
**RESERVOIR ENGINEERING
OF CONVENTIONAL
AND UNCONVENTIONAL
PETROLEUM RESOURCES**

RESERVOIR ENGINEERING OF CONVENTIONAL AND UNCONVENTIONAL PETROLEUM RESOURCES

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**TIGA Petroleum, Inc.
Houston, Texas, USA**

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Dedication

To the enduring memory of my parents, Vincent Nweke and Rosaline Oriaku, for their commitment, courage, and sacrifices they made toward my education and those of my brother and sisters. This book is truly a testament that the seed they planted and nurtured have borne bountiful fruit for all.

Table of Contents

Title	i
Copyright	ii
Dedication	iii
Preface	xxii-xxiii
Acknowledgments	xxiv-xxvi
About the Author	xxvii
Chapter 1 Conventional and Unconventional Reservoirs	1
1.1 Introduction	1
1.2 Conventional Reservoirs Versus Unconventional Reservoirs	1
1.2.1 Conventional Reservoirs	2
1.2.2 Unconventional Reservoirs.....	5
1.2.3 Unconventional Reservoirs in the United States of America (USA)	11
1.2.4 Potential Resources in Unconventional Reservoirs in the World	19
Abbreviations	20
References	21
Chapter 2 Porosity of Reservoir Rocks	23
2.1 Introduction	23
2.2 Total Porosity and Effective Porosity	23
2.3 Sources of Porosity Data	24
2.3.1 Direct Methods for Measurement of Porosity	24
2.3.2 Indirect Methods for Derivation of Porosity	25
2.4 Applications of Porosity Data	28
2.4.1 Volumetric Calculation	29
2.4.2 Calculation of Fluid Saturations	29
2.4.3 Reservoir Characterization	29
Nomenclature	30
Abbreviations	30
References	30
Additional References	31
Problems	31

Chapter 3 Permeability and Relative Permeability	33
3.1 Introduction	33
3.2 Sources of Permeability Data	33
3.2.1 Permeability from Core Samples	34
3.2.2 Permeability from Pressure Transient Tests	34
3.2.3 Permeability from Well Logs Based on Empirical Correlations	34
3.3 Relative Permeability	37
3.4 Sources of Relative Permeability Data	38
3.4.1 Laboratory Measurements of Relative Permeability Data	38
3.4.2 Estimations from Field Data	38
3.4.3 Empirical Correlations	38
3.5 Three-Phase Relative Permeability	41
3.6 Applications of Permeability and Relative Permeability Data	41
Nomenclature	42
Abbreviations	42
References	43
Additional References	44
Problems	45
Chapter 4 Reservoir Fluid Saturations	47
4.1 Introduction	47
4.2 Determination of Water Saturations	47
4.2.1 Clean Sands	48
4.2.2 Shaly Sands	49
4.2.3 Carbonate Rocks	50
4.2.4 Water Saturations from Nuclear Magnetic Resonance Logs	50
4.2.5 Uncertainties in Estimation of Water Saturation	51
4.3 Determination of Reservoir Productive Intervals	51
4.3.1 Net Sands, Net Reservoir, and Net Pay	52
Nomenclature	53
Abbreviations	53
References	53
Additional References	54
Problems	54
Chapter 5 Pressure-Volume-Temperature (PVT) Properties of Reservoir Fluids	55
5.1 Introduction	55
5.2 Phase Diagrams	55
5.2.1 Single-Component Systems	55
5.2.2 Binary Systems	56
5.2.3 Multicomponent Systems	57
5.2.4 Retrograde Behavior of Gas-Condensate Systems	58

5.3 Gas and Gas-Condensate Properties	59
5.3.1 Ideal Gas Equation	59
5.3.2 Real Gas Equation	60
5.3.3 Gas Gravity	60
5.3.4 Reduced Temperature and Pressure	61
5.4 Pseudo-Critical Properties of Gas Mixtures	62
5.4.1 Composition of Gas Mixtures Known	62
5.4.2 Correction for non-Hydrocarbon Gas Impurities	63
5.4.3 Composition of Gas Mixture Unknown	63
5.5 Wet Gas and Gas Condensate	64
5.5.1 Recombination Method	64
5.5.2 Correlation Method	65
5.6 Correlations for Gas Compressibility Factor	68
5.7 Gas Formation Volume Factor (FVF)	70
5.8 Gas Density	70
5.9 Gas Viscosity	70
5.10 Gas Coefficient of Isothermal Compressibility	71
5.11 Correlations for Calculation of Oil PVT Properties	77
5.11.1 Bubble Point Pressure	77
5.11.2 Solution Gas-Oil Ratio (GOR)	78
5.11.3 Oil Formation Volume Factor (FVF)	78
5.11.4 Coefficient of Isothermal Compressibility of Oil	79
5.11.5 Oil Viscosity	80
5.12 Correlations for Calculation of Water PVT Properties	83
5.12.1 Water Formation Volume Factor (FVF)	83
5.12.2 Density of Formation Water	83
5.12.3 Coefficient of Isothermal Compressibility of Formation Water	83
5.12.4 Viscosity of Formation Water	83
Nomenclature	84
Subscripts	84
References	85
Additional References	86
Problems	86
Chapter 6 Reservoir Fluid Sampling and PVT Laboratory Measurements	89
6.1 Overview of Reservoir Fluid Sampling	89
6.2 Reservoir Type and State	92
6.2.1 Undersaturated Oil Reservoirs	92
6.2.2 Undersaturated Gas Condensate Reservoirs	92
6.2.3 Saturated Oil Reservoirs	92
6.2.4 Saturated Gas Condensate Reservoirs	93

