- Preface p. xiii
- 1 Introduction p. 1
- 1.1 Introduction p. 1
- 1.2 Multiphase Flow In A Gas Well p. 2
- 1.3 What Is Liquid Loading? p. 4
- 1.4 Problems Caused By Liquid Loading p. 5
- 1.5 Deliquefying Techniques p. 6
- 1.6 Source of Liquids In A Producing Gas Well p. 8
- 1.6.1 Water Coning p. 8
- 1.6.2 Aquifer Water p. 8
- 1.6.3 Water Produced from Another Zone p. 8
- 1.6.4 Free Formation Water p. 9
- 1.6.5 Water of Condensation p. 9
- 1.6.6 Hydrocarbon Condensates p. 9
- References p. 11
- 2 Recognizing Symptoms of Liquid Loading in Gas Wells p. 13
- 2.1 Introduction p. 13
- 2.2 Presence of Orifice Pressure Spikes p. 14
- 2.3 Decline Curve Analysis p. 14
- 2.4 Drop in Tubing Pressure with Rise in Casing Pressure p. 15
- 2.5 Pressure Survey Showing Tubing Liquid Level p. 18
- 2.6 Well Performance Monitoring p. 21
- 2.7 Annulus Heading p. 21
- 2.7.1 Heading Cycle without Packer p. 21
- 2.7.2 Heading Cycle Controls p. 23
- 2.8 Liquid Production Ceases p. 25
- 2.9 Summary p. 25
- References p. 26
- 3 Critical Velocity p. 27
- 3.1 Introduction p. 27
- 3.2 Critical Flow Concepts p. 27
- 3.2.1 Turner Droplet Model p. 27
- 3.2.2 Critical Rate p. 30
- 3.2.3 Critical Tubing Diameter p. 31
- 3.2.4 Critical Rate for Low Pressure Wells--Coleman Model p. 31
- 3.2.5 Critical Flow Nomographs p. 34
- 3.3 Critical Velocity at Depth p. 38
- 3.4 Critical Velocity in Horizontal Well Flow p. 40
- References p. 41
- 4 Systems Nodal Analysis p. 43
- 4.1 Introduction p. 43
- 4.2 Tubing Performance Curve p. 45
- 4.3 Reservoir Inflow Performance Relationship (IPR) p. 46
- 4.3.1 Gas Well Backpressure Equation p. 47

- 4.3.2 Future IPR Curve with Backpressure Equation p. 49
- 4.4 Intersections of the Tubing Curve and the Deliverability Curve p. 49
- 4.5 Tubing Stability and Flowpoint p. 52
- 4.6 Tight Gas Reservoirs p. 53
- 4.7 Nodal Example--Tubing Size p. 54
- 4.8 Nodal Example--Surface Pressure Effects: Use Compression to Lower Surface Pressure p. 55
- 4.9 Summary Nodal Example of Developing IPR from Test Date with Tubing Performance p. 56
- 4.10 Summary p. 60
- References p. 60
- 5 Sizing Tubing p. 61
- 5.1 Introduction p. 61
- 5.2 Advantages and Disadvantages of Smaller Tubing p. 61
- 5.3 Concepts Required to Size Smaller Tubing p. 62
- 5.3.1 Critical Rate at Surface Conditions p. 65
- 5.3.2 Critical Rate at Bottomhole Conditions p. 65
- 5.3.3 Summary of Tubing Design Concepts p. 66
- 5.4 Sizing Tubing without IPR Information p. 67
- 5.5 Field Example No. 1--Results of Tubing Changeout p. 69
- 5.6 Field Example No. 2--Results of Tubing Changeout p. 69
- 5.7 Pre- and Post-Evaluation p. 71
- 5.8 Where to Set the Tubing p. 72
- 5.9 Hanging Off Smaller Tubing from the Current Tubing p. 74
- 5.10 Summary p. 76
- References p. 76
- 6 Compression p. 79
- 6.1 Introduction p. 79
- 6.2 Nodal Example p. 80
- 6.3 Compression with a Tight Gas Reservoir p. 81
- 6.4 Compression with Plunger Lift Systems p. 82
- 6.5 Compression with Beam Pumping Systems p. 84
- 6.6 Compression with Electric Submersible Systems p. 85
- 6.7 Types of Compressors p. 85
- 6.7.1 Rotary Lobe Compressor p. 86
- 6.7.2 Re-Injected Rotary Lobe Compressor p. 86
- 6.7.3 Rotary Vane Compressor p. 86
- 6.7.4 Liquid Ring Compressor p. 87
- 6.7.5 Liquid Injected Rotary Screw Compressor p. 87
- 6.7.6 Reciprocating Compressor p. 88
- 6.7.7 Sliding Vane Compressor p. 89
- 6.8 Gas Jet Compressors or Eductors p. 90
- 6.9 Summary p. 92
- References p. 93

