Contents

1. Introduction 1

1.1 Introduction 1
1.2 Why Are Pipelines Important? 2
1.3 Pipeline Basics 2
1.4 Pipeline Design Essentials 3
1.4.1 Physical Components 4
1.4.2 Data Acquisition and Control 6
1.5 Pipeline Leaks, Ruptures, Spills, and Theft 8
1.5.1 Breach of Integrity Incident Rates 9
1.5.2 Commodity Theft 11
1.6 Leak Detection Approaches 11
1.7 The Book Structure 12
1.8 Terminology 13
1.9 Nomenclature 14
References 17

2. Pipeline Leak Detection Basics

2.1 The Challenges of Detecting Pipeline Leaks 19
2.2 The Toll Road and the Free-Rider Problem 21
2.2.1 Directly Detecting Free Riders 21
2.2.2 Detecting Free Riders by Counting Cars 24
2.3 Leak Location and Other Issues 29
2.4 Leak Detection and Theft 30
2.5 Functional Requirements 31
2.6 The Fundamental Principles Summarized 32
2.7 Architectural Foundations 34
2.8 A Taxonomy of Pipeline Leak Detection Systems 37

3. Mass Balance Leak Detection

3.1 Leaks and Conservation of Mass 41
3.2 Pipeline Mass Balance Section 42
3.3 Leak Detection by Mass Balance: Foundational Principles 43

3.4 **Volume Balance at Standard Conditions as a Proxy for Mass Balance** 45
3.4.1 Conservation of Standard Volume Is Not a Physical Principle 46
3.4.2 Formulation of Mass Balance Leak Detection in Terms of Volume at STP 48
3.5 **Impact of Uncertainties in Mass/Volume Balances on Leak Detection** 50
3.5.1 Determining the Flow Balance 52
3.5.2 Determining the Packing Rate 53
3.6 **API 1130 Applicable Classification of Mass Balance Systems** 53
3.6.1 Line Balance CPM 54
3.6.2 Volume Balance CPM 54
3.6.3 Modified Volume Balance CPM 54
3.6.4 Compensated Mass Balance 54
3.6.5 Real-Time Model Based Systems 54
3.7 **Our Classification of Mass Balance–Based Leak Detection Systems** 55
References 55

4. Real-Time Transient Model–Based Leak Detection

4.1 **The Real-Time Transient Model** 58
4.1.1 Fundamental Equations and Physics 59
4.2 **Numerical Methods** 65
4.2.1 Explicit Numerical Solution 67
4.2.2 Method of Characteristics Solution 69
4.2.3 Implicit Numerical Solution 71
4.2.4 A Comparison of Numerical Methods 73
4.3 **Measurements and Boundary Conditions** 74
4.3.1 Measurement Placement, Availability, and Reliability 74
4.3.2 Selection of Boundary Conditions 77
4.3.3 Boundary Condition Strategies 78
4.4 **State Estimation and Related Subjects** 79
4.5 **Leak Detection Signals** 81
4.6 **Using the Leak Signals to Detect Leaks** 82
4.7 **Estimating Leak Location** 83
4.8 **Impact of Fluid Type: Liquids, Gases, and Multiphase Flows** 84
4.8.1 Liquid Pipeline Leak Detection 84
4.8.2 Gas Pipeline Leak Detection 85
4.8.3 Liquid Pipelines With Slack Line Flow 85
4.8.4 Multiphase Flow–Based RTTMs 87
4.8.5 Dense Phase Fluids 87
4.9 **RTTM Uncertainty Recap** 88
References 88

7.7 Other External Methods 164
7.7.1 Ultrasonic Meter External Leak Detection 164
7.7.2 Intermittent Leak Detection Systems and Methods 165
7.7.3 Unmanned Aerial Vehicle Leak Detection Technology 166
7.8 General Assessment 167
Reference 169