6.3 Well Conditioning	93
6.4 Subsurface Sampling Methods and Tools	93
6.4.1 Conventional Bottomhole Samplers	93
6.4.2 Pistoned Bottomhole Samplers	94
6.4.3 Single Phase Samplers	94
6.4.4 Exothermic Samplers	94
6.5 Wireline Formation Testers	94
6.5.1 Oil-Based Mud Contamination of WFT Samples	94
6.5.2 Formation Pressures from WFT	96
6.5.3 Capillary Effects on WFT Formation Pressures	96
6.5.4 Effects of Supercharging on WFT Formation Pressures	99
6.5.5 Comments on Applications of WFT Pressure Data	99
6.6 PVT Laboratory Measurements	100
6.6.1 Fluid Composition	100
6.6.2 Constant Composition Expansion (CCE)	100
6.6.3 Differential Liberation (DL)	101
6.6.4 Constant Volume Depletion (CVD)	101
6.6.5 Separator Tests	102
6.6.6 Viscosity Measurements	103
6.7 Applications of Laboratory PVT Measurements	103
6.7.1 Calculation of Oil FVF and Solution GOR	103
6.7.2 Calculation of Gas Compressibility Factor, Gas FVF, and Total FVF	103
6.7.3 Calculation of Oil Compressibility Factor	104
Nomenclature	105
Subscripts	105
Abbreviations	105
References	106
Additional References	106
Problems	107
Appendix 6A Typical Reservoir Fluid Study for a Black Oil Sample	109
Appendix 6B Typical Reservoir Fluid Study for a Gas Condensate Sample	112
Chapter 7 PVT Properties Predictions from Equations of State	117
7.1 Historical Introduction to Equations of State (EOS)	117
7.2 van der Waals (vdW) EOS	117
7.3 Soave-Redlich-Kwong (SRK) EOS	118
7.4 Peng-Robinson (PR) EOS	119
7.5 Phase Equilibrium of Mixtures	119
7.6 Roots from Cubic EOS	120
7.7 Volume Translation	121
7.8 Two-Phase Flash Calculation	122
7.8.1 Generalized Procedure for Two-Phase Flash Calculations	122

7.9	Bubble Point and Dew Point Pressure Calculations	123
7.10	Characterization of Hydrocarbon Plus Fractions	123
7.11	Phase Equilibrium Predictions with Equations of State	125
	Nomenclature	128
	Subscripts	128
	Superscripts	128
	Abbreviations	128
	References	129
	Problems	130
Chapter 8	The General Material Balance Equation	131
8.1	Introduction	131
8.2	Derivation of the General Material Balance Equation (GMBE)	131
8.2.1	Development of Terms in the Expression of Eq. (8.1)	131
8.3	The GMBE for Gas Reservoirs	133
8.4	Discussion on the Application of the GMBE	133
	Nomenclature	134
	Subscripts	134
	Abbreviations	134
	References	134
	Problems	135
Chapter 9	Gas Reservoirs	137
9.1	Introduction	137
9.2	Volumetric Gas Reservoirs	137
9.2.1	Volumetric Calculations for Dry Gas Reservoirs	137
9.2.2	Volumetric Calculations for Wet Gas and Retrograde Gas Condensate Reservoirs	138
9.2.3	Material Balance for Volumetric Dry Gas, Wet Gas, and Retrograde Gas Condensate Reservoirs	139
9.3	Gas Reservoirs with Water Influx	141
9.3.1	Volumetric Approach	141
9.3.2	Material Balance Approach	142
9.3.3	The Cole Plot	142
9.3.4	The Havlena-Odeh Straight Line Method	142
9.4	Water Influx Models	143
9.4.1	Fetkovich Aquifer Model	144
9.4.2	Carter-Tracy Aquifer Model	146
9.5	Geopressured Gas Reservoirs	149
9.5.1	The Ramagost and Farshad Method	150
9.5.2	The Roach Method	152
9.6	Case Histories of Two Gas Reservoirs	154
9.6.1	The Case History of Red Hawk Reservoir	154
9.6.2	The Case History of West Cameron 580 Reservoirs	164

