

Contents

<i>Preface</i>	<i>page</i> xxiii
<i>Acknowledgements</i>	xxv
<i>Nomenclature</i>	xxvii
1 Introduction	1
1.1 Initial Considerations	1
1.2 Do We Need a Flowmeter?	2
1.3 How Accurate?	4
1.4 A Brief Review of the Evaluation of Standard Uncertainty	8
1.5 Note on Monte Carlo Methods	10
1.6 Sensitivity Coefficients	10
1.7 What Is a Flowmeter?	11
1.8 Chapter Conclusions (for those who Plan to Skip the Mathematics!)	14
1.9 Mathematical Postscript	15
1.A Statistics of Flow Measurement	17
1.A.1 Introduction	17
1.A.2 The Normal Distribution	17
1.A.3 The Student <i>t</i> Distribution	20
1.A.4 Practical Application of Confidence Level	21
1.A.5 Types of Error	22
1.A.6 Combination of Uncertainties	23
1.A.7 Uncertainty Range Bars, Transfer Standards and Youden Analysis	24
2 Fluid Mechanics Essentials	27
2.1 Introduction	27
2.2 Essential Property Values	27
2.3 Flow in a Circular Cross-Section Pipe	27
2.4 Flow Straighteners and Conditioners	31
2.5 Essential Equations	34

2.6	Unsteady Flow and Pulsation	36
2.7	Compressible Flow	38
2.8	Multiphase Flow	40
2.9	Cavitation, Humidity, Droplets and Particles	42
2.10	Gas Entrapment	43
2.11	Steam	45
2.12	Chapter Conclusions	45
2.A	Further Aspects of Flow Behaviour, Flow Conditioning and Flow Modelling	46
2.A.1	Further Flow Profile Equations	46
2.A.2	Non-Newtonian Flows	47
2.A.3	Flow Conditioning	47
2.A.4	Other Installation Considerations	50
2.A.5	Computational Fluid Dynamics (CFD)	50
3	Specification, Selection and Audit	52
3.1	Introduction	52
3.2	Specifying the Application	52
3.3	Notes on the Specification Form	53
3.4	Flowmeter Selection Summary Table	56
3.5	Draft Questionnaire for Flowmeter Audit	62
3.6	Final Comments	62
3.A	Specification and Audit Questionnaires	63
3.A.1	Specification Questionnaire	63
3.A.2	Supplementary Audit Questionnaire	65
4	Calibration	67
4.1	Introduction	67
4.1.1	Calibration Considerations	67
4.1.2	Typical Calibration Laboratory Facilities	70
4.1.3	Calibration from the Manufacturer's Viewpoint	71
4.2	Approaches to Calibration	72
4.3	Liquid Calibration Facilities	75
4.3.1	Flying Start and Stop	75
4.3.2	Standing Start and Stop	77
4.3.3	Large Pipe Provers	80
4.3.4	Compact Provers	80
4.4	Gas Calibration Facilities	85
4.4.1	Volumetric Measurement	85
4.4.2	Mass Measurement	86
4.4.3	Gas/Liquid Displacement	86
4.4.4	pV/T Method	87
4.4.5	Critical Nozzles	87
4.4.6	Soap Film Burette Method	88

4.5	Transfer Standards and Master Meters	88
4.6	In Situ Calibration	91
4.6.1	Provers	92
4.7	Calibration Uncertainty	98
4.8	Traceability and Accuracy of Calibration Facilities	100
4.9	Chapter Conclusions	101
4.A	Calibration and Flow Measurement Facilities	101
4.A.1	Introduction	101
4.A.2	Flow Metrology Developments	102
4.A.3	Multiphase Calibration Facilities	105
4.A.4	Gas Calibration Facilities	105
4.A.5	Gas Properties	108
4.A.6	Case Study of a Water Flow Calibration Facility Which Might Be Used in a Manufacturing Plant or a Research Laboratory from the Author's Experience	108
4.A.7	Example of a Recent Large Water Calibration Facility	113
5	Orifice Plate Meters	116
5.1	Introduction	116
5.2	Essential Background Equations	118
5.3	Design Details	121
5.4	Installation Constraints	124
5.5	Other Orifice Plates	128
5.6	Deflection of Orifice Plate at High Pressure	129
5.7	Effect of Pulsation	131
5.8	Effects of More than One Flow Component	136
5.9	Accuracy Under Normal Operation	139
5.10	Industrially Constructed Designs	141
5.11	Pressure Connections	142
5.12	Pressure Measurement	144
5.13	Temperature and Density Measurement	147
5.14	Flow Computers	148
5.15	Detailed Studies of Flow through the Orifice Plate, Both Experimental and Computational	148
5.16	Application, Advantages and Disadvantages	150
5.17	Chapter Conclusions	151
5.A	Orifice Discharge Coefficient Equation	152
5.A.1	Stolz Orifice Discharge Coefficient Equation as Given in ISO 5167: 1981	152
5.A.2	Orifice Discharge Coefficient Equation as set out by Gallagher (1990)	153
5.A.3	Orifice Discharge Coefficient Equation as Given in ISO 5167-2: 2003	154

