surface description	62
4.5.1	Overview of description methods	62
4.5.2	Free surface reconstruction	64
4.5.3	Free surface advection	66
4.5.4	Aerated cells	67
4.6	Open boundaries	71
4.6.1	Inflow and outflow boundary conditions	71
4.6.2	Absorbing boundary condition	72
5	Results for offshore applications	75
5.1	Introduction	75
5.2	1D Water piston	76
5.3	Rising bubble	77
5.4	Disc entry	79
5.5	Wave propagation: Rienecker-Fenton wave	82
5.6	Dambreak experiment	84
5.7	Sloshing experiment	89
5.8	Wave run-up tests	109
6	Conclusions	117

Bibliography	121
Samenvatting	127
Acknowledgements	132

