国外油气勘探开发新进展丛书

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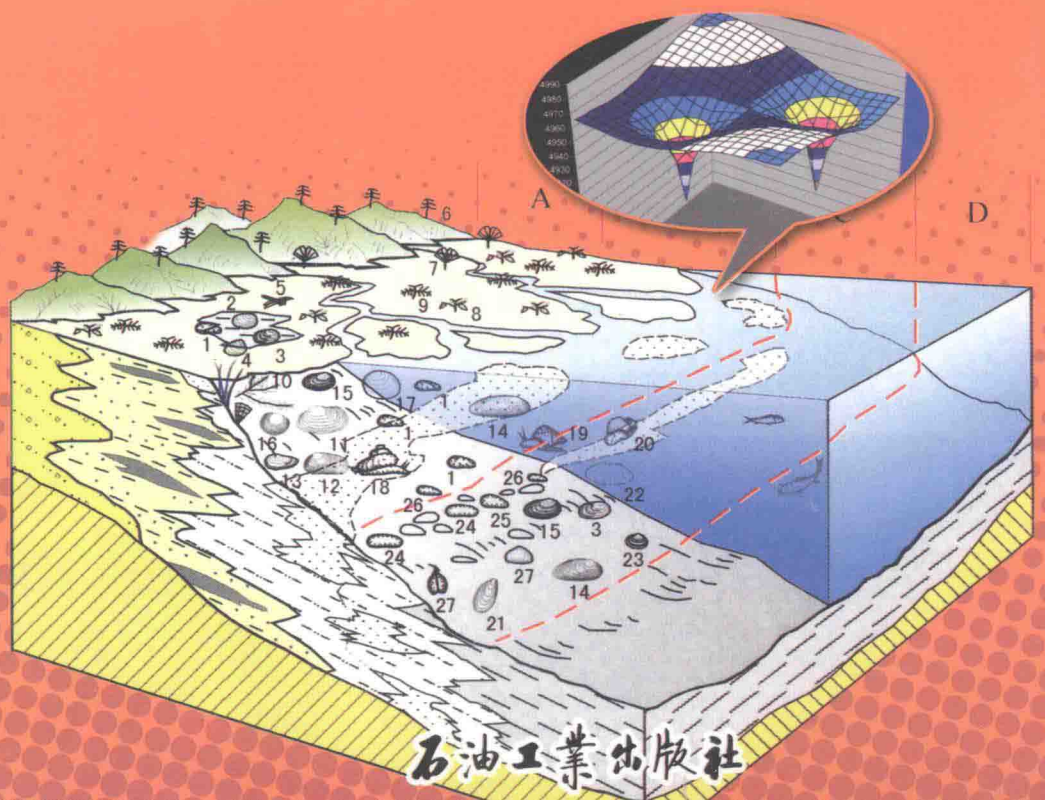
六

Reservoir Engineering Handbook

油藏工程手册

（第三版）（原书影印版）

[美] 塔雷克·艾哈迈德 著



石油工业出版社

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RESERVOIR ENGINEERING HANDBOOK

Third Edition

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内 容 提 要

本书主要论述油藏流体状态基本原理，油藏中流体性质，实验室分析岩石性质，渗透性的相关概念，油藏流体流动的基本原理，油气井动态分析，气水锥进，水侵，采油机理和物质平衡方程，油藏动态预测，注水基本原理，蒸汽—液体两相平衡，储量下降分析和曲线分析等方面内容。每章配有例题以便读者理解。

本书可供从事油气田开发工作的相关技术人员和石油高校师生参考。

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《国外油气勘探开发新进展丛书（六）》

编　委　会

序

为了及时学习国外油气勘探开发新理论、新技术和新工艺，推动中国石油上游业务技术进步，本着先进、实用、有效的原则，勘探与生产分公司和石油工业出版社组织多方力量，对国外著名出版社和知名学者最新出版的、代表最先进理论和技术水平的著作进行了引进，并翻译和出版。

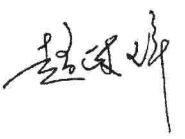
从2001年起，在跟踪国外油气勘探、开发最新理论新技术发展和最新出版动态基础上，从生产需求出发，通过优中选优已经翻译出版了五期28本专著。在这套系列丛书中，有些代表了某一专业的最先进理论和技术水平，有些非常具有实用性，也是生产中所亟需。这些译著发行后，得到了企业和科研院校广大生产管理、科技人员的欢迎，并在实用中发挥了重要作用，达到了促进生产、更新知识、提高业务水平的目的。该套系列丛书也获得了我国出版界的认可。2002年丛书第2辑整体获得了中国出版工作者协会颁发的“引进版科技类优秀图书奖”，2006年丛书第4辑的《井喷与井控手册》再次获得了中国出版工作者协会的“引进版科技类优秀图书奖”，产生了很好的社会效益。

