

RESERVOIR

FOURTH EDITION

TAREK AHMED

ENGINEERING

HANDBOOK



CONTENTS

Acknowledgments, *xi*
Preface to the Fourth Edition, *xii*
Preface to the Third Edition, *xiii*
Preface to the Second Edition, *xiv*
Preface to the First Edition, *xv*
About the Author, *xvi*

1 Fundamentals of Reservoir Fluid Behavior 1

Classification of Reservoirs and Reservoir Fluids, 1; Problems, 27;
References, 27

2 Reservoir-Fluid Properties 29

Properties of Natural Gases, 29; Behavior of Ideal Gases, 30;
Behavior of Real Gases, 36; Effect of Nonhydrocarbon Components
on the Z-Factor, 44; Correction for High-Molecular-Weight Gases,
49; Direct Calculation of Compressibility Factors, 54;
Compressibility of Natural Gases, 59; Gas Formation Volume Factor,
65; Gas Viscosity, 67; Methods of Calculating the Viscosity of
Natural Gases, 68; Properties of Crude Oil Systems, 75; Methods of
Calculating Viscosity of the Dead Oil, 115; Methods of Calculating
the Saturated Oil Viscosity, 117; Methods of Calculating the
Viscosity of the Undersaturated Oil, 119; Properties of Reservoir
Water, 124; Problems, 126; References, 133

3	Laboratory Analysis of Reservoir Fluids	136
	Composition of the Reservoir Fluid, 137; Constant-Composition Expansion Tests, 137; Differential Liberation (Vaporization) Test, 149; Separator Tests, 152; Extrapolation of Reservoir Fluid Data, 164; Laboratory Analysis of Gas-Condensate Systems, 171; Problems, 184; References, 188	
4	Fundamentals of Rock Properties	189
	Porosity, 190; Saturation, 195; Wettability, 199; Surface and Interfacial Tension, 200; Capillary Pressure, 203; Permeability, 227; Rock Compressibility, 254; Net Pay Thickness, 260; Reservoir Heterogeneity, 261; Areal Heterogeneity, 274; Problems, 281; References, 286	
5	Relative Permeability Concepts	288
	Two-Phase Relative Permeability, 289; Relative Permeability Ratio, 308; Dynamic Pseudo-Relative Permeabilities, 311; Normalization and Averaging Relative Permeability Data, 313; Three-Phase Relative Permeability, 320; Problems, 329; References, 330	
6	Fundamentals of Reservoir Fluid Flow	331
	Types of Fluids, 332; Flow Regimes, 334; Reservoir Geometry, 336; Number of Flowing Fluids in the Reservoir, 339; Fluid Flow Equations, 340; Steady-State Flow, 342; Unsteady-State Flow, 373; Constant-Terminal-Pressure Solution, 384; Constant-Terminal-Rate Solution, 384; Pseudosteady-State Flow, 413; Principle of Superposition, 442; Transient Well Testing, 453; Problems, 476; References, 482	
7	Oil Well Performance	484
	Vertical Oil Well Performance, 484; Horizontal Oil Well Performance, 528; Problems, 542; References, 544	
8	Gas Well Performance	546
	Vertical Gas Well Performance, 546; Horizontal Gas Well Performance, 577; Problems, 580; References, 581	

9 Gas and Water Coning	583
Coning, 584; Coning in Vertical Wells, 587; Breakthrough Time in Vertical Wells, 620; After Breakthrough Performance, 624; Coning in Horizontal Wells, 629; Horizontal Well Breakthrough Time, 638; Problems, 646; References, 648	
10 Water Influx	650
Classification of Aquifers, 651; Recognition of Natural Water Influx, 654; Water Influx Models, 655; Problems, 728; References, 731	
11 Oil Recovery Mechanisms and the Material Balance Equation	733
Primary Recovery Mechanisms, 734; The Material Balance Equation, 752; Problems, 806; References, 809	
12 Predicting Oil Reservoir Performance	810
Phase 1. Reservoir Performance Prediction Methods, 811; Phase 2. Relating Reservoir Performance to Time, 850; Problems, 853; References, 854	
13 Gas Reservoirs	855
The Volumetric Method, 856; The Material Balance Method, 859; Material Balance Equation as a Straight Line, 874; Abnormally Pressured Gas Reservoirs, 880; Problems, 906; References, 908	
14 Principles of Waterflooding.	909
Factors to Consider in Waterflooding, 910; Optimum Time to Waterflood, 915; Effect of Trapped Gas on Waterflood Recovery, 917; Selection of Flooding Patterns, 927; Overall Recovery Efficiency, 932; I. Displacement Efficiency, 934; II. Areal Sweep Efficiency, 985; III. Vertical Sweep Efficiency, 1041; Methods of Predicting Recovery Performance for Layered Reservoirs, 1058; Waterflood Surveillance, 1069; Problems, 1085; References, 1094	
15 Vapor-Liquid Phase Equilibria	1096
Vapor Pressure, 1096; Equilibrium Ratios, 1099; Flash Calculations, 1103; Equilibrium Ratios for Real Solutions, 1107; Equilibrium Ratios for the Plus Fraction, 1120; Applications of the Equilibrium	

Ratio in Reservoir Engineering, 1122; Equations of State, 1154;
Applications of the Equation of State in Petroleum Engineering,
1194; Splitting and Lumping Schemes of the Plus Fraction, 1207;
Problems, 1225; References, 1229

16 Analysis of Decline and Type Curves 1235

Decline-Curve Analysis, 1235; Type-Curve Analysis, 1264;
Problems, 1333; References, 1335

17 Fractured Reservoirs 1338

Naturally Fractured Reservoirs, 1340; Fractured Carbonates, 1341;
Fractured Shales, 1344; Fractured Sandstones, 1346; Behavior of
Naturally Fractured Reservoirs, 1346; Hydraulically Fractured
Wells, 1375; Infinite-Conductivity Vertical Fractures, 1380;
Finite-Conductivity Fractures, 1381; Uniform-Flux Fractures, 1381;
Fracture Linear Flow, 1385; Bilinear Flow, 1386; Formation
Linear Flow, 1394; Infinite Acting Pseudoradial Flow, 1397;
References, 1427

Appendix, 1433

Index, 1445