

Contents

About the Authors	xxiii
Foreword	xxv
Preface to the Third Edition	xxvii
Endorsements for the Third Edition	xxix

CHAPTER 1	Natural Gas Fundamentals	1
1.1	Introduction	1
1.2	Natural gas history	1
1.3	Natural gas origin and sources	2
1.4	Natural gas composition and classification	3
1.5	Natural gas phase behavior	4
1.6	Natural gas properties	6
	1.6.1 Chemical and physical properties	6
	1.6.2 Thermodynamic properties	15
1.7	Natural gas reserves	16
1.8	Natural gas exploration and production	16
	1.8.1 Conventional gas	17
	1.8.2 Unconventional gas	20
	1.8.3 Well deliverability	22
1.9	Natural gas transportation	24
	1.9.1 Pipelines	25
	1.9.2 Liquefied natural gas	25
	1.9.3 Compressed natural gas	26
	1.9.4 Gas-to-liquids	27
	1.9.5 Gas-to-solid	28
	1.9.6 Gas-to-wire	29
	1.9.7 Comparison of various methods	30
1.10	Natural gas processing	33
1.11	Sales gas transmission	33
1.12	Underground gas storage	33
	1.12.1 Depleted reservoirs	34
	1.12.2 Aquifers	34
	1.12.3 Salt caverns	34
	References	35
CHAPTER 2	Raw Gas Transmission	37
2.1	Introduction	37
2.2	Multiphase flow terminology	37

2.2.1	Superficial velocity	38
2.2.2	Mixture velocity	38
2.2.3	Holdup	38
2.2.4	Phase velocity	39
2.2.5	Slip	39
2.2.6	Mixture density	40
2.2.7	Mixture viscosity	40
2.2.8	Mixture pressure drop	41
2.2.9	Mixture enthalpy	41
2.3	Multiphase flow regimes	42
2.3.1	Two-phase flow regimes	42
2.3.2	Three-phase flow regimes	48
2.3.3	Gas-condensate flow regimes	49
2.4	Determining multiphase flow design parameters	49
2.4.1	Steady-state two-phase flow	50
2.4.2	Steady-state three-phase flow	56
2.4.3	Transient multiphase flow	57
2.4.4	Multiphase gas and condensate flow	59
2.5	Predicting temperature profile of multiphase pipeline	60
2.6	Velocity criteria for sizing multiphase pipelines	64
2.7	Multiphase pipeline operations	65
2.7.1	Leak detection	65
2.7.2	Pipeline depressurization	66
2.7.3	Pigging	66
2.8	Multiphase flow assurance	68
2.8.1	Gas hydrates	68
2.8.2	Corrosion	86
2.8.3	Wax	90
2.8.4	Slugging	102
2.8.5	Flow assurance risk management	111
	References	114
CHAPTER 3	Basic Concepts of Natural Gas Processing	123
3.1	Introduction	123
3.2	Natural gas processing objectives	123
3.3	Gas processing plant configurations	124
3.3.1	Gas plant with hydrocarbon dewpointing	125
3.3.2	Gas plant for NGL production	128
3.4	Finding the best gas processing route	131
3.5	Support systems	132
3.5.1	Utility and off-site	132
3.5.2	Process control	132
3.5.3	Safety systems	133