Nomenclature	173
Subscripts	173
Abbreviations	173
References	174
Additional References	174
Problems	175
Appendix 9A Correlations for Estimating Residual Gas Saturations for Gas Reservoirs Under Water Influx	177
Appendix 9B Dimensionless Pressure for Finite and Infinite Aquifers	178
Appendix 9C Dimensionless Pressure for Infinite Aquifers	179
Chapter 10 Oil Reservoirs	181
10.1 Introduction	181
10.2 Oil Reservoir Drive Mechanisms	181
10.3 Gravity Drainage Mechanism	182
10.4 Volumetric Undersaturated Oil Reservoirs	183
10.4.1 Volume Calculations Above Bubble Point Pressure	183
10.4.2 Volume Calculations Below Bubble Point Pressure	185
10.5 Undersaturated Oil Reservoirs with Water Influx	186
10.5.1 Volumetric Method	186
10.5.2 Material Balance Method	186
10.6 Volumetric Saturated Oil Reservoirs	192
10.6.1 Volumetric Method	192
10.6.2 Material Balance Method	193
10.7 Material Balance Approach for Saturated Oil Reservoirs with Water Influx	193
10.8 Case History of Manatee Reservoirs	194
10.8.1 Reservoir Geology	196
10.8.2 Rock and Fluid Properties	200
10.8.3 Reservoir Pressure and Production Data	200
Nomenclature	203
Subscripts	203
Abbreviations	203
References	204
Problems	204
Chapter 11 Production Forecasting for Conventional and Unconventional Reservoirs	207
11.1 Introduction	207
11.2 Flow Regimes	207
11.3 Arps' Decline Equations	209
11.3.1 Range of Values for Arps' b Parameter	210
11.3.2 Effective and Nominal (Exponential) Decline Rates	210
11.3.3 Type Curves for Analysis of Production Data	211

11.3.4 Normalized Rates and Pressures	212
11.3.5 Flowing Material Balance	212
11.3.6 Diagnostic Plots	213
11.3.7 Transient Decline Models	214
11.3.8 Construction of Type Wells for Production Forecasting	215
11.3.9 Analyses of Well Production Data Using a Step-by-Step Procedure	216
Nomenclature	229
Subscripts	229
Abbreviations	229
References	230
Problems	230
Appendix 11 Data for Examples 11.1 and 11.2	236
Chapter 12 Fluid Flow in Petroleum Reservoirs	253
12.1 Introduction	253
12.2 Fluid Types	253
12.2.1 Incompressible Fluids	253
12.2.2 Slightly Compressible Fluids	253
12.2.3 Compressible Fluids	254
12.3 Definition of Fluid Flow Regimes	254
12.3.1 Transient Flow	254
12.3.2 Pseudosteady-State (PSS) Flow	255
12.3.3 Steady-State (SS) Flow	255
12.4 Darcy Fluid Flow Equation	255
12.5 Radial Forms of the Darcy Equation	256
12.5.1 Steady-State Flow, Incompressible Fluids	256
12.5.2 Average Permeability of Parallel Beds	257
12.5.3 Average Permeability of Serial Concentric Segments	258
12.5.4 Pseudosteady State, Incompressible Fluids	259
12.5.5 Steady-State Flow, Compressible Fluids	260
12.6 Derivation of the Continuity Equation in Radial Form	261
12.7 Derivation of Radial Diffusivity Equation for Slightly Compressible Fluids	261
12.8 Solutions of the Radial Diffusivity Equation for Slightly Compressible Fluids	262
12.8.1 Constant Terminal Rate Solution	262
12.8.2 Constant Terminal Pressure Solution	265
12.9 Derivation of the Radial Diffusivity Equation for Compressible Fluids	267
12.10 Transformation of the Gas Diffusivity Equation with Real Gas Pseudo-Pressure Concept ...	267
12.11 The Superposition Principle	270
12.11.1 Applications of Constant Terminal Rate Solutions with Superposition Principle	270
12.11.2 Applications of Constant Terminal Pressure Solution with Superposition Principle ...	273

