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M. R. Riazi





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Foreword

THIS PUBLICATION, *Exploration and Production of Petroleum and Natural Gas*, was sponsored by ASTM Committee D18 on Soil and Rock and co-sponsored by D02 on Petroleum Products, Liquid Fuels, and Lubricants. This publication is Manual 73 of ASTM International's manual series.

This book is dedicated to my family: Shiva, Touraj, and Nazly, and to my late parents.

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Preface

Oil and gas have been the main sources of energy the world over for the past century and will remain important sources of energy at least for the first half of this century and possibly beyond. Currently, more than half of the world's energy is produced from oil and gas resources, and energy needs are increasing. In addition, oil and gas provide the main feedstocks for the petrochemical industry. World population is expected to increase to more than 8.5 billion by 2035, which will demand an increase in energy of 40 % in the next two decades. With these increases in energy consumption it is becoming necessary to consider unconventional types of oil and gas such as heavy oil, sand oil, and shale oil and shale gas, which require more rigorous production processes. Natural gas has an increasingly important role in supplying cleaner energy, with lower carbon emission than other hydrocarbon-type energy sources such as oil or coal. Consequently, advances in technology are absolutely essential to ensure that the use of fossil fuels remains affordable and clean.

The evolution of the modern petroleum industry began with the birth of oil production in Pennsylvania in the nineteenth century. Current production methods are much more complex than those of the last century, and there is significant research concerning optimum production and use of available hydrocarbon resources. In the past few decades there has been an increase in the number of publications that report advancements in the hydrocarbon exploration and production industry. *Exploration and Production of Petroleum and Natural Gas* is a continuation of those efforts and attempts to bring together the most recent advances in various areas of petroleum upstream activities, with an emphasis on economic and environmental considerations, production of unconventional oil and gas resources, drilling methods, offshore activities, and future trends in the industry.

The primary goal of this book is to provide a comprehensive reference that covers the latest developments in all aspects of petroleum and natural gas exploration and production in the upstream sector of the petroleum industry. Another objective of this book is to describe the latest technology available to those working in the petroleum upstream industry, especially designers, researchers, operators, managers, decision-makers, business people, and government officials. Some 30 authors from both academia and industry have contributed to the 24 chapters in this volume. The book begins with introduction of reservoir types, specifications, and characterization (Chapter 1), followed by Chapter 2, with presentation of data on world oil and gas reserves and production rates, which provide availability of these resources and production life in different countries and continents.

The two most important parameters of a reservoir, the hydrocarbon in place and the recoverable reserve, are determined by the reservoir rock and fluid properties along with the fluid distribution. Chapter 3 discusses the properties of rocks and reservoir fluids, and their physical and chemical interactions that control the microscopic distribution of the fluids and

the production of hydrocarbons. Laboratory measurements of some of those properties are also discussed. Chapter 4, written by two practicing engineers, discusses fundamentals of geomechanics of petroleum reservoirs and its application in drilling technology, offshore technology, high pressure water flood management, thermal recovery methods, and production from unconventional oil and gas resources.

Chapters 5 through 7 are devoted to simulation and data analysis in petroleum systems. The general objective of Chapter 5 on pool-forming simulation is to build the history of oil and gas generation, migration, and accumulation in the petroleum system and then to proceed with quantitative basin analysis and to assess oil and gas resources, as well as identification of conditions for sealing and storage of hydrocarbon traps. Chapter 6 is written by two experts in the field of data mining and data-driven analytics. Oil field data mining provides the means for making the most of the investment that has gone into collection and storage of the data. Oil field data mining is a set of tools and technologies used to extract information and knowledge from the collected data in the exploration and production industry. Data-driven analytics have proven to be valuable in understanding the complex nature of the production process, which could help to optimize completion design and production. Chapter 7 gives an overview of reservoir simulation techniques. Numerical simulation of a reservoir refers to the construction and operation of a model whose behavior describes the appearance and flow characteristics of an actual reservoir. The necessity of reservoir simulation in the oil industry operations can be justified by considering the need for reservoir management. A proper reservoir management requires the use of available financial, technological, and human resources to maximize recovery while minimizing costs.

