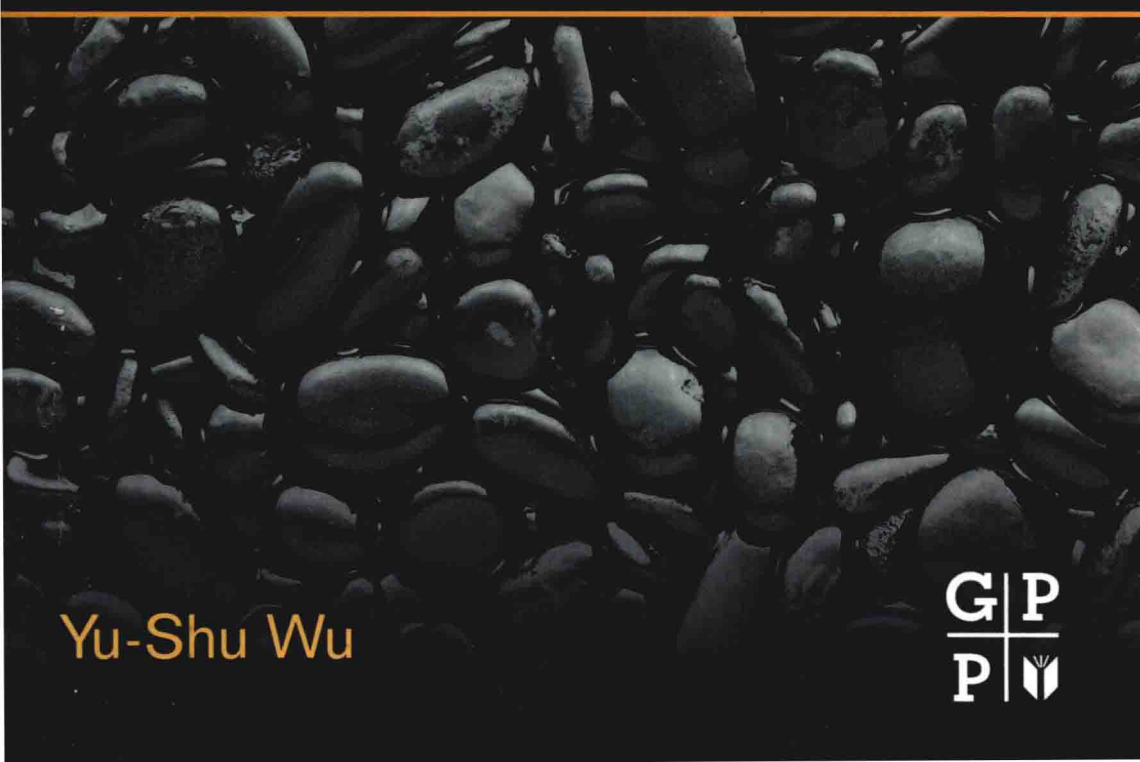
Multiphase Fluid Flow in Porous and Fractured Reservoirs



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MULTIPHASE FLUID FLOW IN POROUS AND FRACTURED RESERVOIRS

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DEDICATION

This book is dedicated to my family, teachers, colleagues and students.

PREFACE

This book focuses on the physics of multiphase fluid flow and displacement in porous and fractured media as well as quantitative approaches and analyses for describing such physical processes in reservoirs. The book is intended to complement the existing literature by presenting new advances and updated developments in multiphase fluid flow in porous media. The material of this book is based primarily on (1) a series of peer-reviewed papers, published by me or with co-authors and (2) the course notes that I have used to teach undergraduate and graduate courses on *petroleum reservoir engineering* and *multiphase fluid flow in porous media* at the Colorado School of Mines. The publications that this book is based on are related to the research on the subject of multiphase fluid flows in porous and fractured media, which I have carried out or been involved with since the late 1980s at the University of California, Berkeley, California (CA); HydroGeoLogic, Inc., Reston, Virginia; the Lawrence Berkeley National Laboratory, Berkeley, CA; and the Colorado School of Mines, Golden Colorado.

The book can be used as a textbook or reference for senior undergraduate and graduate students in petroleum engineering, hydrogeology or groundwater hydrology, soil sciences, and other related engineering fields, such as civil and environmental engineering. It can also serve as a reference book for hydrogeologists, petroleum reservoir engineers, and other engineers and scientists working in the area of flow and transport in porous media.

The content of the book is organized to cover fundamentals of multiphase fluid flow in porous media. It discusses the physical processes and principles governing multiphase porous-medium flow using Darcy's law, relative permeability, and capillary-pressure concepts. This book uses the black-oil model as an example of immiscible multiphase fluid flow to discuss flow-governing equations and approaches for their solution to quantity flow and displacement processes in reservoirs. Specifically, this book presents the extensions of the classical Buckley–Leverett fractional flow theory to one-dimensional linear and radial composite systems, to analysis of immiscible displacement of non-Newtonian fluids in porous media, and to non-Darcy displacement using *Forchheimer* and Barree and Conway non-Darcy flow models. In addition, the book reviews the concept, approach, and development for modeling multiphase flow in

fractured porous media and multiphase fluid flow and heat transfer in reservoirs. In an effort to include the new developments, the book also presents mathematical formulations and numerical modeling approaches for multiphase flow coupled with geomechanics and for flow in unconventional petroleum reservoirs.

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I would also like to thank my colleague at CSM, Dr. Philip H. Winterfeld, for his thorough technical review of the manuscript and sharing his expertise in reservoir simulation. I am highly indebted to Prof. Jun Yao at the China University of Petroleum (Huadong) for offering and hosting me for a sabbatical leave in the fall of 2014, while I taught several courses related to *multiphase fluid flow in porous media* and had the time to write the majority of the manuscript.

I would like to take this opportunity to thank many of my current and former colleagues and friends in the US and China who have made this book possible. Specifically, I would like to thank the faculty and students of the Petroleum Engineering Department at CSM for their criticisms and suggestions to improve the materials of the book. I am grateful to many of my former colleagues in the Earth Sciences Division of the Lawrence Berkeley National Laboratory, Berkeley, California, and in HydroGeoLogic Inc., Reston, Virginia, for the opportunities of working together on studies of flow and transport in porous media over past decades.

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