12.12 Well Productivity Index	276
12.13 Well Injectivity Index	277
Nomenclature	277
Subscripts	278
Abbreviations	278
References	278
Additional References	278
Problems	278
Appendix 12A Chart for Exponential Integral	281
Appendix 12B Tabulation of p_D vs t_D for Radial Flow, Infinite Reservoirs with Constant Terminal Rate at Inner Boundary	282
Appendix 12C Tabulation of p_D vs t_D for Radial Flow, Finite Reservoirs with Closed Outer Boundary and Constant Terminal Rate at Inner Boundary	283
Appendix 12D Tabulation of p_D vs t_D for Radial Flow, Finite Reservoirs with Constant Pressure Outer Boundary and Constant Terminal Rate at Inner Boundary	285
Appendix 12E Tabulation of Q_D vs t_D for Radial Flow, Infinite Reservoirs with Constant Terminal Pressure at Inner Boundary	291
Appendix 12F Tabulation of Q_D vs t_D for Radial Flow, Finite Reservoirs with Closed Outer Boundary and Constant Terminal Pressure at Inner Boundary	293
Chapter 13 Well Test Analysis: Straightline Methods	297
13.1 Introduction	297
13.2 Basic Concepts in Well Test Analysis	297
13.2.1 Radius of Investigation	297
13.2.2 Skin and Skin Factor	298
13.2.3 Flow Efficiency and Damage Ratio	299
13.2.4 Effective Wellbore Radius	300
13.2.5 Drawdown Well Tests	300
13.2.6 Buildup Well Tests	301
13.2.7 Wellbore Storage	302
13.3 Line Source Well, Infinite Reservoir Solution of the Diffusivity Equation with Skin Factor	302
13.4 Well Test Analyses with Straightline Methods	304
13.4.1 Slightly Compressible Fluids	304
13.4.2 Compressible Fluids	319
13.5 Special Topics in Well Test Analyses	336
13.5.1 Multiphase Flow	336
13.5.2 Wellbore Storage Effects	338
13.5.3 Wellbore Phase Redistribution Effects	338
13.5.4 Boundary Effects	338
13.5.5 Multilayered Reservoirs	339

Nomenclature	340
Subscripts	341
Abbreviations	341
References	341
Additional References	343
Problems	343
Chapter 14 Well Test Analysis: Type Curves	297
14.1 Introduction	347
14.2 What Are Type Curves?	347
14.3 Gringarten Type Curves	347
14.3.1 Unit-Slope Line	348
14.4 Bourdet Derivative Type Curves	349
14.5 Agarwal Equivalent Time	349
14.6 Type-Curve Matching	350
14.7 Procedures for Manual Application of Type-Curve Matching in Well Test Analysis	350
14.8 Stages of the Type-Curve Matching Procedures	351
14.8.1 Identification of the Interpretation Model	351
14.8.2 Calculation from Interpretation Model Parameters	352
14.8.3 Validation of the Interpretation Model Results	352
Nomenclature	355
Subscripts	355
Abbreviations	355
References	355
Problems	356
Appendix 14A Characteristic Shapes of Pressure and Pressure-Derivative Curves for Selected Well, Reservoir, and Boundary Models	357
Appendix 14B Data for Example 14.1	359
Appendix 14C Calculation of Pressure Derivatives	362
Chapter 15 Well Test Analysis: Hydraulically Fractured Wells and Naturally Fractured Reservoirs	363
15.1 Introduction	363
15.2 Hydraulically Fractured Wells	363
15.3 Definition of Dimensionless Variables for Fractured Wells	363
15.4 Flow Regimes in Fractured Wells	363
15.4.1 Fracture Linear Flow	364
15.4.2 Bilinear Flow	364
15.4.3 Formation Linear Flow	364
15.4.4 Pseudo-radial Flow	364
15.5 Fractured Well Flow Models	364
15.5.1 Finite Conductivity Vertical Fracture	364
15.5.2 Infinite Conductivity Vertical Fracture	364
15.5.3 Uniform Flux Vertical Fracture	365

15.6 Fractured Well Test Analysis: Straightline Methods	365
15.6.1 Bilinear Flow	365
15.6.2 Procedure for Application of Straightline Methods on Well Test Data During Bilinear Flow Regime	366
15.6.3 Formation Linear Flow	366
15.6.4 Procedure for Application of Straightline Methods on Well Test Data During Formation Linear Flow Regime	367
15.6.5 Pseudo-Radial Flow	368
15.6.6 Procedure for Application of Straightline Methods on Well Test Data During Pseudo-Radial Flow Regime	368
15.7 Fractured Well Test Analysis: Type-Curve Matching	368
15.7.1 Identification of the Interpretation Model	369
15.7.2 Calculation from Interpretation Model Parameters	369
15.7.3 Validation of the Interpretation Model Results	370
15.7.4 Procedure for Analysis of Well Test from Hydraulically Fractured Wells	370
15.8 Naturally Fractured Reservoirs	374
15.9 Naturally Fractured Reservoir Models	374
15.9.1 Homogeneous Reservoir Model	374
15.9.2 Multiple Region or Composite Reservoir Model	375
15.9.3 Anisotropic Reservoir Model	376
15.9.4 Single Fracture Model	376
15.9.5 Double Porosity Model	377
15.10 Well Test Analysis in Naturally Fractured Reservoirs Based on Double Porosity Model	378
15.11 Well Test Analysis in NFRs: Straightline Methods	378
15.12 Well Test Analysis in NFRs: Type Curves	380
15.13 Procedure for Analysis of Well Test from NFRs Assuming Double Porosity Behavior	381
15.13.1 Identification of Flow Periods	381
15.13.2 Calculation of Fracture and Reservoir Parameters from Type Curves	381
15.13.3 Validation of Results with Straightline Methods	381
Nomenclature	386
Subscripts	386
Abbreviations	386
References	387
Additional References	387
Problems	388
Chapter 16 Well Test Analysis: Deconvolution Concepts	389
16.1 Introduction	389
16.2 What Is Deconvolution?	389
16.3 The Pressure-Rate Deconvolution Model	390
16.3.1 The von Schroeter et al. ³ Deconvolution Algorithm	390