今年在前五期出版的基础上，经过多次调研、筛选，又推选出了国外最新出版的6本专著，即《螺杆泵与井下螺杆钻具》、《气井排水采气》、《钻井和修井作业实用公式与计算手册（第二版）》、《未来能源》、《油藏工程手册》、《层序地层学原理》，以飨读者。其中《油藏工程手册》、《层序地层学原理》以原版影印版的方式引进出版，以满足广大读者希望能够看到原汁原味的外文书的期望，这也顺应了国内石油行业广大员工外语水平普遍提高的趋势。

在本套丛书的引进、翻译和出版过程中，勘探与生产分公司和石油工业出版社组织了一批著名专家、教授和有丰富实践经验的工程技术人员担任翻译和审校人员，使得该套丛书能以较高的质量和效率翻译出版，并和广大读者见面。

希望该套丛书在相关企业、科研单位、院校的生产和科研中发挥应有的作用。

中国石油天然气股份有限公司副总裁



This book is dedicated to my children,

Justin, Brittany, Carsen, and Jennifer Ahmed.

I do hope that at least one of them will

grow up to be a petroleum engineer

in the future.

ACKNOWLEDGMENTS

Much of the material on which this book is based was drawn from the publications of the Society of Petroleum Engineers (SPE). Tribute is due to the SPE and the petroleum engineers, scientists, and authors who have made numerous and significant contributions to the field of reservoir engineering. This book reflects my style of teaching during my tenure at Montana Tech of the University of Montana and my understanding of the subject of reservoir engineering. I would like to thank all my former students at Montana Tech for putting up with me and my Egyptian temper; it was fun. I am sure they will remember that I did my best to teach them reservoir engineering and my sincere desire to help them with their careers.

I hope that my friends and colleagues in academia will enjoy this edition of the book. I know most of them were so surprised to see me crossing the line and joining the "dark side" after years of teaching at Montana Tech, but surprisingly, I am enjoying the dark side very much, so you guys take it easy on me next time. Thanks to Dr. Bob Chase, Dr. Tom Blasingame, Dr. J. Tiab, and Dr. F. Civan for their constructive (I think) criticism and discussions.

I would also like to express my deep thanks to Anadarko Petroleum Corporation for granting me permission to publish this book and, in particular, Bob Daniels, Senior VP for International Exploration and Production, and Mark Pease, Senior VP for North America Exploration and Production.

For the past 3½ years, I have had the pleasure of knowing and working with Anadarko's Chief Technical Engineer, Scott Albertson. I always enjoy our "painful" early-morning technical discussions, as well as exchanging ideas and bouncing mathematical derivations off him, even when his mind is floating somewhere in la-la land. Scott is capable of exhibiting many different facial expressions that he has mastered over the years, and they are, indeed, more powerful than words. Usually, many of his facial expressions can give me the clue, the light, and perhaps the answer to my question (seldom, but remotely possible, in the neighborhood of P-1). I would like also to thank my friend, Senior Staff Reservoir Engineer, Brian Roux, for sharing his considerable knowledge and experience with me and for reading the first few pages of the manuscript (I think he has read the first 7 pages) at Landry's. The truth is that Scott and Brian are two of the brightest engineers that I have ever worked with.

I would like to thank Aydin Centilmen for helping me learn VIP software; I owe him a big lunch at Taco Bell for that. I also would like to thank the following engineers for their support and technical advice: chief engineer, Steve Martin; Julie Struble (only 5 feet tall, but a pure powerhouse); Tom Bergstresser (Tom is not an engineer; he has a PhD in Geology, but nobody is perfect, of course); manager of CBM group, Brad Miller; senior reservoir engineer, Walt Dobbs; acquisitions manager, Craig Walter; manager of EOR group, Dane Cantwell; and senior engineering advisor, Frank Lim.

I would like to thank the editorial staff—in particular, Christine Brandt of SPI Publisher Services—for their work and professionalism. Lastly, this edition of the book could not have been completed without my special friend, Wendy. I would like to thank Wendy for her superb typing, hard work, and encouragement.

PREFACE TO THE THIRD EDITION

To make the third edition of this textbook as complete as possible, I have included the following: a new chapter on decline curve and type curve analysis, a section on tight and shallow gas reservoirs, and waterflood surveillance techniques.

Many of my colleagues have provided me with valuable recommendations and suggestions that I have included through the textbook to make it more comprehensive in treating the subject of reservoir engineering.

PREFACE TO THE SECOND EDITION

I have attempted to construct the chapters following a sequence that I have used for several years in teaching three undergraduate courses in reservoir engineering. Two new chapters have been included in this second edition; Chapter 14 and 15. Chapter 14 reviews principles of waterflooding with emphasis on the design of a waterflooding project. Chapter 15 is intended to introduce and document the practical applications of equations of state in the area of vapor-liquid phase equilibria. A comprehensive review of different equations of state is presented with an emphasis on the Peng-Robinson equation of state.

