Abstract

Canada contains reserves of oil sand and heavy oil resources considered to be the largest amount of unconventional hydrocarbons deposited in unfavorable conditions. It needs more efforts and technological advancement to recover oil from such reserves. Steam flooding enhanced oil recovery technique is applied for more than 70% of heavy oil reservoirs to extract the oil. Three-dimensional (3D) displacement model can represent an appropriate approach and model for the steam flooding process. However, their physical limitations make it impossible to duplicate the real behavior of a reservoir in larger scale. So, it is important to develop scaling criteria for depicting the actual fluid behavior for unconventional reservoirs.

Scaled physical models have the unique advantage of capturing all physical phenomena occurring in a particular process by transforming the parameters into dimensionless numbers. This concept is applicable to fluid flow through porous media, where continuous alteration of rock and fluid properties can be characterized by various dimensionless numbers. In this study a set of dimensionless groups were developed using both inspectional and dimensional analyses. The new groups of dimensionless numbers can be used to characterize the reservoir rock and fluid properties for better explanation of complex rock/fluid phenomena for the steam flooding process. It should be noted that the complete set of scaling criteria is very difficult to satisfy. Therefore, some of the similarity groups must be relaxed in order to satisfy the most important parameters of the specific reservoir activities. The choice of which requirements to relax depends on the particular process being modeled. Scaling of the phenomena considered to be least important to a particular process might be relaxed without significantly affecting the major features of the process. The choice of an approach depends on the importance of the phenomena that are not scaled by that approach. Major scaling groups were found by applying different elimination techniques. The effect of those dominant dimensionless groups on recovery was evaluated through the study of process controlling parameters. A new group which is called Dykstra-Parsons coefficient is introduced to incorporate the reservoir heterogeneity. A combined dimensionless group was proposed to characterize and evaluate the performance and found to have the largest effect on oil recovery. Sensitivity analysis of scaling numbers is performed to find out the relative effect of each dimensionless numbers on oil recovery. Finally, a numerical simulation study is performed to quantify the effect of steam quality and permeability variations for different reservoirs.

This research work leads to the development of a procedure that can be applied to design a steam flooding EOR process. This process allows the assessment of different parameters to aid in the selection of optimum additive concentration to account for the uncertainties due to reservoir heterogeneity. The process is flexible; it can be applied to wide range of reservoir types as there exists a physical commonality between laboratory and field scale.

DEDICATION

To my dearest parents, my beloved wife and daughter

ACKNOWLEDGEMENTS

This thesis becomes a reality with the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

First, I would like to offer this endeavor to our Almighty God for the wisdom He bestowed upon me, the strength, peace of mind and good health to finish this research.

I sincerely wish to acknowledge my academic adviser, Dr. M. Enamul Hossain for his excellence guidance, continuous support, constructive comments and encouragement throughout my M. Eng. studies at Memorial University of Newfoundland. I am highly indebted to my academic adviser, Dr. Salim Ahmed for his guideline, valuable advice, inspiration, help as well as his time and attention.

I would like to express my heartfelt appreciation to my family members for their trust, support and patience during the whole period of the study. I want to especially thank my beloved and supportive wife HAPPY, who is always by my side when I need her most and helped me in making this study, and my lovable daughter, ANEESHA who served as my inspiration to pursue this undertaking.

I would like to express my heartiest appreciation and gratitude to head as well as all the faculty members of the Department of Process Engineering, staff and fellow students for their support and help and to make this study enjoyable and fruitful.

I would like to acknowledge School of Graduate Studies of Memorial University of Newfoundland, Research & Development Corporation of Newfoundland and Labrador (RDC), and Statoil Canada Ltd. for providing financial support to accomplish this research.

I am also thankful to my wonderful research group members and friends. Thank you all for being with me when I need help and support.

CO-AUTHORSHIP STATEMENT

I, Arifur Rahman, hold the primary author status for all the chapters in the thesis. However, each manuscript is co-authored by my supervisor and co-researcher, whose contributions have facilitated the development of this work as described below.

- **Arifur Rahman, Fatema Akter Happy, Salim Ahmed, M. Enamul Hossain. "Development of scaling criteria for enhanced oil recovery: A review", This article has been published in the Journal of Petroleum Science and Engineering.**

  Statement: I, Arifur Rahman, the primary author and carried out the research and develop the literature review of scaling criteria development for different EOR process. I drafted the manuscript and incorporated the comments of the co-authors in the final manuscript. Co-authors helped in conceiving the idea and selection of appropriate approach for steam flooding process.

- **Arifur Rahman, Salim Ahmed, M. Enamul Hossain. "Development of Scaling Criteria for Steam Flooding Process using Rock and Fluid Memory Concept", to be submitted to a journal.**

  Statement: I, Arifur Rahman, the primary author and carried out the research and development of scaling criteria. I drafted the manuscript and incorporated the comments of the co-authors in the final manuscript. Co-authors helped in conceiving the idea and selection of appropriate approach for steam flooding process.

- **Arifur Rahman, Salim Ahmed, M. Enamul Hossain. "Scaled Physical Model Studies of Steam Flooding EOR Process", to be submitted to a journal.**

  Statement: I, Arifur Rahman, the primary author and carried out the research and development of scaled physical model of steam flooding EOR process. I drafted the manuscript and incorporated the comments of the co-authors in the final manuscript. Co-authors helped in conceiving the idea and improve the design of a steam flooding process.

- **Arifur Rahman, Salim Ahmed, M. Enamul Hossain. "Sensitivity Analysis of Scaled Model and Numerical Simulation Study of Steam Flooding Process", to be submitted to a journal.**

  Statement: I, Arifur Rahman, the primary author and carried out the research to study sensitivity analysis of scaled physical model and numerical simulation of steam flooding EOR process. I drafted the manuscript and incorporated the comments of the co-authors in the final manuscript. Co-authors helped in conceiving the idea and improve the quality of the manuscript.

Table of Contents

Contents	Page no.

LIST OF TABLES

LIST OF FIGURES