Technologies and Mathematical Modeling of Fines-Assisted Oil and Gas Recovery

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A thesis submitted for the degree of

Doctor of Philosophy (Ph.D.)

Australian School of Petroleum

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Table of Contents

Abstract

This is a PhD thesis by publication. It includes seven published/accepted for publication journal papers and two submitted papers in academic peer reviewed journals. The content of the thesis is also published in ten full volume technical papers of Society of Petroleum Engineering (SPE).

The thesis develops a theory for single and two-phase flow in porous media accounting for mobilization, migration, and straining of the natural reservoir fines. This phenomenon has been widely reported in laboratory studies and also well history data. The existing mathematical model, widely used in petroleum reservoir simulation, does not agree with laboratory observations. It contains phenomenological empirical constants which cannot be predicted theoretically.

The new closed system of governing equations, proposed in the current thesis, is free of the above mentioned shortcomings. The proposed system contains a new theoretical function describing the rock capacity to liberate fines so-called maximum retention function. This function is based on the micro scale conditions of mechanical equilibrium of fine particles in the porous space. The mechanical equilibrium condition is a torque balance of drag, lifting, electrostatic, gravity, and capillary forces. The maximum retention function is derived for both single-phase and two-phase flows in porous media. The comparison between the modified particle detachment model and the maximum retention function and laboratory and well data has shown a good agreement, which validates the model.

An exact analytical solution for single-phase flow in porous media with alternating velocity accounting for fines lifting has been derived, allowing for

mathematical description of a laboratory test on the suspension injection into reservoir cores with alternating velocities. Good agreement between the laboratory test results and the mathematical modeling predictions validates the theory developed.

Both analytical and numerical models for two-phase flow with induced fines migration have been developed. In reservoir scale approximation, the equivalence between the fines assisted water-flood and adsorption-free polymer flood has been investigated. It allows using the existing commercial simulators to model low salinity water-flood. The results of the modeling allow proposing a new technologically effective and economical method for improved sweep efficiency by fines assisted water-flooding.

Moreover, modeling of low salinity water injection shows that permeability reduction due to induced fines migration can slow down the encroaching water in oil/gas reservoir under strong water support. It decreases water production during pressure depletion of oil/gas reservoirs and improves the recovery. Also, a small volume injection of low salinity water can be used to reduce the water conning problem in oil/gas wells and prolong the wells production life.

Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution to Abbas Zeinijahromi and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Abbas Zeinijahromi 21/08/2012

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Thesis by Publication

Published Journal Papers

Bedrikovetsky, P., **Zeinijahromi, A**., Siqueira, F., Furtado, C. and de Souza, A., 2012. Particle Detachment Under Velocity Alternation During Suspension Transport in Porous Media. *Transport in Porous Media*, 91(1): 173-197.

Zeinijahromi, A., Lemon, P. and Bedrikovetsky, P., 2011. Effects of Induced Migration of Fines on Water Cut during Waterflooding. *Journal of Petroleum Science and Engineering*, 78: 609-617.

Zeinijahromi, A., Vaz A., Bedrikovetsky, P., 2012, Well impairment by fines migration in gas fields. *Journal of Petroleum Science and Engineering, 88–89:125–135.*

Zeinijahromi, A., Vaz A., Bedrikovetsky, P., Borazjani, S. 2012. Effects of Fines Migration on Well Productivity during Steady State Production. *Journal of Porous Media. 15(7): 665-679.*

Lemon, P., **Zeinijahromi, A**., Bedrikovetsky, P. and Shahin, I., 2011. Effects of Injected-Water Salinity on Waterflood Sweep Efficiency through Induced Fines Migration. *Journal of Canadian Petroleum Technology*, 50(9): 82-94.

Bedrikovetsky, P., Vaz A., Machado F., **Zeinijahromi, A**., Borazjani, S. 2012. Skin due to Fines Mobilisation, Migration, and Straining during Steady State Oil Production. *Journal of Petroleum Science and Technology, 30:1539-1547.*

Papers Accepted for Publication

Zeinijahromi, A., Nguyen T. K. P, Bedrikovetsky, P. accepted for publication 06/2012. Mathematical Model for Fines Migration Assisted Waterflooding with Induced Formation Damage, *SPE Journal.*

Submitted Journal Papers

Hussain, F., **Zeinijahromi, A**., Bedrikovetsky, P., Cinar, Y., Badalyan, A., Carageorgos, T. submitted 04/2012. Improved Oil Recovery by Mobilizing Fines during Waterflooding (Laboratory-Based Incremental Recovery). *Journal of Canadian Petroleum Technology*.