- 7 Plunger Lift p. 95
- 7.1 Introduction p. 95
- 7.2 Plungers p. 97
- 7.3 Plunger Cycle p. 99
- 7.4 Plunger Lift Feasibility p. 100
- 7.4.1 GLR Rule of Thumb p. 101
- 7.4.2 Feasibility Charts p. 102
- 7.4.3 Maximum Liquid Production with Plunger Lift p. 105
- 7.4.4 Plunger Lift with Packer Installed p. 106
- 7.4.5 Plunger Lift Nodal Analysis p. 107
- 7.5 Plunger System Line-Out Procedure p. 108
- 7.5.1 Considerations Before Kickoff p. 109
- 7.5.2 Kickoff p. 111
- 7.5.3 Cycle Adjustment p. 112
- 7.5.4 Stabilization Period p. 113
- 7.5.5 Optimization p. 113
- 7.5.6 Monitoring p. 115
- 7.6 Problem Analysis p. 116
- 7.6.1 Motor Valve p. 118
- 7.6.2 Controller p. 121
- 7.6.3 Arrival Transducer p. 123
- 7.6.4 Wellhead Leaks p. 124
- 7.6.5 Catcher Not Functioning p. 124
- 7.6.6 Pressure Sensor Not Functioning p. 125
- 7.6.7 Control Gas to Stay on Measurement Chart p. 126
- 7.6.8 Plunger Operations p. 126
- 7.6.9 Head Gas Bleeding Off Too Slowly p. 133
- 7.6.10 Head Gas Creating Surface Equipment Problems p. 134
- 7.6.11 Low Production p. 135
- 7.6.12 Well Loads up Frequently p. 135
- 7.7 New Plunger Concept p. 136
- 7.8 Operation with Weak Wells p. 138
- 7.8.1 Casing Plunger for Weak Wells p. 138
- 7.8.2 Plunger with Side String: Low Pressure Well Production p. 142
- 7.9 Plunger Summary p. 144
- References p. 144
- 8 Use of Foam to Deliquefy Gas Wells p. 147
- 8.1 Introduction p. 147
- 8.2 Liquid Removal Process p. 148
- 8.2.1 Surface De-Foaming p. 150
- 8.3 Foam Selection p. 150
- 8.4 Foam Basics p. 153
- 8.4.1 Foam Generation p. 153
- 8.4.2 Foam Stability p. 153

- 8.4.3 Surfactant Types p. 155
- 8.4.4 Foaming with Brine/Condensate Mixtures p. 158
- 8.5 Operating Considerations p. 163
- 8.5.1 Surfactant Selection p. 163
- 8.5.2 Bureau of Mines Testing Procedures p. 163
- 8.5.3 Unloading Techniques and Equipment p. 166
- 8.5.4 Determining Surface Surfactant Concentration p. 169
- 8.5.5 Instrumentation p. 173
- 8.5.6 Chemical Treatment Problems p. 173
- 8.6 Summary p. 174
- References p. 175
- 9 Hydraulic Pumps p. 177
- 9.1 Introduction p. 177
- 9.2 Advantages and Disadvantages p. 182
- 9.3 The 1 1/4-Inch Jet Pump p. 185
- 9.4 System Comparative Costs p. 188
- 9.5 Hydraulic Pump Case Histories p. 188
- 9.6 Summary p. 189
- References p. 189
- 10 Use of Beam Pumps to Deliquefy Gas Wells p. 191
- 10.1 Introduction p. 191
- 10.2 Basics of Beam Pump Operation p. 193
- 10.3 Pump-Off Control p. 195
- 10.3.1 Design Rate with Pump-Off Control p. 196
- 10.3.2 Use of Surface Indications for Pump-Off Control p. 197
- 10.4 Gas Separation to Keep Gas Out of the Pump p. 199
- 10.4.1 Set Pump Below the Perforations p. 200
- 10.4.2 "Poor-Boy" or Limited-Entry Gas Separator p. 201
- 10.4.3 Collar-Sized Separator p. 202
- 10.5 Handling Gas through the Pump p. 203
- 10.5.1 Compression Ratio p. 204
- 10.5.2 Variable Slippage Pump to Prevent Gas-Lock p. 206
- 10.5.3 Pump Compression with Dual Chambers p. 206
- 10.5.4 Pumps that Open the Traveling Valve Mechanically p. 206
- 10.5.5 Pumps to Take the Fluid Load Off the Traveling Valve p. 206
- 10.6 Inject Liquids Below a Packer p. 207
- 10.7 Other Problems Indicated by the Shape of the Pump Card p. 209
- 10.8 Summary p. 213
- References p. 214
- 11 Gas Lift p. 215
- 11.1 Introduction p. 215
- 11.2 Continuous Gas Lift p. 217
- 11.2.1 Basic Principles of Continuous Gas Lift p. 217
- 11.3 Intermittent Gas Lift p. 217