PREFACE TO THE FIRST EDITION

This book explains the fundamentals of reservoir engineering and their practical application in conducting a comprehensive field study. Chapter 1 reviews fundamentals of reservoir fluid behavior with an emphasis on the classification of reservoir and reservoir fluids. Chapter 2 documents reservoir-fluid properties, while Chapter 3 presents a comprehensive treatment and description of the routine and specialized PVT laboratory tests. The fundamentals of rock properties are discussed in Chapter 4 and numerous methodologies for generating those properties are reviewed. Chapter 5 focuses on presenting the concept of relative permeability and its applications in fluid flow calculations.

The fundamental mathematical expressions that are used to describe the reservoir fluid flow behavior in porous media are discussed in Chapter 6, while Chapters 7 and 8 describe the principle of oil and gas well performance calculations, respectively. Chapter 9 provides the theoretical analysis of coning and outlines many of the practical solutions for calculating water and gas coning behavior. Various water influx calculation models are shown in Chapter 10, along with detailed descriptions of the computational steps involved in applying these models. The objective of Chapter 11 is to introduce the basic principle of oil recovery mechanisms and to present the generalized form of the material balance equation. Chapters 12 and 13 focus on illustrating the practical applications of the material balance equation in oil and gas reservoirs.

CONTENTS

CHAPTER 1

FUNDAMENTALS OF RESERVOIR FLUID BEHAVIOR

Naturally occurring hydrocarbon systems found in petroleum reservoirs are mixtures of organic compounds that exhibit multiphase behavior over wide ranges of pressures and temperatures. These hydrocarbon accumulations may occur in the gaseous state, the liquid state, the solid state, or in various combinations of gas, liquid, and solid.

These differences in phase behavior, coupled with the physical properties of reservoir rock that determine the relative ease with which gas and liquid are transmitted or retained, result in many diverse types of hydrocarbon reservoirs with complex behaviors. Frequently, petroleum engineers have the task to study the behavior and characteristics of a petroleum reservoir and to determine the course of future development and production that would maximize the profit.

The objective of this chapter is to review the basic principles of reservoir fluid phase behavior and illustrate the use of phase diagrams in classifying types of reservoirs and the native hydrocarbon systems.

CLASSIFICATION OF RESERVOIRS AND RESERVOIR FLUIDS

Petroleum reservoirs are broadly classified as oil or gas reservoirs. These broad classifications are further subdivided depending on:

- The composition of the reservoir hydrocarbon mixture
- Initial reservoir pressure and temperature
- Pressure and temperature of the surface production

The conditions under which these phases exist are a matter of considerable practical importance. The experimental or the mathematical determinations of these conditions are conveniently expressed in different types of diagrams commonly called *phase diagrams.* One such diagram is called the *pressure-temperature diagram.*

Pressure-Temperature Diagram

Figure 1-1 shows a typical pressure-temperature diagram of a multicomponent system with a specific overall composition. Although a different hydrocarbon system would have a different phase diagram, the general configuration is similar.

These multicomponent pressure-temperature diagrams are essentially used to:

- Classify reservoirs
- Classify the naturally occurring hydrocarbon systems
- Describe the phase behavior of the reservoir fluid

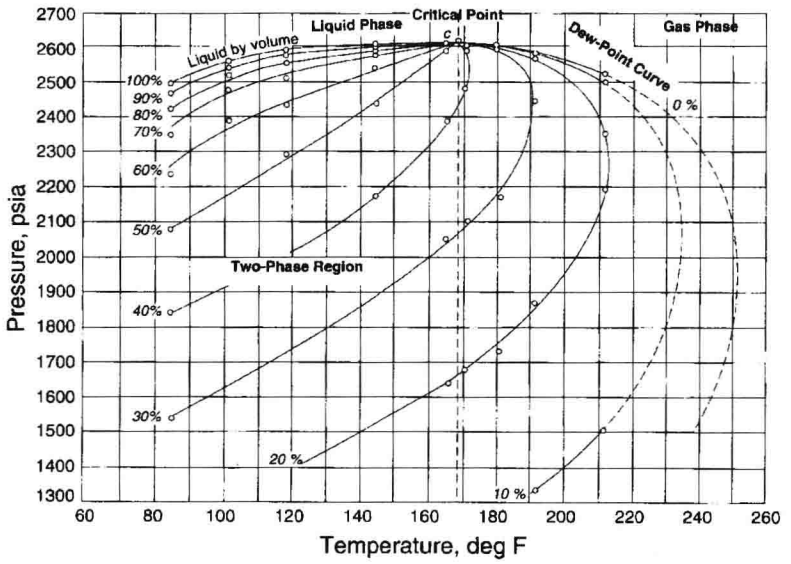


Figure 1-1. Typical p-T diagram for a multicomponent system.