5.B	Review of Recent Published Research on Orifice Plates	156
5.B.1	Installation Effects on Orifice Plates	156
5.B.2	Pulsation	157
5.B.3	Contamination	157
5.B.4	Drain Holes	158
5.B.5	Flow Conditioning for Orifice Meters	158
5.B.6	Plate Thickness for Small-Diameter Orifice Plates	160
5.B.7	Variants on the Orifice Plate	160
5.B.8	Impulse Lines	160
5.B.9	Lagging Pipes	160
5.B.10	Gas Conditions	160
5.B.11	Emissions Testing Uncertainty	161
5.B.12	CFD Related to Orifice Plates	161
6	Venturi Meter and Standard Nozzles	163
6.1	Introduction	163
6.2	Essential Background Equations	165
6.3	Design Details	167
6.4	Commercially Available Devices	168
6.5	Installation Effects	168
6.6	Applications, Advantages and Disadvantages	170
6.7	Chapter Conclusions	171
6.A	Research Update	172
6.A.1	Design and Installation	172
6.A.2	Meters in Nuclear Core Flows	173
6.A.3	Special Conditions	173
7	Critical Flow Venturi Nozzle	177
7.1	Introduction	177
7.2	Design Details of a Practical Flowmeter Installation	178
7.3	Practical Equations	181
7.4	Discharge Coefficient C	183
7.5	Critical Flow Function C_*	185
7.6	Design Considerations	185
7.7	Measurement Uncertainty	187
7.8	Notes on the Calculation Procedure	188
7.9	Industrial and Other Experience	189
7.10	Advantages, Disadvantages and Applications	190
7.11	Chapter Conclusions	190
7.A	Critical Flow Venturi Nozzle – Recent Published Work	190
8	Other Momentum-Sensing Meters	195
8.1	Introduction	195
8.2	Variable Area Meter	196

8.2.1	Operating Principle and Background	196
8.2.2	Design Variations	196
8.2.3	Remote Readout Methods	198
8.2.4	Design Features	199
8.2.5	Calibration and Sources of Error	200
8.2.6	Installation	201
8.2.7	Unsteady and Pulsating Flows	201
8.2.8	Industrial Types, Ranges and Performance	201
8.2.9	Manufacturing Variation	202
8.2.10	Computational Analysis of the Variable Area Flowmeter	203
8.2.11	Applications	203
8.3	Spring-Loaded Diaphragm (Variable Area) Meters	204
8.4	Target (Drag Plate) Meter	208
8.5	Integral Orifice Meters	209
8.6	Dall Tubes and Devices that Approximate to Venturis and Nozzles	209
8.7	Wedge Meter	212
8.8	V-Cone Meter (Cone Meter)	213
8.9	Differential Devices with a Flow Measurement Mechanism in the Bypass	216
8.10	Slotted Orifice Plate	216
8.11	Pipework Features – Inlets and Pipe Lengths	217
8.12	Pipework Features – Bend or Elbow used as a Meter	218
8.13	Averaging Pitot	220
8.14	Laminar or Viscous Flowmeters	223
8.15	Chapter Conclusions	227
8.A	History, Equations and Maximum Permissible Error Limits for the VA Meter	228
8.A.1	Some History	228
8.A.2	Equations	229
8.A.3	Maximum Permissible Error Limits	232
9	Positive Displacement Flowmeters	234
9.1	Introduction	234
9.1.1	Background	234
9.1.2	Qualitative Description of Operation	235
9.2	Principal Designs of Liquid Meters	236
9.2.1	Nutating Disc Meter	236
9.2.2	Oscillating Circular Piston (Also Known as Rotary Piston) Meter	237
9.2.3	Multirotor Meters	237
9.2.4	Oval Gear Meter	238
9.2.5	Sliding Vane Meters	240
9.2.6	Helical Rotor Meter	242
9.2.7	Reciprocating Piston Meters	243