3.6	Contractual agreements	133
3.6.1	Keep-whole contracts	134
3.6.2	Flat fees contracts	134
3.6.3	Percentage of proceeds contracts	134
3.6.4	Processing fee contracts	135
	References	135
CHAPTER 4	Phase Separation	137
4.1	Introduction.....	137
4.2	Gravity separators.....	137
4.2.1	General description.....	138
4.2.2	Separator selection	140
4.2.3	Gravity separation theory	142
4.2.4	Design considerations.....	144
4.3	Multistage separation.....	145
4.4	Centrifugal separators.....	145
4.5	Twister supersonic separator	146
4.6	Slug catchers.....	148
4.7	High-efficiency liquid/gas coalescers.....	150
4.7.1	Aerosols	150
4.7.2	Coalescer construction/operation principles	151
4.7.3	Modeling the liquid/gas coalescer	154
4.7.4	Coalescer performance/operational limits	157
4.7.5	Liquid/gas coalescer applications	157
4.8	High-efficiency liquid–liquid coalescers.....	157
4.8.1	Emulsions	157
4.8.2	Coalescer principles and materials of construction.....	158
4.8.3	Coalescer mechanism of operation	158
4.8.4	Liquid–liquid coalescer performance.....	161
4.8.5	Limitations of using coalescers.....	162
4.8.6	Applications.....	162
4.9	Practical design of separation systems.....	162
	References	165
CHAPTER 5	Condensate Production	169
5.1	Introduction.....	169
5.2	Condensate stabilization.....	170
5.2.1	Stabilization by cascade flash separation.....	170
5.2.2	Stabilization by distillation	171
5.2.3	Design considerations.....	173
5.2.4	Operating problems	174
5.3	Condensate hydrotreating.....	174
5.4	Effluent treatment	176

5.4.1	MEG regeneration and reclaiming	176
5.4.2	Sour water stripping	177
5.5	Condensate storage	178
5.5.1	Tank design considerations	178
5.5.2	Tank emission control	180
CHAPTER 6	Natural Gas Treating	181
6.1	Introduction	181
6.2	Gas treating specifications	181
6.3	Gas treating processes	182
6.4	Chemical absorption processes	183
6.4.1	Alkanolamine solvents	183
6.4.2	The potassium carbonate solution	195
6.5	Physical solvent processes	196
6.5.1	Propylene carbonate	198
6.5.2	Dimethyl ether of polyethylene glycol	202
6.5.3	Methanol (Rectisol process)	207
6.5.4	<i>N</i> -Methyl-2-pyrrolidone	208
6.6	Mixed physical and chemical absorption processes	208
6.7	Solid bed absorption processes	210
6.7.1	Iron sponge process	210
6.7.2	Zinc oxide process	211
6.7.3	PURASPEC TM _{JM}	211
6.7.4	Slurry processes	213
6.8	Solid bed adsorption process	213
6.9	Membrane	214
6.10	Cryogenic fractionation	218
6.11	Microbiological treatment processes	218
6.12	Selecting the gas treating process	219
	References	220
CHAPTER 7	Natural Gas Dehydration	223
7.1	Introduction	223
7.2	Water content determination	224
7.3	Glycol dehydration	226
7.3.1	Conventional TEG dehydration process	227
7.3.2	Enhanced TEG dehydration process	229
7.3.3	Glycol injection process	230
7.3.4	TEG unit design considerations	232
7.3.5	Operational problems	235
7.3.6	Future technology developments	237
7.4	Solid-bed dehydration	237
7.4.1	Adsorption capacity	238
7.4.2	Adsorbent selection	238