- 11.4 Gas Lift System Components p. 218
- 11.5 Continuous Gas Lift Design Objectives p. 220
- 11.6 Gas Lift Valves p. 221
- 11.6.1 Orifice Valves p. 222
- 11.6.2 IPO Valves p. 222
- 11.6.3 PPO Valves p. 223
- 11.7 Gas Lift Completions p. 224
- 11.7.1 Conventional Gas Lift Design p. 224
- 11.7.2 Chamber Lift Installations p. 227
- 11.7.3 Horizontal Well Installations p. 229
- 11.7.4 Coiled Tubing Gas Lift Completions p. 231
- 11.7.5 Gas Pump Concept p. 234
- 11.7.6 Gas Circulation p. 235
- 11.8 Gas Lift without Gas Lift Valves p. 235
- 11.9 Summary p. 236
- References p. 237
- 12 Electric Submersible Pumps p. 239
- 12.1 Introduction p. 239
- 12.2 ESP System p. 240
- 12.3 What Is A "Gassy" Well? p. 243
- 12.4 Completions and Separators p. 245
- 12.5 Injection of Produced Water p. 248
- 12.6 Summary p. 248
- References p. 250
- 13 Progressive Cavity Pumps p. 251
- 13.1 Introduction p. 251
- 13.2 PCP System Selection p. 253
- 13.2.1 Rotor p. 253
- 13.2.2 Stator p. 254
- 13.2.3 Surface Drive p. 257
- 13.3 Selection and Operational Factors p. 257
- 13.3.1 Important Factors for Sizing the System p. 257
- 13.3.2 Steps to Size the PCP p. 259
- 13.4 Ancillary Equipment p. 263
- 13.4.1 Flow Detection Devices p. 264
- 13.4.2 Rod Guides p. 265
- 13.4.3 Gas Separators p. 265
- 13.4.4 Tubing Anchor/Catcher p. 266
- 13.5 Troubleshooting PCP Systems p. 266
- 13.6 Summary p. 268
- References p. 268
- 14 Other Methods to Attach Liquid-Loading Problems p. 271
- 14.1 Introduction p. 271
- 14.2 Thermal Methods for Water of Condensation p. 271

- 14.2.1 Thermal Lift p. 273
- 14.2.2 Thermal Liner p. 276
- 14.2.3 Thermal Coatings/Liners p. 277
- 14.2.4 With Packer Installed, Draw a Vacuum on the Annulus p. 278
- 14.3 Cycling p. 278
- 14.4 Tubing/Annulus Switching Control p. 279
- 14.5 Tubing Flow Control p. 280
- 14.6 Tubing Collar Inserts for Producing Below Critical Velocity p. 281
- 14.7 Summary p. 282
- References p. 282
- Appendix A Development of Critical Velocity Equations p. 283
- A.1 Introduction p. 283
- A.1.1 Physical Model p. 283
- A.2 Equation Simplification p. 286
- A.3 Turner Equations p. 287
- A.4 Coleman Equations p. 287
- References p. 288
- Appendix B Development of Plunger Lift Equations p. 289
- B.1 Introduction p. 289
- B.2 Minimum Casing Pressure p. 289
- B.3 Maximum Casing Pressure p. 291
- B.4 Summary p. 291
- Reference p. 292
- Appendix C Gas Fundamentals p. 293
- C.1 Introduction p. 293
- C.2 Phase Diagram p. 293
- C.3 Gas Apparent Molecular Weight and Specific Gravity p. 293
- C.4 Gas Law p. 295
- C.5 Z Factor p. 296
- C.6 Gas Formation Volume Factor p. 298
- C.7 Pressure Increase in Static Column of Gas p. 299
- C.8 Calculate the Pressure Drop in Flowing Dry Gas Well: Cullender and Smith Method p. 300
- C.9 Pressure Drop in a Gas Well Producing Liquids p. 302
- C.9.1 Calculated Result with Dry Gas and Gas with Liquids p. 303
- C.10 Gas Well Deliverability Expressions p. 303
- C.10.1 Backpressure Equation p. 303
- C.10.2 Darcy Equation p. 305
- References p. 307
- Index p. 309