SECOND EDITION

Reservoir Formation Damage

FUNDAMENTALS, MODELING, ASSESSMENT, AND MITIGATION

Faruk Civan

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RESERVOIR FORMATION DAMAGE

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PREFACE

Formation damage is an undesirable operational and economic problem that can occur during the various phases of oil and gas recovery from subsurface reservoirs including production, drilling, hydraulic fracturing, and workover operations. Formation damage assessment, control, and remediation are among the most important issues to be resolved for efficient exploitation of hydrocarbon reservoirs. Such damage is caused by various adverse processes including chemical, physical, biological, and thermal interactions of formation and fluids, and deformation of formation under stress and fluid shear. Formation damage indicators include permeability impairment, skin damage, and decrease of well performance. The properly designed experimental and analytical techniques presented in this book can help understanding, diagnosis, evaluation, prevention, and controlling of formation damage in oil and gas reservoirs.

This book provides an understanding of the fundamentals of the relevant processes causing formation damage and reducing the flow efficiency in the near-wellbore formation during the various phases of oil and gas production; an update review of the various approaches used in the modeling and simulation of formation damage for model-assisted analysis and interpretation of laboratory core tests, and for prediction and control of formation damage; and the techniques used for assessment, diagnosis, minimization, and control of formation damage in petroleum reservoirs. It focuses on the theory, modeling, and simulation of the rock, fluid, and particle interactions, fluid and particle invasion, filter cake, in situ mobilization, migration, and deposition of fines, organic and inorganic precipitation and scale formation, alteration of porosity, permeability, and

texture in laboratory cores and reservoir formations, and the effects of single- and multiphase fluid systems.

Formation damage is evolving to be more science than art. Formation damage is an interesting interdisciplinary subject that attracts many researchers. Cost-effective mitigation of formation damage is still as much art as science. This book is a recapitulation of the present state-of-the-art knowledge in the area of formation damage. It is intended to be a convenient source of information, widely spread over different sources. I have tried to cover the relevant material with sufficient detail, without overwhelming the readers. This book can be used by those who are engaged in the various aspects of formation damage problems associated with the production of hydrocarbons from subsurface reservoirs. It may serve as a useful reference and provides the knowledge of the theoretical and practical aspects of formation damage for various purposes, including model-assisted interpretation of experimental test data, prediction and simulation of various formation damage scenarios, evaluation of alternative strategies for formation damage minimization, and scientific guidance for conducting laboratory and field tests.

Exhaustive effort has been made to gather, analyze, and systematically present the state-of-the-art knowledge accumulated over the years in the area of formation damage in petroleum reservoirs. This book is intended to provide a quick and coordinated overview of the fundamentals, and the experimental and theoretical approaches presented in selected publications. However, it should not be viewed as a complete encyclopedic documentation of the reported studies. It discusses processes causing formation damage and reducing the productivity of wells in petroleum reservoirs and systematically presents various approaches used in the diagnoses, measurement, evaluation, and simulation of formation damage. The techniques for assessment, minimization, control, and remediation of the reservoir formation damage are described.

This book is intended for the petroleum, chemical, and environmental engineers, geologists, geochemists, and physicists involved in formation damage control, and for the undergraduate senior and graduate petroleum engineering students. The material presented in this book originates from my industry short courses and curriculum courses at the Mewbourne School of Petroleum and Geological Engineering at the University of Oklahoma. This book can be used in industry training courses and undergraduate senior and graduate level petroleum engineering courses. It is recommended for formation damage courses and as a companion for drilling, production, and stimulation courses. Readers will

- learn the mechanisms and theoretical background of the common formation damage processes
- be familiar with the testing, modeling, and simulation techniques available for formation damage assessment
- be able to develop strategies for better management of the adverse processes to minimize and avoid formation damage in petroleum reservoirs.

I am indebted to the researchers who have contributed to the understanding and handling of the various issues and aspects of formation damage and mitigation. Their efforts have led to the accumulation of a substantial amount of knowledge and expertise on formation damage and helped develop techniques and optimal strategies for effective detection, evaluation, and mitigation of formation damage in subsurface reservoirs. Their works have been published in various literatures. I am pleased to have had the opportunity to analyze, integrate, transfer, and present the state-of-the-art knowledge of formation damage in a consistent manner in one source for the readers of this book, based on more than 870 references. I believe that most effective learning is through teaching. I have enjoyed such exercise as it provided tremendous opportunities to others to benefit from my teaching.