Chapter 8 reviews various drilling methods used for oil and gas production, related safety issues, and a brief overview of offshore drilling technology, including innovations for harsh environments. Primary production facilities—onshore, floating vessels, offshore, and even ocean floor facilities—are introduced in Chapter 9. These facilities include gravity separators, flow measuring devices, oil-water separation, compressors, pumps, handling produced water, solid separation devices. Design aspects as well as operating conditions for these facilities are also discussed in this chapter, which is written by an experienced professional expert working in this field. Chapters 10 and 11 are devoted to enhanced oil recovery methods (EOR) for both conventional and unconventional reservoirs, respectively. In order to achieve oil recovery factors higher than 30 % from mature reservoirs, it is necessary to implement EOR processes. In Chapter 10, a brief description of the most common EOR processes is presented, as well as information on recent developments and field applications. Chapter 11 presents the latest technology in producing oil from unconventional reservoir formations, which may include oil sands, extra-heavy oil, tight oil, tight gas, shale gas, coalbed methane, gas hydrates, oil shale, igneous, basement, and volcanic reservoir rocks. Applications of thermal methods for oil recovery from extra-heavy oil, bitumen and oil sands reservoirs are discussed with greater details in Chapter 11. Unconventional resources include fossil fuels for which production is not mature or there are concerns on economical or environmental issues. During the first decade of the twenty-first century, successful development of unconventional gas and oil reservoirs in North America, especially production from shale gas and oil shale reservoirs, is transforming the global energy landscape. Chapter 12 discusses hydraulic fracturing, which is an advanced technology for production from shale-hosted hydrocarbons as presented in Chapter 13.

Natural gas remains one of the most important sources of energy and its role in the energy supply is continuously increasing. Chapter 14 is entirely devoted to production methods for natural gas and well performance by two experts in this field. Chapter 15 discusses the importance of natural gas hydrates as a potential source of energy, as well as problems caused by formation of hydrates in production wells and pipelines. One of the emerging technologies in the field of oil production is in the application of microorganisms to increase oil recovery (usually referred to as MEOR) from mature

reservoirs as an alternative to the traditional chemical EOR methods. This topic is discussed in Chapter 16, as the successful application of biotechnological process in oil reservoirs requires a deep knowledge of their structure and characterization. Chapter 17 discusses one of the major problems in oil production due to formation of asphaltenes and reduction in oil production due to blockage of wells causing significant financial damage during the production activities. In Chapter 17 the conditions that lead to precipitation of asphaltene and methods of its prevention are presented by experts in this field from Rice University.

In Chapter 18, transportation and storage of oil and gas are discussed. After brief historical developments in hydrocarbon transportation, issues such as pipeline cost, operating conditions, transportation by tanker, and types of storage tanks, as well as safety and environmental issues associated with transportation and storage of oil and gas, are covered in this chapter. Environmental, health and safety concerns associated with oil and gas production are discussed in Chapter 19. The U.S. Gulf of Mexico is one of three major deepwater producing regions in the world, but little information exists that examines development strategies and profitability. Deepwater structures are expensive to fabricate and install and at the end will be expensive to decommission. Chapters 20 and 21 are written by an experienced expert on the Gulf of Mexico and are related to economic issues in offshore production of oil and gas. Deepwater developments are expensive, complex, and risky endeavors, and these two chapters discuss how acceptable financial return can be achieved in an uncertain environment.

Changing trends in the exploration and production of hydrocarbons is an important issue for every government in planning for its energy demand and consumption; these are discussed in Chapter 22. Due to population and economic growth, world energy demand is continuously increasing and hydrocarbon productions play an important role in meeting such demand in light of other energy sources as discussed in this chapter. Production of oil requires a significant amount of energy, which is usually produced by combustion of hydrocarbon type fuels. This in turn contributes to production of CO_2 and subsequent environmental impacts. One alternative approach to this problem is use of renewable energy such as solar energy to provide at least part of the energy required for oil production. This issue and related CO_2 constraints in energy production are discussed in Chapter 23. Hydrocarbon sources are limited and the world will eventually run out of oil. Various enhanced oil recovery (EOR) methods are being examined by different oil companies around the world to produce remaining oil which will be economically, technically, and environmentally sound and acceptable at the current or future cost/price range. These issues are discussed in Chapter 24 by an author with significant industrial experience in the field. This is the closing chapter, which can serve as a guide to researchers and oil companies in directing their efforts for exploration and production of oil and gas in the coming decades.