9.2.8	Precision Gear (Spur Gear) Flowmeters	244
9.3	Calibration, Environmental Compensation and Other Factors Relating to the Accuracy of Liquid Flowmeters	245
9.3.1	Calibration Systems	246
9.3.2	Clearances	249
9.3.3	Leakage Through the Clearance Gap Between Vane and Wall	249
9.3.4	Slippage Tests	251
9.3.5	The Effects of Temperature and Pressure Changes	252
9.3.6	The Effects of Gas in Solution	252
9.4	Accuracy and Calibration	253
9.5	Principal Designs of Gas Meters	254
9.5.1	Wet Gas Meter	255
9.5.2	Diaphragm Meter	256
9.5.3	Rotary Positive Displacement Gas Meter	257
9.6	Positive Displacement Meters for Multiphase Flows	258
9.7	Meter Using Liquid Plugs to Measure Low Flows	261
9.8	Applications, Advantages and Disadvantages	261
9.9	Chapter Conclusions	262
9.A	Basic Analysis and Recent Research	263
9.A.1	Theory for a Sliding Vane Meter	263
9.A.1.1	Flowmeter Equation	264
9.A.1.2	Expansion of the Flowmeter Due to Temperature	265
9.A.1.3	Pressure Effects	266
9.A.1.4	Meter Orientation	267
9.A.1.5	Analysis of Calibrators	268
9.A.1.6	Application of Equations to a Typical Meter	270
9.A.2	Recent Theoretical and Experimental Research	271
10	Turbine and Related Flowmeters	279
10.1	Introduction	279
10.1.1	Background	279
10.1.2	Qualitative Description of Operation	279
10.1.3	Basic Theory	280
10.2	Precision Liquid Meters	287
10.2.1	Principal Design Components	287
10.2.2	Dual Rotor Meters	288
10.2.3	Bearing Design Materials	288
10.2.4	Strainers	290
10.2.5	Materials	290
10.2.6	Size Ranges	290
10.2.7	Other Mechanical Design Features	291
10.2.8	Cavitation	291
10.2.9	Sensor Design and Performance	292

10.2.10	Characteristics	293
10.2.11	Accuracy	294
10.2.12	Installation	295
10.2.13	Maintenance	297
10.2.14	Viscosity, Temperature and Pressure	298
10.2.15	Unsteady Flow	299
10.2.16	Multiphase Flow	300
10.2.17	Signal Processing	301
10.2.18	Applications	301
10.2.19	Advantages and Disadvantages	302
10.3	Precision Gas Meters	303
10.3.1	Principal Design Components	303
10.3.2	Bearing Design	303
10.3.3	Materials	303
10.3.4	Size Range	303
10.3.5	Accuracy	304
10.3.6	Installation	306
10.3.7	Sensing and Monitoring	308
10.3.8	Unsteady Flow	308
10.3.9	Applications	310
10.3.10	Advantages and Disadvantages	311
10.4	Water Meters	311
10.4.1	Principal Design Components	311
10.4.2	Bearing Design	312
10.4.3	Materials	312
10.4.4	Size Range	313
10.4.5	Sensing	313
10.4.6	Characteristics and Accuracy	313
10.4.7	Installation	313
10.4.8	Special Designs	314
10.5	Other Propeller and Turbine Meters	314
10.5.1	Quantum Dynamics Flowmeter	314
10.5.2	Pelton Wheel Flowmeters	314
10.5.3	Bearingless Flowmeter	314
10.5.4	Vane Type Flowmeters	315
10.6	Chapter Conclusions	316
10.A	Turbine Flowmeter Theoretical and Experimental Research	317
10.A.1	Derivation of Turbine Flowmeter Torque Equations	317
10.A.2	Transient Analysis of Gas Turbine Flowmeter	322
10.A.3	Recent Developments	324
11	Vortex Shedding, Swirl and Fluidic Flowmeters	327
11.1	Introduction	327
11.2	Vortex Shedding	327