16.4	Application of Deconvolution to Pressure-Rate Data	390
16.5	Examples on the Application of the von Schroeter Deconvolution Algorithm to Real Well Test Data	391
16.6	General Guidelines for Application of von Schroeter Deconvolution Algorithm to Pressure-Rate Data from Well Tests	395
	References	396
	Additional References	396
	Problems	396
Chapter 17 Well Test Analysis: Diagnostic Fracture Injection		
	Tests in Unconventional Reservoirs	397
17.1	Introduction	397
17.2	Typical DFIT Profile	397
17.3	Simple Fracture Orientation Models	398
17.4	Design, Planning, and Execution of DFIT	399
	17.4.1 Selection of Test Interval	399
	17.4.2 Injection Rates and Volumes	399
	17.4.3 Selection of Shut-in Methods	400
	17.4.4 Selection of Equipment for DFIT	400
	17.4.5 Modeling DFIT with a Hydraulic Fracture Model	401
	17.4.6 Other DFIT Execution Guidelines	401
17.5	Analyses of Diagnostic Fracture Injection Tests (DFITs)	401
	17.5.1 Diagnostic Analyses	401
	17.5.2 Before Closure Analysis (BCA)	407
	17.5.3 After Closure Analysis (ACA)	408
17.6	Procedure for DFIT Analyses	411
	Nomenclature	420
	Subscripts	420
	Abbreviations	420
	References	421
	Additional References	421
	Problems	421
	Appendix 17A Input Data For Example 17.1	422
	Appendix 17B Diagnostic Plots Data For Example 17.1	427
	Appendix 17C BCA and ACA Plots Data For Example 17.1	429
Chapter 18 Immiscible Fluid Displacement		
	18.1 Introduction	435
	18.2 Basic Concepts in Immiscible Fluid Displacement	435
	18.2.1 Rock Wettability	435
	18.2.2 Capillary Pressure	436
	18.2.3 Relative Permeability	438

18.2.4	Mobility and Mobility Ratio	438
18.2.5	Fluid Displacement Efficiency	438
18.2.6	Volumetric Displacement Efficiency	438
18.2.7	Total Recovery Efficiency	438
18.3	Fractional Flow Equations	438
18.3.1	Fractional Flow Equation for Oil Displaced by Water	439
18.3.2	Fractional Flow Equation for Oil Displaced by Gas	440
18.4	The Buckley-Leverett Equation	441
18.5	The Welge Method	443
18.5.1	Water Saturation at the Flood Front	443
18.5.2	Average Water Saturation Behind the Flood Front	443
18.5.3	Average Water Saturation after Water Breakthrough	444
18.6	Summary	446
	Nomenclature	447
	References	447
	Additional References	448
	Problems	448
Chapter 19	Secondary Recovery Methods	451
19.1	Introduction	451
19.2	Waterflooding	451
19.2.1	Waterflood Patterns	451
19.2.2	Waterflood Design	452
19.2.3	Recommended Steps in Waterflood Design	453
19.2.4	Waterflood Management	453
19.2.5	Management of Waterflooded Reservoirs	457
19.3	Gasflooding	458
19.3.1	Applications of Gasflooding	458
19.3.2	Gasflood Design	458
19.3.3	Recommended Steps in Gasflood Design	459
19.3.4	Gasflood Management	459
19.3.5	Management of Gasflood Reservoirs	460
	Nomenclature	461
	Abbreviations	461
	References	461
	Additional References	462
	Problems	462
Chapter 20	Low Salinity Waterflooding	465
20.1	Introduction	465
20.2	Laboratory Displacement Experiments Using Sandstone Cores	466
20.3	Field Tests in Sandstone Reservoirs	466
20.4	Laboratory Displacement Experiments Using Carbonate Cores	466