Nguyen T. K. P., **Zeinijahromi A**., Bedrikovetsky, P. submitted 08/2011. Fines migration assisted improved gas recovery during gas field depletion. *Journal of Petroleum Science and Engineering.*

Statement of Authors' Contributions

This thesis comprises a portfolio of nine publications that have been published, accepted for publication and/or submitted for publications in accordance with 'Academic Program Rules and Specifications 2012'. All journals to which the papers have been submitted are indexed in the 'ERA 2012 Journal List' database. The research summarized in the papers that constitute this thesis was undertaken within 'Formation Damage and EOR Research Group' at Australian School of Petroleum and with other universities and industry collaborators. Hence all the papers presented herein are co-authored and detail statements of relative contributions are endorsed by the co-authors.

STATEMENT OF AUTHORSHIP

Particle Detachment under Velocity Alternation during Suspension Transport in Porous Media

P. Bedrikovetsky, A. Zeinijahromi, F. Siqueira, C. Furtado, A. de Souza

Transport Porous Media, 2012, 91(1), 173-197

A. Zeinijahromi (Candidate)

Statement of contribution (in terms of the conceptualization of the work, its realization and its documentation)

Derivation of the exact solution, numerical calculations, comparative study between test and model data, participating in writing the text and formulating the final conclusions

Certification that the statement of contribution is accurate

Signed ……………………………………………………………………………*Date*………………

F. Siqueira

Statement of contribution (in terms of the conceptualization of the work, its realization and its documentation)

Development of analytical model, mathematical numerical modelling, sensitivity study

Certification that the statement of contribution is accurate and permission is given for the inclusion of the paper in the thesis

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C. Furtado

Statement of contribution (in terms of the conceptualization of the work, its realization and its documentation)

Carrying out the laboratory tests

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A. de Souza

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Formulation of the problem

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P. Bedrikovetsky

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Development of basic equations, writing the manuscript, acted as corresponding author

Certification that the statement of contribution is accurate and permission is given for the inclusion of the paper in the thesis

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Well impairment by fines production in gas fields

A. Zeinijahromi, A. Vaz, P. Bedrikovetsky

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Derivation of the exact solution, numerical calculations, comparative study between test and model data, participating in writing the text

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Effects of Fines Migration on Well Productivity during Steady State Production

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Journal of Porous Media, 2012, 15 (7): 665–679

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Derivation of the exact solution, numerical calculations, comparative study between test and model data, participating in writing the text

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A. Vaz,

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Skin due to Fines Mobilisation, Migration and Straining during Steady State Oil Production

P. Bedrikovetsky, A. Vaz, F. Machado, A. Zeinijahromi, S. Borazjani

Journal of Petroleum Science and Technology: accepted for publication 12/2011

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Performed analysis, interpreted data and wrote manuscript

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A. Vaz,

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Numerical modelling. Contributed to planning of article and provided critical evaluation

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Effects of induced fines migration on water cut during waterflooding

A. Zeinijahromi, , P. Lemon, P. Bedrikovetsky

Journal of Petroleum Science and Engineering, 2011, 78, 609-617

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Derivation of the exact solution, numerical calculations, comparative study between test and model data, participating in writing the text

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Effects of Injected -Water Salinity on Waterflood Sweep Efficiency Through Induced

P. Lemon, A. Zeinijahromi , P. Bedrikovetsky, I. Shahin

Journal of Canadian Petroleum Technology, 2011, 50(9), 82-94

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Improved Oil Recovery with Waterflooding by Mobilising Fines (laboratory-based incremental recovery)

F. Hussain, A. Zeinijahromi, P. Bedrikovetsky, Y. Cinar, A. Badalyan, T. Carageorgos

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Mathematical Model for Fines Migration Assisted Waterflooding with Induced Formation Damage

A. Zeinijahromi, T. K. P Nguyen, P. Bedrikovetsky

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Fines migration assisted improved gas recovery during gas field depletion

T. K. P Nguyen, A. Zeinijahromi, P. Bedrikovetsky

Journal of Petroleum Science and Technology, 2011: submitted paper

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