7.4.3	Adsorption technology.....	243
7.4.4	Operation of solid-bed dehydrator	247
7.4.5	Dehydration unit design considerations	251
7.4.6	Operational problems.....	253
7.5	Other gas dehydration processes	258
7.6	Gas dehydration process selection.....	259
7.7	Mercury removal.....	260
7.7.1	Nonregenerative mercury sorbents.....	260
7.7.2	Regenerative mercury adsorbents.....	261
7.7.3	Process selection considerations.....	261
	References	262
CHAPTER 8	Natural Gas Liquids Recovery	265
8.1	Introduction.....	265
8.2	Refrigeration processes.....	266
8.2.1	Propane refrigeration.....	266
8.2.2	Cascade refrigeration.....	268
8.2.3	Mixed refrigerants	270
8.3	Liquid recovery processes	271
8.3.1	Hydrocarbon dew pointing with Joule–Thomson cooling	271
8.3.2	Hydrocarbon dew pointing with propane refrigeration	272
8.3.3	Deep hydrocarbon dew pointing	273
8.3.4	Turboexpander NGL recovery processes.....	274
8.3.5	Lean oil absorption.....	279
8.3.6	Modern NGL recovery processes.....	281
8.3.7	Other hydrocarbons removal processes	287
8.4	Selection of NGL recovery process	289
8.5	NGL recovery technology development	290
8.6	NGL recovery unit design considerations.....	290
8.7	NGL recovery unit operating problems	290
8.8	NGL fractionation.....	291
8.9	Liquid product processing	293
8.9.1	NGL contaminant treating.....	293
8.9.2	Dehydration	297
	References	298
CHAPTER 9	Sulfur Recovery and Handling	301
9.1	Introduction	301
9.2	Sulfur properties.....	301
9.3	Sulfur recovery.....	302
9.3.1	Modified Claus process.....	303
9.3.2	Direct oxidation processes.....	309

9.3.3	Small- and medium-scale processes.....	311
9.3.4	Microbiological treatment processes.....	314
9.4	Tail gas cleanup	314
9.4.1	Reduction processes.....	314
9.4.2	SO ₂ scrubbing processes.....	317
9.4.3	Catalytic oxidation.....	318
9.4.4	Other tail gas treating configurations	318
9.5	Sulfur degassing.....	320
9.5.1	D'GAASS process	321
9.5.2	Aquisulf process.....	322
9.6	Sulfur storage and handling.....	322
9.6.1	Molten sulfur handling system.....	323
9.6.2	Sulfur forming.....	323
9.6.3	Conveying formed sulfur.....	324
9.6.4	Storage of formed sulfur.....	324
9.7	SRU design considerations	324
9.7.1	Piping	325
9.7.2	Acid gas feed drums	325
9.7.3	Combustion air blowers.....	326
9.7.4	Main burner and reaction furnace	326
9.7.5	Waste heat boiler.....	326
9.7.6	Sulfur condensers.....	327
9.7.7	Sulfur pit	327
9.8	SRU operation problems.....	327
9.8.1	Proper air ratio	327
9.8.2	Reactor activity	328
9.8.3	Excessive COS and CS ₂	329
9.8.4	Leakage of reheat exchanger.....	329
9.8.5	Reactor pressure drop	329
9.8.6	Carbon deposits.....	329
9.8.7	Catalyst support screens	330
9.8.8	Water vapor and carbon dioxide.....	330
9.8.9	Steam heater.....	330
9.8.10	Combustion air control	330
9.9	Selecting the sulfur recovery process.....	331
9.10	Sulfur disposal by acid gas injection.....	332
	References.....	333
CHAPTER 10	Nitrogen Rejection	335
10.1	Introduction	335
10.2	Nitrogen rejection options	335
10.2.1	Cryogenic processes.....	335
10.2.2	Noncryogenic processes.....	336
10.3	Nitrogen rejection unit integration	336

10.4	Cryogenic nitrogen rejection	338
10.4.1	Classical single-column design.....	338
10.4.2	Modified single-column design	339
10.4.3	Double-column design	340
10.4.4	Two-column design.....	343
10.4.5	Process selection	344
10.5	Design considerations	345
10.5.1	Feed gas characteristics	345
10.5.2	Reflux and reboiler duties.....	345
10.5.3	Temperature and pressure control.....	346
10.5.4	Insulation.....	346
10.5.5	Reboiler hydraulics	346
10.6	Operating problems.....	346
10.6.1	Feed contaminants	346
10.6.2	Foaming.....	347
10.6.3	High methane content in nitrogen vent.....	347
10.6.4	Hydrate formation.....	347
10.6.5	Nitrogen safety.....	347
10.6.6	BAHX failure	347
CHAPTER 11	Natural Gas Compression	349
11.1	Introduction	349
11.2	Reciprocating compressors	350
11.3	Centrifugal compressors	351
11.4	Comparison between compressors	353
11.5	Compressor selection	354
11.6	Thermodynamics of gas compression	355
11.6.1	Basic relations.....	356
11.6.2	Isentropic model	357
11.6.3	Polytropic model.....	360
11.6.4	Real gas behavior.....	361
11.7	Compression ratio	362
11.8	Compressor design.....	364
11.8.1	Determining number of compression stages	364
11.8.2	Compression power calculation.....	366
11.9	Compressor control.....	367
11.9.1	Reciprocating compressors	368
11.9.2	Centrifugal compressors	369
11.10	Compressor performance maps	375
11.10.1	Reciprocating compressors	375
11.10.2	Centrifugal compressors	375
11.11	Example for operating a compressor in a pipeline system.....	376
	References.....	380