20.5	Field Tests in Carbonate Reservoirs	466
20.6	Mechanisms for LSE	467
20.6.1	Mechanisms for LSE in Sandstone Cores and Reservoirs	467
20.6.2	Mechanisms for LSE in Carbonate Cores/Reservoirs	468
20.7	Guidelines for Planning, Designing, and Installing LSWF Projects	469
20.8	Brief Case History of Claire Ridge LSWF Project	476
20.8.1	An Overview of Clair Ridge Field	476
20.8.2	Low Salinity Coreflood Tests	476
20.8.3	Reservoir Modeling and Analysis	477
20.8.4	Selection of Water Injection Facilities	477
	Nomenclature	477
	Abbreviations	477
	References	478
	Additional References	480
	Problems	480
Chapter 21	Enhanced Oil Recovery	481
21.1	Introduction	481
21.2	EOR Processes	481
21.3	EOR Screening Criteria	483
21.3.1	EOR Screening Criteria for Miscible Gas Injection Processes	484
21.3.2	EOR Screening Criteria for Chemical Flooding Processes	484
21.3.3	EOR Screening Criteria for Thermal Processes	484
21.4	Miscible Gas Injection Processes	485
21.4.1	Basic Concepts on Miscibility for Gas Displacement Processes	485
21.4.2	First-Contact Miscibility (FCM)	486
21.4.3	Multiple-Contact Miscibility (MCM)	486
21.4.4	Vaporizing Gas Drive MCM Process	486
21.4.5	Condensing Gas Drive MCM Process	487
21.4.6	Combined Condensing/Vaporizing (CV) Gas Drive MCM Process	488
21.5	Methods for Determination of MMP or MME for Gasfloods	488
21.5.1	Analytical Techniques for Estimation of MMP or MME	488
21.5.2	Experimental Methods	496
21.6	Types of Miscible Gas Flooding	497
21.6.1	Nitrogen/Flue-gas Miscible Gas Flooding	497
21.6.2	Hydrocarbon (HC) Miscible Gas Flooding	498
21.6.3	Carbon Dioxide Gas Flooding	498
21.6.4	Types of Miscible Gas Injection Strategies	499
21.7	Chemical Flooding Processes	499
21.7.1	Polymer/Surfactant Flooding	499
21.7.2	Alkali/Surfactant/Polymer (ASP) Flooding	499
21.7.3	Polymer Flooding	500
21.7.4	Microbial Enhanced Oil Recovery (MEOR)	500

21.8 Thermal Processes	500
21.8.1 Steamflooding Methods	501
21.8.2 Steamflood Models	502
21.8.3 Management of Steamflood Projects	503
21.8.4 In-Situ Combustion (ISC)/High Pressure Air Injection (HPAI)	504
21.9 Implementation of EOR Projects	504
21.9.1 Process Screening and Selection	505
21.9.2 Quick Economic Evaluation of Selected Processes	505
21.9.3 Geologic and Reservoir Modeling of Selected Processes	506
21.9.4 Expanded Economic Evaluation of Selected Processes	506
21.9.5 Pilot Testing	506
21.9.6 Upgrade Geologic and Reservoir Models with Pilot Test Data/Results	507
21.9.7 Final Detailed Economic Evaluation	507
21.9.8 Field-Wide Project Implementation	507
21.9.9 EOR Process Project Management	507
Nomenclature	508
Abbreviations	508
References	508
Additional References	511
Problems	512
Chapter 22 Geologic Modeling and Reservoir Characterization	515
22.1 Introduction	515
22.2 Sources of Data for Geologic Modeling and Reservoir Characterization	515
22.2.1 Seismic Data	515
22.2.2 Outcrop and Basin Studies	515
22.2.3 Well Log Data	516
22.2.4 Core Data	516
22.2.5 Formation Pressures and Fluid Properties Data	516
22.2.6 Pressure Transient Test Data	516
22.2.7 Reservoir Performance Data	516
22.3 Data Quality Control and Quality Assurance	516
22.4 Scale and Integration of Data	517
22.5 General Procedure for Geologic Modeling and Reservoir Characterization	517
22.5.1 Generation of Geologic Surfaces or Horizons	517
22.5.2 Structural Modeling	517
22.5.3 Stratigraphic Modeling	518
22.5.4 Correlation and Assignment of Well Log Data	518
22.5.5 Property Data Modeling	518
22.5.6 Uncertainty Analysis	524

22.5.7 Upscaling of Geologic Model to Reservoir Flow Model	525
Nomenclature	533
Abbreviations	533
References	533
Additional References	534
Problems	535
Chapter 23 Reservoir Simulation	537
23.1 Introduction	537
23.2 Derivation of the Continuity Equation in Rectangular Form	539
23.3 Flow Equations for Three-Phase Flow of Oil, Water, and Gas	539
23.4 Basic Concepts, Terms, and Methods in Reservoir Simulation	541
23.4.1 Grid Systems	541
23.4.2 Timesteps	545
23.4.3 Formulations of Simulator Equations	545
23.4.4 Material Balance Errors and Other Convergence Criteria	546
23.4.5 Numerical Dispersion	546
23.4.6 Well Model	547
23.4.7 Model Initialization	548
23.4.8 History Matching	548
23.4.9 Predictions	550
23.4.10 Uncertainty Analysis	550
23.5 General Structure of Reservoir Flow Models	550
23.5.1 Definition of Model and Simulator	551
23.5.2 Geologic Model Data	551
23.5.3 Fluid Properties Data	551
23.5.4 Rock/Fluid Properties Data	551
23.5.5 Model Equilibration Data	551
23.5.6 Well Data	551
23.5.7 Simulator Data Output	551
Nomenclature	552
Subscripts	552
Abbreviations	552
References	553
Additional References	554
Problems	555