11.3	Industrial Developments of Vortex-Shedding Flowmeters	329
11.3.1	Experimental Evidence of Performance	329
11.3.2	Bluff Body Shape	331
11.3.3	Standardisation of Bluff Body Shape	334
11.3.4	Sensing Options	334
11.3.5	Cross-Correlation and Signal Interrogation Methods	339
11.3.6	Other Aspects Relating to Design and Manufacture	339
11.3.7	Accuracy	340
11.3.8	Installation Effects	341
11.3.9	Effect of Pulsation and Pipeline Vibration	344
11.3.10	Two-Phase Flows	345
11.3.11	Size and Performance Ranges and Materials in Industrial Designs	347
11.3.12	Computation of Flow Around Bluff Bodies	348
11.3.13	Applications, Advantages, and Disadvantages	349
11.3.14	Future Developments	350
11.4	Swirl Meter – Industrial Design	351
11.4.1	Design and Operation	351
11.4.2	Accuracy and Ranges	351
11.4.3	Installation Effects	352
11.4.4	Applications, Advantages and Disadvantages	352
11.5	Fluidic Flowmeter	352
11.5.1	Design	353
11.5.2	Accuracy	355
11.5.3	Installation Effects	355
11.5.4	Applications, Advantages and Disadvantages	355
11.6	Other Proposed Designs	355
11.7	Chapter Conclusions	356
11.A	Vortex Shedding Frequency	358
11.A.1	Vortex Shedding from Cylinders	358
11.A.2	Order of Magnitude Calculation of Shedding Frequency	358
12	Electromagnetic Flowmeters	362
12.1	Introduction	362
12.2	Operating Principle	362
12.3	Limitations of the Theory	364
12.4	Design Details	366
12.4.1	Sensor or Primary Element	366
12.4.2	Transmitter or Secondary Element	370
12.5	Calibration and Operation	373
12.6	Industrial and Other Designs	374
12.7	Installation Constraints – Environmental	377
12.7.1	Surrounding Pipe	377
12.7.2	Temperature and Pressure	378

12.8	Installation Constraints – Flow Profile Caused by Upstream Pipework	379
12.8.1	Introduction	379
12.8.2	Theoretical Comparison of Meter Performance Due to Upstream Flow Distortion	379
12.8.3	Experimental Comparison of Meter Performance Due to Upstream Flow Distortion	380
12.8.4	Conclusions on Installation Requirements	381
12.9	Installation Constraints – Fluid Effects	382
12.9.1	Slurries	382
12.9.2	Change of Fluid	383
12.9.3	Non-Uniform Conductivity	383
12.10	Multiphase Flow	383
12.11	Accuracy Under Normal Operation	384
12.12	New Industrial Developments	385
12.13	Applications, Advantages and Disadvantages	387
12.13.1	Applications	387
12.13.2	Advantages	388
12.13.3	Disadvantages	389
12.14	Chapter Conclusions	389
12.A	Brief Review of Theory, Other Applications and Recent Research	390
12.A.1	Introduction	390
12.A.2	Electric Potential Theory	392
12.A.3	Development of the Weight Vector Theory	392
12.A.4	Rectilinear Weight Function	393
12.A.5	Axisymmetric Weight Function	394
12.A.6	Performance Prediction	395
12.A.7	Further Research	396
12.A.8	Verification	398
12.A.9	Application to Non-Conducting Dielectric Fluids	400
12.A.10	Electromagnetic Flowmeters Applied to Liquid Metals	403
13	Magnetic Resonance Flowmeters	408
13.1	Introduction and Some Early References	408
13.2	Developments in the Oil and Gas Industry	409
13.3	A Brief Introduction to the Physics	409
13.4	Outline of a Flowmeter Design	414
13.5	Chapter Conclusions	417
14	Ultrasonic Flowmeters	419
14.1	Introduction	419
14.2	Essential Background to Ultrasonics	420
14.3	Transit-Time Flowmeters	423
14.3.1	Transit-Time Flowmeters – Flowmeter Equation and the Measurement of Sound Speed	423