8. Leak Detection System Infrastructure

8.1 Field Instrumentation 171
8.1.1 Measurement Uncertainty 171
8.1.2 Time Skew 172
8.1.3 Data Sampling Processing Best Practices 175
8.1.4 Dealing With Calibration and Other Instrument Maintenance 178
8.2 Supporting Telecommunication and Network Infrastructure 179
8.2.1 Telecommunication Infrastructures 179
8.2.2 Telecommunication Redundancy 182
8.2.3 Telecommunication Issues 183
8.2.4 Telecommunication Best Practices 183
8.3 SCADA System Considerations 184
8.3.1 SCADA HMI Considerations 187
8.4 Historical Archiving of Data 188
8.4.1 Archiving Measurement Data 188
8.4.2 Archiving Leak Detection Results and Control Actions 189
8.5 Resilient System Design 190
References 191

9. Leak Detection Performance, Testing, and Tuning

9.1 Performance Metrics 193
9.1.1 Primary Performance Metrics and Leak Detection Performance Mapping 194
9.1.2 Derived Metrics and LDS System Efficiency 202
9.2 Tuning and Tradeoffs 206
9.3 LDS Performance Testing and Evaluation 214
9.3.1 Commodity Withdrawal Testing for CPM Systems 214
9.3.2 Field Point Edit-Based Testing of CPM Systems 216
9.3.3 LDS Software-Based Testing 217
9.4 LDS Tuning 219
9.5 Performance Standards 222
References 222

10. Human Factor Considerations in Leak Detection

10.1 The Human–Machine Signal Detection Control Loop 223
10.1.1 Diagnosing Alarms in the Face of Uncertainty 223
10.1.2 Human Factors in the Control Room 225

10.1.3 Data Display, Presentation, and Integration 228
10.1.4 CRM Regulatory Requirements, Industry Standards, and Recommended Practices 231
10.1.5 Alarm Management Overview 233
10.1.6 Balancing Sensitivity and False Alarms 234
10.1.7 Training 237
10.1.8 Human Factors Summary 238
10.2 Direct Observation Leak Detection 238
10.2.1 Physical Release Models 239
10.2.2 Detection of Leaks by the Public 247
References 252

11. Implementation and Installation of Pipeline Leak Detection Systems

11.1 Performance Requirement Specification 255
11.2 Leak Detection Technology/Methodology Decision 258
11.3 LDS System Integration Requirements 263
11.3.1 External Leak Detection Integration Requirements 263
11.3.2 Internal Leak Detection Integration Requirements 264
11.4 System Testing 266
11.5 Vendor Identification and Assessment 266
11.6 Commissioning 270
11.7 Long-Term Support Issues 270
References 273

12. Regulatory Requirements

12.1 The United States of America Regulatory Environment 275
12.1.1 US Interstate Federal Regulations 277
12.2 Canada 281
12.3 Germany 283
12.4 Regulatory Requirements in Other Jurisdictions 284
12.4.1 Brazil 284
12.4.2 Great Britain 284
References 285

13. Leak Detection and Risk-Based Integrity Management

13.1 Quantifying Integrity Breach Risk and Impact 288
13.1.1 Liquid Pipeline Spill Risk, Magnitude, and Cost 288
13.1.2 Liquid Commodity Spill Source Classification 297
13.1.3 Gas-Phase Commodity Integrity Breaches 298
13.1.4 Leak Detection Technology Versus Other Detection Mechanisms 300
13.2 Understanding the Consequences of a Spill 303
13.2.1 Low-Vapor-Pressure Liquid Pipeline Spills 303
13.2.2 HVL Spills 304

13.2.3 Gas Pipeline Ruptures 305
13.2.4 Summary 305
13.3 Leak Detection as a Component of Pipeline Loss-of-Integrity Risk Management 306
13.3.1 Analytical Basis 306
13.3.2 Pipeline Design to Minimize Loss of Containment Impact 307
13.3.3 Preventive Maintenance Program 308
13.3.4 Effective Leak Detection Program, Technology, and Procedures 308
13.3.5 Effective Response Plan 313
13.4 Conclusion 313
References 314

Index 317