Chapter 24 Reservoir Management	559
24.1 Introduction	559
24.2 Reservoir Management Principles	559
24.2.1 Conservation of Reservoir Energy	560
24.2.2 Early Implementation of Simple, Proven Strategies	560
24.2.3 Systematic and Sustained Practice of Data Collection	560
24.2.4 Application of Emerging Technologies for Improved Hydrocarbon Recovery	560
24.2.5 Long-Term Retention of Staff in Multi-Disciplinary Teams	560
24.3 Case Histories Demonstrating Applications of Reservoir Management Principles	561
24.3.1 The Case History of 26R Reservoir (1976–1996)	561
24.3.2 Application of Reservoir Management Principles to 26R Reservoir	564
24.3.3 The Case History of MBB/W31S Reservoirs (1976–1999)	566
24.3.4 Application of Reservoir Management Principles to MBB/W31S Reservoirs	568
24.3.5 The Case History of the Shaybah Field	571
24.3.6 Application of Reservoir Management Principles to the Shaybah Field	572
References	575
Additional References	577
Problems	577
 Chapter 25 Economic Evaluation of Petroleum Projects and Property	 589
25.1 Introduction	589
25.2 Classification of Oil and Gas Resources	589
25.2.1 Definition of Terms in the SPE PRMS	590
25.2.2 Estimation of Recoverable Resources	591
25.2.3 Analytic Methods for Resource Determination	591
25.2.4 Resource Assessment Techniques	593
25.3 Time Value of Money	593
25.3.1 Future Worth (Value) of a Single Payment	594
25.3.2 Present Worth (Value) of a Single Payment	595
25.3.3 Uniform Series Compound Amount	595
25.3.4 Sinking Fund Deposit Amount	596
25.3.5 Capital Recovery Amount	597
25.3.6 Uniform Series Present Worth Amount	597
25.3.7 Timing of Payments (or Investments) Considerations	598
25.3.8 Non-Uniform Series of Payments (or Investments)	600
25.3.9 Period, Nominal, and Effective Interest Rates	602
25.3.10 The Rule of 72	603
25.3.11 The Rule of 78	604
25.3.12 Cash Flow Diagram	606

25.4 Economic Valuation Parameters	607
25.4.1 Valuation Parameters Not Based on the Time Value of Money	608
25.4.2 Valuation Parameters Based on the Time Value of Money	609
25.4.3 Recommended Practice for Economic Valuations	619
25.5 Depreciation, Depletion, and Amortization	619
25.5.1 Depreciation Methods	619
25.5.2 Depletion Methods	622
25.5.3 Amortization Methods	622
25.6 Economic Evaluation of a Petroleum Property	623
25.6.1 Economic Evaluation of an Onshore Petroleum Property in the USA	623
25.6.2 Economic Evaluation of a Petroleum Property in Other Parts of the World	624
25.7 Decision and Risk Analysis Applied to Petroleum Evaluations	626
Nomenclature	627
Abbreviations	627
References	628
Problems	628
Appendix 25A Economic Evaluation of a Drilling Prospect from paper SPE 68588	632
Appendix 25B Cash Flow Model for a Multi-Well Development Project	635
Appendix 25C Worksheet for a PSC with Fixed Scale	642
INDEX	645-670

Preface

This book was envisioned as a partial but important update of the original book, “Petroleum Reservoir Engineering Practice,” published in 2010 by Prentice Hall. The vision was to add several chapters on analyses of unconventional reservoirs and a chapter on economic evaluation of petroleum projects to the original book. I think this book provides adequate coverage of both subjects which will enhance its value to engineers. A chapter was added on low salinity waterflooding as an important technology for improved oil recovery. Another important expansion of the book is the addition of problems at the end of each chapter to help readers test their understanding of the subject matter presented in the chapter. The addition of problems will also assist lecturers to assign homework from the book. Except in these four main areas, this book retains substantial portions of material covered in the original book although important changes in wording and presentation were made in this version.

Unconventional reservoirs have completely changed the landscape in American petroleum industry. United States of America (USA) is currently one of the largest oil producers in the world surpassing Saudi Arabia and Russia. This tremendous reversal in oil productivity trend is driven by revolution in the productivity of unconventional reservoirs in the USA. In Chapter 1, the differences between conventional and unconventional reservoirs are presented. Also, in this chapter, unconventional reservoirs were shown to hold the future of hydrocarbon supply in the USA and the rest of the world. The potential of unconventional resources are almost limitless as the technologies developed in the USA are applied to similar resources found around the world. Engineers pursuing a career in the petroleum industry are advised to develop knowledge and skills on the engineering of unconventional reservoirs.