Many of the figures, tables, and other relevant materials used in the preparation of this book were extracted from the literature published by various researchers, companies, and organizations. These include the following: Academic Press; AAPG – American Association of Petroleum Geologists; ACS – American Chemical Society; AGU – American Geophysical Union; AIChE – American Institute of Chemical Engineers; American Institute of Physics; API – American Petroleum Institute; ASME – American Society of Mechnical Engineers; A.A. Balkema Publisher; Baroid Drilling Fluids, Inc.; Canadian Institute of Mining, Metallurgy and Petroleum; *Chemical Processing* magazine; Chemicky Prumysl; Computational Mechanics, Inc.; Elsevier Science, The Geological Society Publishing House, IEEE – Institute of Electrical and Electronics Engineers, Inc.; ICheme-Institute of Chemical Engineers; International Institute for Geothermal Research, Italy; Ilinois State Geological Survey; John Wiley & Sons Limited; Marcel Dekker, Inc.; M-I L.L.C.; OSA – The Optical Society of America; Petroleum Society of CIM; Plenum Press; Routledge/Taylor & Francis Group LLC.; Sarkeys Energy Center at the University of Oklahoma; SPE – Society of Petroleum Engineers; Springer-Verlag; SPWLA – Society of

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This book provides a broad background and knowledge on the practical and theoretical aspects of the various problems dealing with the processes and operations causing formation damage in subsurface geological porous formations. I wish that this book will be a convenient, informative, and useful companion for those involved in the reservoir formation damage issues at various capacities, from practitioners to academicians.

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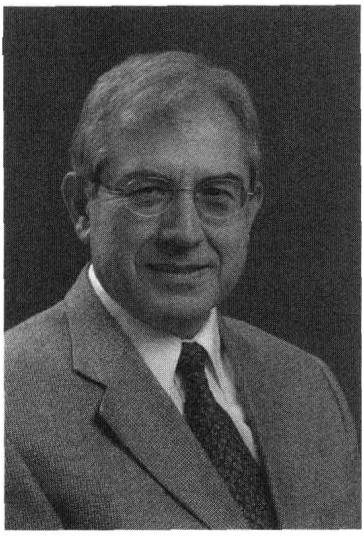

Faruk Civan is an Alumni Professor of the Mewbourne School of Petroleum and Geological Engineering at the University of Oklahoma in Norman. Previously, he worked in the Chemical Engineering department at the Technical University of Istanbul, Turkey.

Dr. Civan received an Advanced Engineering Degree from the Technical University of Istanbul, Turkey; an MS degree from the University of Texas at Austin, Texas; and a PhD degree from the University of Oklahoma, Norman, Oklahoma. All of his degrees are in chemical engineering.

Dr. Civan specializes in petrophysics and reservoir characterization; formation and well damage modeling, diagnosis, assessment, and mitigation; reservoir and well analyses, modeling, and simulation; natural gas engineering, measurement, processing, hydrates, transportation, and storage; carbon dioxide sequestration; coalbed methane production; improved reservoir recovery techniques; corrosion protection in oil and gas wells; filtration and separation techniques; and air, water, and ground pollution modeling and control.

He has published more than 200 technical articles in journals, edited books, handbook, and encyclopedia, and conference proceedings, and presented 85 invited seminars and/or lectures at various technical meetings, companies, and universities. He teaches industry short courses on

a number of topics worldwide. Additionally, he has written numerous reports on his funded research projects. Dr. Civan's publications have been cited frequently in various publications, as reported by the Science Author Citation Index.

Dr. Civan has received 20 honours and awards, including five distinguished lectureship awards and the 2003 SPE Distinguished Achievement Award for Petroleum Engineering Faculty.

He is a member of the Society of Petroleum Engineers, the American Society of Mechanical Engineers, and the American Institute of Chemical Engineers. Dr. Civan serves as a member of the editorial boards of the *Journal of Petroleum Science and Engineering, Turkish Oil and Gas Journal, Journal of Porous Media*, and *Journal of Energy Resources Technology*. He has served on numerous petroleum and chemical engineering, and other related conferences and meetings in various capacities, including as committee chairman and member, session organizer, chair or co-chair, instructor, and as member of the editorial board of the *Society of Petroleum Engineers Reservoir Engineering Journal* and the special authors series of the *Journal of Petroleum Technology.*

CONTENTS

CHAPTER 1

OVERVIEW OF FORMATION DAMAGE

Summary

A comprehensive review of the various types of formation damage problems encountered in petroleum reservoirs is presented. The factors and processes causing these problems are described in detail. The design of a team effort necessary for understanding and controlling of the formation damage problems in the field is explained. The motivation for the writing of this book and the specific objectives are stated. The approach taken in the presentation of the materials in this book is explained. A brief executive summary of the topics covered in the book is given. The roles played by different professionals, such as the petroleum and chemical engineers, chemists, physicist, geologists, and geochemists, are described.

1.1 INTRODUCTION

Formation damage is a generic terminology referring to the impairment of the permeability of petroleum-bearing formations by various adverse processes. Formation damage is an undesirable operational and economic problem that can occur during the various phases of oil and gas recovery from subsurface reservoirs including drilling, production, hydraulic fracturing, and workover operations (Civan, 2005). As expressed by Amaefule et al. (1988), "Formation damage is an expensive headache to the oil and gas industry." Bennion (1999) described formation damage as, "The impairment of the invisible, by the inevitable and uncontrollable, resulting in an indeterminate reduction of the unquantifiable!" Formation damage assessment, control, and remediation are among the most important