Pore Network Modelling of Gas Flow Processes in Porous Media with Special Application to CO_2 Sequestration

Usman Bagudu BEng, MSc

Thesis submitted for the degree of
Doctor of Philosophy

Institute of Petroleum Engineering
School of Energy, Geoscience, Infrastructure and Society
Heriot-Watt University
Edinburgh

February, 2015

Abstract

This thesis describes the development of a pore network model and its application to the analysis of the underlying physical mechanisms governing gas flow behaviour in porous media. The main focus of the study is CO_2 and CH_4 injection for EOR and storage applications as well as the evolution of solution gas following depressurization of hydrocarbon-saturated porous media. The model incorporates algorithms that dynamically track interface movements during both steady and unsteady-state flow under the coupled influence of capillary, gravity, and viscous forces. The model has been validated against laboratory experiments and the roles played by key system parameters have been identified.

For injection processes, simulation results show that gravity-driven regimes fall into two broad categories of quasi-stable and migratory regimes, depending on the governing Bond number. The transition from non-dispersive to dispersive migratory flow was found to be largely independent of injection rate but a strong function of pore size distribution variance and system connectivity. CO_2 and CH_4 regimes in brine were found to exhibit striking similarities, suggesting that CH_4-brine relative permeability curves could be used to accurately parameterize simulation models of CO_2 storage in aquifers. Decreasing the interfacial tension was found to dampen viscous fingering but exacerbates gravity override which suggests that standard laboratory methods for analysing CO_2 EOR processes are likely to overestimate displacement efficiency. Other sensitivity studies highlight the pore to core scale variables that control caprock sealing mechanisms, and residual and solubility trapping during CO_2 injection for storage, and their implications at the reservoir scale.

For depressurization, simulations performed on a pore network anchored to measured petrophysical properties of a 0.23mD fractured chalk core from a North Sea reservoir show a very weak correlation between depletion rate and critical gas saturation, contrary to conventional belief. Depressurization oil recovery efficiency was found to increase with increase in initial water saturation but the presence of fractures caused the critical saturation to decrease by approximately 60%.

Acknowledgements

First and foremost, I'm most grateful to Dr Steven McDougall, for his leap of faith in recruiting me for this research project and his unwavering guidance and support each step of the way. The open and energetic spirit that he has brought to this work will continue to be an inspiration. I hope that this thesis can repay some of this generosity.

My heartfelt thanks to Professor Eric Mackay, for his kindness, encouragement, and for the masterful way in which he has helped me to focus on the bigger picture. The part he played in extending my personal maintenance allowance beyond the original end date is gratefully acknowledged.

I'm very grateful to Scottish Carbon Capture and Storage and Foundation CMG for providing the funds that made this research possible. Special thanks are due to Drs. Simon Mathias and Gillian Pickup, for agreeing to serve as my external and internal examiners, respectively. I also thank my colleagues within the Institute of Petroleum Engineering, for their friendship and for unwittingly making this otherwise challenging voyage a more exciting and memorable one: Dr Cyril Okocha (now with Clariant Oil Services), Haiyun Yan, Viswa Chandra, and Obinna Chudi deserve special mention.

I thank my parents, Hajiya Safetu Usman and Alhaji Mohammad Bagudu Audu, for their encouragement and understanding.

DECLARATION STATEMENT

(Research Thesis Submission Form should be placed here)

Table of Contents