In Chapters 2 to 7, the sources and applications of basic rock and fluid properties data that are fundamental for all petroleum reservoir engineering calculations are presented. Chapter 2 presents the sources and applications of porosity. Chapter 3 covers sources and applications of permeability and relative permeability. Chapter 4 discusses methods and models for determination of fluid saturations, and classification of reservoir rocks for volumetric calculations. These topics are presented at the introductory to intermediate levels. The main objective is to emphasize the importance of these sources of data as basic inputs for most reservoir engineering calculations. Chapter 5 was devoted to rigorous calculations of Pressure-Volume-Temperature (PVT) properties of reservoir fluids from correlations. In concert with Chapter 5, Chapter 6 presents routine reservoir fluid sampling methods, and laboratory measurements of PVT properties from reservoir fluid samples. In Chapter 7, the prediction of PVT properties from equations of state is presented. The application of equations of state in compositional simulation justified the presentation of this subject at the intermediate-to-advance levels for many engineers who are involved in compositional reservoir simulation work.

The fundamentals of petroleum reservoir engineering are treated from Chapters 8 to 10. The general material balance equation is developed from basic concepts in Chapter 8 and applied as a fundamental tool for basic reservoir engineering analysis. In Chapter 9, volumetric and graphical methods for calculation of gas-in-place for different types of gas reservoirs are discussed. This approach is extended to oil reservoirs in Chapter 10. The use of case histories to illustrate analytic methods for evaluation of performance of gas and oil reservoirs is demonstrated in Chapters 9 and 10.

Production forecasting for conventional and unconventional reservoirs is discussed in Chapter 11. This is based primarily on Arps’ decline equations which have become the workhorse of the petroleum industry for production forecasting on conventional and unconventional reservoirs. The methodologies (decline curve analysis or DCA) for using Arps’ equation for production forecasting on conventional reservoirs are applicable to unconventional reservoirs although rate transient analysis (RTA) techniques should be applied to account for production characteristics of unconventional reservoirs such as relatively long transient flow periods and influence of boundary dominated flows (BDF). The Stretched Exponential Decline Model (SEDM) and the Duong Model are presented in the chapter as two transient decline models which can be coupled with the modified Arps’ decline equations to improve production forecasting for unconventional reservoirs. These applications are illustrated with examples.

Fluid flow in petroleum reservoirs is introduced in Chapter 12 with the derivation of the continuity equation and the radial diffusivity equation. In Chapter 12, the fundamental equations that form the bases for pressure transient analysis (PTA) by straightline methods are developed and applied later in Chapter 13. The use of type curves in well test analysis, especially Gringarten and Bourdet type curves, are presented in Chapter 14 with emphasis on procedures for type-curve matching. Well test analysis methods for hydraulically fractured wells and naturally

fractured conventional reservoirs are presented in Chapter 15. Deconvolution concepts for well test analysis are covered in Chapter 16. This is followed with the presentation of well test analysis in unconventional reservoirs in Chapter 17 based mainly on diagnostic fracture injection tests (DFIT). Note that many characteristic behaviors of fracture flow are applicable to both conventional and unconventional reservoirs.

Basic concepts in immiscible fluid displacement are discussed in Chapter 18. These include derivations of the fractional flow equation, the Buckley-Leverett equation, and the Welge method. This is followed with the introduction of secondary recovery methods in Chapter 19 focused mainly on waterflooding and gasflooding.

Low salinity waterflooding is presented in Chapter 20 as an improved oil recovery method distinct from secondary recovery methods of Chapter 19 or enhanced oil recovery methods presented in Chapter 21. This definition of low salinity waterflooding is solely at the discretion of this author since it can be categorized as a secondary recovery method or an enhanced oil recovery method depending on any particular perspective. Either categorization is completely acceptable to the author.

Enhanced oil recovery methods are discussed in Chapter 21. In the chapter, special emphasis is placed on screening criteria and field implementation of enhanced oil recovery processes because many engineers should expect to be involved in such activities someday in their careers.

Chapters 18 to 21 are designed to introduce practicing engineers to fundamental methodologies for application of secondary, improved, and enhanced oil recovery processes, and also to develop practical procedures for field implementation of these processes.

Geologic modeling and reservoir characterization methods and procedures are presented in Chapter 22. This is followed with concepts in reservoir simulation in Chapter 23. In both chapters, the focus was on presenting methods and procedures for applying these tools on the practical aspects of building reservoir models rather than on theory.

The principles of reservoir management that I first enunciated in 2003 are presented in Chapter 24. These principles of reservoir management were developed from my experience from managing various types of reservoirs around the world. The principles are simple and practical and can be applied to any reservoir anywhere in the world. The application of the five principles of reservoir management are illustrated with case histories in Chapter 24.

Economic evaluation is key to the success of any petroleum project. Every project in the petroleum industry must be shown to be economic and profitable before it can be sanctioned and implemented. Chapter 25 presents fundamental criteria that can be used to judge the economic profitability of most projects. The chapter also discusses concepts, contracts, and economic models used in many petroleum operations involving host countries and international oil companies.

This book could not have been written without the support of my wife and children who endured long hours of my seclusion over many years to work on material for the book. I am very grateful for their patience and understanding. I give special thanks to my wife, Anulika, and my children (Nkemdirim, Chukwuemeka, Chioma, Ifeoma, Obinna, and Ezenwanyi). The odyssey of writing this book made my love for them much stronger.

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