- CHAPTER 12 Sales Gas Transmission 383**
 - 12.1 Introduction 383
 - 12.2 Gas flow fundamentals..... 383
 - 12.2.1 General flow equation 384
 - 12.2.2 Friction factor correlations 385
 - 12.2.3 Simplified flow equations 388
 - 12.3 Predicting gas temperature profile 390
 - 12.4 Transient flow in gas transmission pipelines..... 392
 - 12.5 Compressor stations 394
 - 12.5.1 Station facilities 395
 - 12.5.2 Compressors arrangements 399
 - 12.5.3 Station control 399
 - 12.5.4 Acoustical treatment 400
 - 12.5.5 Reliability and availability 401
 - 12.6 Reduction and metering stations..... 402
 - 12.6.1 Filters..... 402
 - 12.6.2 Heaters..... 403
 - 12.6.3 Pressure reduction and regulation system 403
 - 12.6.4 Metering system..... 403
 - 12.7 Design considerations of sales gas pipelines..... 403
 - 12.7.1 Line sizing criteria 403
 - 12.7.2 Compressor station spacing 404
 - 12.7.3 Compression power..... 408
 - 12.8 Pipeline operations 409
 - References 410

- CHAPTER 13 Gas Processing Plant Automation 413**
 - 13.1 Introduction 413
 - 13.2 Early methods of gas plant automation 413
 - 13.3 Microprocessor-based automation 414
 - 13.3.1 Programmable logic controllers..... 414
 - 13.3.2 Distributed control systems 414
 - 13.3.3 Standards and protocols 416
 - 13.4 Control of equipment and process systems 417
 - 13.4.1 Gas gathering 417
 - 13.4.2 Gas treating 418
 - 13.4.3 Sulfur recovery..... 418
 - 13.4.4 Gas dehydration 419
 - 13.4.5 Liquids recovery 420
 - 13.4.6 NGL fractionation 422
 - 13.4.7 Centrifugal compressors 422
 - 13.4.8 Centrifugal pumps..... 423
 - 13.4.9 Reciprocating pumps 423
 - 13.4.10 Utilities 423

13.5	Automation applications	424
13.5.1	Data historians.....	424
13.5.2	Asset and performance management.....	425
13.5.3	Statistical process control	426
13.5.4	Advanced regulatory control.....	427
13.5.5	Multivariable predictive control	427
13.5.6	Optimization.....	429
13.5.7	Leveraging automation	431
13.6	Condensate stabilizer case study	433
	References.....	436
CHAPTER 14	Gas Processing Plant Operations.....	437
14.1	Introduction	437
14.2	Commissioning and start-up	437
14.2.1	Mechanical completion and precommissioning	437
14.2.2	Control systems testing.....	438
14.2.3	Initial start-up procedures	440
14.2.4	Process commissioning.....	440
14.2.5	Performance testing	442
14.3	Control room management	442
14.3.1	Roles and responsibilities	443
14.3.2	Process safety management	443
14.3.3	Hazard and operability study.....	445
14.3.4	Layer of protection analysis	446
14.3.5	Fatigue mitigation	448
14.3.6	Alarm management.....	449
14.3.7	Training	453
14.4	Maintenance	454
14.4.1	Types of maintenance	455
14.4.2	Enterprise asset management systems.....	457
14.4.3	Reliability centered maintenance.....	457
14.5	Troubleshooting.....	458
14.5.1	Troubleshooting steps	459
14.5.2	Troubleshooting documentation	461
14.5.3	Instrumentation	461
14.5.4	Process troubleshooting	463
14.6	Turnarounds.....	464
	References.....	464
CHAPTER 15	Dynamic Simulation of Gas Processing Plants..	467
15.1	Introduction	467
15.2	Areas of application of dynamic simulation	467
15.2.1	Plant design.....	468
15.2.2	Plant operation	471