14.3.2	Effect of Flow Profile and Use of Multiple Paths	427
14.3.3	Transducers	432
14.3.4	Size Ranges and Limitations	437
14.3.5	Clamp-on Meters	437
14.3.6	Signal Processing and Transmission Timing	439
14.3.7	Reported Accuracy	442
	14.3.7.1 Reported Accuracy – Spool Piece Meters	442
	14.3.7.2 A Manufacturer's Accuracy Claims	443
	14.3.7.3 Clamp-on Accuracy	444
14.3.8	Installation Effects	447
	14.3.8.1 Effects of Distorted Profile by Upstream Fittings	447
	14.3.8.2 Pipe Roughness and Deposits	453
	14.3.8.3 Unsteady and Pulsating Flows	454
	14.3.8.4 Multiphase Flows	454
	14.3.8.5 Flow Straighteners and Conditioners	455
14.3.9	Other Experience of Transit-Time Meters	456
14.3.10	Experience with Liquid Meters	456
14.3.11	Gas Meter Developments	457
14.3.12	Applications, Advantages and Disadvantages of the Transit-Time and Related Designs	463
14.4	Doppler Flowmeter	466
	14.4.1 Simple Explanation of Operation	466
	14.4.2 Operational Information for the Doppler Flowmeter	468
	14.4.3 Applications, Advantages and Disadvantages for the Doppler Flowmeter	468
14.5	Correlation Flowmeter	469
	14.5.1 Operation of the Correlation Flowmeter	469
	14.5.2 Installation Effects for the Correlation Flowmeter	470
	14.5.3 Other Published Work on the Correlation Flowmeter	471
	14.5.4 Applications, Advantages and Disadvantages for the Correlation Flowmeter	472
14.6	Other Ultrasonic Applications	472
14.7	Conclusions on Ultrasonic Flowmeters	473
14.A	Mathematical Methods and Further Research Relating to Ultrasonic Flowmeters	474
	14.A.1 Simple Path Theory	474
	14.A.2 Use of Multiple Paths to Integrate Flow Profile	477
	14.A.3 Weight Vector Analysis	478
	14.A.4 Development of Modelling of the Flowmeter	479
	14.A.5 Doppler Theory and Developments	482
15	Acoustic and Sonar Flowmeters	484
15.1	Introduction	484
15.2	SONARtrac® Flowmeter	484

15.2.1	Basic Explanation of How the Passive Sonar Flowmeter Works	484
15.2.2	A Note on Turbulent Eddies and Transition to Laminar Flow in the Pipe	485
15.2.3	Flow Velocity Measurement	485
15.2.4	Speed of Sound and Gas Void Fraction (Entrained Air Bubbles) Measurement	486
15.2.5	Localised Velocity Measurements	487
15.2.6	The Convective Ridge	487
15.2.7	Calibration	489
15.2.8	Sound Speed Used to Obtain Fluid Parameters	490
15.2.9	Additional Sensors	491
15.2.10	Clamp-on System	491
15.2.11	Liquid, Gas and Multicomponent Operation	492
15.2.12	Size Range and Flow Range	493
15.2.13	Signal Handling	493
15.2.14	Accuracy Claims	494
15.2.15	Installation Effects	494
15.2.16	Published Information	496
15.2.17	Applications	496
15.3	ActiveSONAR™ Flowmeter	496
15.3.1	Single and Multiphase Flows	497
15.3.2	Brief Summary of Meter Range, Size etc.	497
15.4	Other Related Methods Using Noise Emissions	498
15.5	Chapter Conclusions	500
16	Mass Flow Measurement Using Multiple Sensors for Single-Phase Flows	501
16.1	Introduction	501
16.2	Multiple Differential Pressure Meters	502
16.2.1	Hydraulic Wheatstone Bridge Method	504
16.2.2	Theory of Operation	504
16.2.3	Industrial Experience	505
16.2.4	Applications	505
16.3	Multiple Sensor Methods	506
16.4	Chapter Conclusions	507
17	Multiphase Flowmeters	508
17.1	Introduction	508
17.2	Multiphase and Multi-Component Flows	509
17.3	Two-Phase/Component Flow Measurements	509
17.3.1	Liquid/Liquid Flows and Water-Cut Measurement	510
17.3.2	Entrained Solid in Fluid Flows	510
17.3.3	Metering Wet-Gas	511

17.4	Multiphase Flowmeters	514
17.4.1	Categorisation of Multiphase Flowmeters	514
17.4.2	Multiphase Flowmeters (MPFMs) for Oil Production	515
17.4.3	Developments and References Since the Late 1990s	519
17.5	Accuracy	527
17.6	Chapter Conclusions	528
18	Thermal Flowmeters	530
18.1	Introduction	530
18.2	Capillary Thermal Mass Flowmeter – Gases	530
18.2.1	Description of Operation	531
18.2.2	Operating Ranges and Materials for Industrial Designs	534
18.2.3	Accuracy	535
18.2.4	Response Time	535
18.2.5	Installation	535
18.2.6	Applications	536
18.3	Calibration of Very Low Flow Rates	536
18.4	Thermal Mass Flowmeter – Liquids	537
18.4.1	Operation	537
18.4.2	Typical Operating Ranges and Materials for Industrial Designs	538
18.4.3	Installation	538
18.4.4	Applications	538
18.5	Insertion and In-Line Thermal Mass Flowmeters	538
18.5.1	Insertion Thermal Mass Flowmeter	540
18.5.2	In-Line Thermal Mass Flowmeter	541
18.5.3	Range and Accuracy	542
18.5.4	Materials	542
18.5.5	Installation	542
18.5.6	Applications	543
18.6	Chapter Conclusions	544
18.A	Mathematical Background to the Thermal Mass Flowmeters	545
18.A.1	Dimensional Analysis Applied to Heat Transfer	545
18.A.2	Basic Theory of ITMFs	546
18.A.3	General Vector Equation	548
18.A.4	Hastings Flowmeter Theory	549
18.A.5	Weight Vector Theory for Thermal Flowmeters	551
18.A.6	Other Recently Published Work	552
19	Angular Momentum Devices	553
19.1	Introduction	553
19.2	The Fuel Flow Transmitter	554
19.2.1	Qualitative Description of Operation	554
19.2.2	Simple Theory	557