Every attempt has been made to avoid overlap between chapters; however, there are some topics that have been included in more than one chapter when relevant to both chapters. The petroleum upstream industry is a diverse and complex industry and it is almost impossible to include all aspects of it in a single book. However, we tried to cover the most vital issues and we believe this is the most comprehensive resource published to date for use by people involved in this worldwide industry. We hope this contribution will be useful to them. In writing this book we benefited from the published works of many researchers, which are cited at the end of each chapter. We welcome comments and suggestions from readers. Authors with years of experience made unique contributions not available in any similar publications. I am grateful to all of them for their efforts in bringing this book to fruition. I also thank the large number of anonymous reviewers who went through lengthy manuscripts and provided us with their constructive comments and suggestions, which greatly enhanced the quality of the manual. Many publishers, organizations, and companies provided us with permission to use their published data, graphs, and figures and we thank them for their cooperation in supporting this publication effort.

I am also thankful to ASTM International for sponsoring publication of this book, especially to Kathy Dernoga, Monica Siperko, Scott Emery, Erica Korman, and other ASTM staff involved in this project. Kathy Dernoga's review and encouragement were essential to the completion of this work. The support and encouragement of ASTM's Committee on Publications as well as sponsorship of this project by Committees D18 on Soil and Rock and D02 on Petroleum Products, Liquid Fuels, and Lubricants are appreciated. The submission and reviewing processes were managed and conducted by Heather Blasco and Sara Welliver and I am thankful for their cooperation in uploading the manuscripts to the online reviewing site, inviting reviewers, and handling all manuscripts submitted for this manual. Also, thanks to Rebecca L. Edwards, senior project manager at Cenvo Publisher Services for copyediting and production. Finally, and most importantly, I would like to thank my family, especially my wife, Shiva, for her patience, understanding, cooperation, and moral support, which were essential throughout this work.

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M. R. Riazi (www.RiaziM.com) is currently the chair of chemical engineering at Kuwait University. He was previously a faculty member of chemical and petroleum engineering at various universities in US, Canada, Europe and the Middle East. He has about 140 publications including 5 books and a solutions manual as well as about 100 conference presentations mainly in the fields of petroleum and chemical technology. He has been invited speaker and consultant to more than 50 major oil companies and research centers worldwide and has conducted about 70 workshops and short courses in some 40 countries. He is the founding editor and editor in chief of IJOGCT (London, UK) and an editor of Journal of Petroleum Science and Engineering (Elsevier). He received several research and teaching awards including an award by the former Amir of Kuwait. He also received Diploma of Honor from National (American) Petroleum Engineering Society for outstanding services to the petroleum industry and is a Fellow of American Institute of Chemical Engineers (AIChE).

Exploration and Production of Petroleum and Natural Gas provides a comprehensive and thorough coverage of a topical area which is critically important for the entire World including the hydrocarbon producing and exporting countries as well as the hydrocarbon importing countries. In this book, Professor Riazi has managed to bring together an impressive list of authors who are known as the leading specialists in their respective areas. The overall framework of the book provides an effective platform to the authors to communicate and disburse their wealth of knowledge with their counterparts in the technical world of exploration and development of hydrocarbon resources. The “Exploration and Production of Petroleum and Natural Gas,” is a treat for engineers and scientists who will find at their fingertips all the related up-to-date technical advances from hydrocarbon reservoir characterization to geomechanics of petroleum reservoirs, from drilling and production operations to environmental and safety issues related to oil and gas production, from transportation of oil and gas to risk analysis and management.

—Turgay Ertekin
Head of Department of Energy and Mineral Engineering, Penn State University

This peer reviewed book *Exploration and Production of Petroleum and Natural Gas* provides a comprehensive and thorough understanding of the hydrocarbon energy production sector. The book covers everything from exploration & characterization of reserves, to extraction, transportation, and decommissioning of wells. Also included are chapters for environmental, safety, economics, and future trends. It will be a valuable resource of information for both technical and non-technical professionals. The book is well written, organized nicely and contains lots of tables and figures that make it easy to read and understand. This is another high quality publication by ASTM.

—Wayne Smith
Vice-President, Real-Time Analyzers, Inc.

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