15.3	Modeling considerations	473
15.3.1	Level of detail in the model	473
15.3.2	Model speed	474
15.3.3	Equipment specific considerations	474
15.4	Control of equipment and process systems	477
15.4.1	Gas gathering and transmission	477
15.4.2	Gas treating	477
15.4.3	Sulfur recovery	477
15.4.4	Gas dehydration	477
15.4.5	Liquids recovery, natural gas liquefaction	478
15.4.6	NGL fractionation	478
15.5	Case study I: Analysis of a fuel gas system start-up	478
15.5.1	Introduction	478
15.5.2	Steady-state analysis	479
15.5.3	Dynamic analysis	480
15.5.4	Conclusion	481
15.6	Case study II: Online dynamic model of a trunk line	481
	References	485
CHAPTER 16 Real-Time Optimization of Gas Processing Plants		
		487
16.1	Introduction	487
16.2	Real-time optimization	487
16.2.1	Physical properties	489
16.2.2	Optimization models	491
16.2.3	Plant model integration	502
16.3	RTO project considerations	504
16.4	Example of RTO	505
16.4.1	Process description	506
16.4.2	Plant operation	506
16.4.3	Production objectives	509
16.4.4	Project drivers	509
16.4.5	Features of the optimization model	512
	References	516
CHAPTER 17 Maximizing Profitability of Gas Plant Assets		
		517
17.1	Introduction	517
17.2	The performance strategy—integrated gas plant	518
17.3	Strategies for organizational behavior and information	519
17.4	Organizational behavior model	519
17.4.1	Information quality	520
17.4.2	Perception of information	522
17.4.3	Capability to perform	524
17.4.4	Organizational hierarchy of needs	526

17.5	The successful information strategy	528
17.6	The impact of living with information technology	529
17.7	Vision of the modern plant operation	530
17.8	Operations strategy	531
17.9	Model-based asset management	532
17.10	Optimization	533
	17.10.1 Tools for optimization	534
	17.10.2 Optimization alternatives	534
17.11	Industrial relevance	536
17.12	The technology integration challenge	537
17.13	Scientific approach	537
17.14	Other miscellaneous initiatives	539
17.15	Conclusion	539
	References	541
CHAPTER 18	Gas Plant Project Management	543
18.1	Introduction	543
18.2	Project management overview	543
18.3	Industry perspective	544
18.4	The project management process	545
	18.4.1 Defining business and project objectives	546
	18.4.2 Contracting strategy	548
	18.4.3 Conceptual estimates and schedules	549
	18.4.4 Project execution planning	551
	18.4.5 Pre-project planning measurement	552
	18.4.6 The responsibility matrix	552
18.5	Project controls	554
	18.5.1 Project timeline	555
	18.5.2 Risk management	556
18.6	Quality assurance	564
18.7	Commissioning and start-up	565
18.8	Operate and evaluate	566
18.9	Project closeout	567
18.10	Conclusion	567
	References	568
	Appendix 1: Conversion Factors	571
	Appendix 2: Standard Gas Conditions	573
	Appendix 3: Physical Properties of Fluids	575
	Index	581