19.2.3	Calibration Adjustment	558
19.2.4	Meter Performance and Range	558
19.2.5	Application	559
19.3	Chapter Conclusions	559
20	Coriolis Flowmeters	560
20.1	Introduction	560
20.1.1	Background	560
20.1.2	Qualitative Description of Operation	563
20.1.3	Experimental and Theoretical Investigations	564
20.1.4	Shell-Type Coriolis Flowmeter	566
20.2	Industrial Designs	566
20.2.1	Principal Design Components	569
20.2.2	Materials	572
20.2.3	Installation Constraints	574
20.2.4	Vibration Sensitivity	576
20.2.5	Size and Flow Ranges	577
20.2.6	Density Range and Accuracy	578
20.2.7	Pressure Loss	578
20.2.8	Response Time	579
20.2.9	Zero Drift	580
20.3	Accuracy Under Normal Operation	581
20.4	Published Information on Performance	582
20.4.1	Early Industrial Experience	583
20.4.2	Gas-Liquid	583
20.4.3	Sand in Water (Dominick et al. 1987)	584
20.4.4	Pulverised Coal in Nitrogen (Baucom 1979)	584
20.4.5	Water-in-Oil Measurement	584
20.4.6	Two- and Three-Component Flows	585
20.5	Calibration	585
20.6	Applications, Advantages, Disadvantages, Cost Considerations	587
20.6.1	Applications	587
20.6.2	Advantages	589
20.6.3	Disadvantages	590
20.6.4	Cost Considerations	591
20.7	Chapter Conclusions	591
20.A	Notes on the Theory of Coriolis Meters	593
20.A.1	Simple Theory	593
20.A.2	Note on Hemp's Weight Vector Theory	595
20.A.3	Theoretical Developments	597
20.A.4	Coriolis Flowmeter Reviews	601
21	Probes for Local Velocity Measurement in Liquids and Gases	603
21.1	Introduction	603
21.2	Differential Pressure Probes – Pitot Probes	604

21.3	Differential Pressure Probes – Pitot-Venturi Probes	607
21.4	Insertion Target Meter	608
21.5	Insertion Turbine Meter	609
21.5.1	General Description of Industrial Design	609
21.5.2	Flow-Induced Oscillation and Pulsating Flow	611
21.5.3	Applications	612
21.6	Insertion Vortex Probes	612
21.7	Insertion Electromagnetic Probes	614
21.8	Insertion Ultrasonic Probes	615
21.9	Thermal Probes	616
21.10	Chapter Conclusions	616
22	Verification and In Situ Methods for Checking Calibration	617
22.1	Introduction	617
22.2	Verification	617
22.3	Non-Invasive, Non-Intrusive and Clamp-On Flowmeter Alternatives	620
22.3.1	Use of Existing Pipe Work	620
22.3.2	Other Effects: Neural Networks, Tracers, Cross-Correlation	622
22.3.3	Other Flowmeter Types in Current Use	622
22.4	Probes and Tracers	623
22.5	Microwaves	624
22.6	Chapter Conclusions	624
23	Remote Data Access Systems	625
23.1	Introduction	625
23.2	Types of Device – Simple and Intelligent	626
23.3	Simple Signal Types	627
23.4	Intelligent Signals	629
23.5	Selection of Signal Type	630
23.6	Communication Systems	630
23.7	Remote Access	630
23.8	Future Implications	631
24	Final Considerations	633
24.1	Is there an Opportunity to Develop New Designs in Collaboration with the Science Base?	633
24.2	Is Manufacture of High Enough Quality?	633
24.3	Does the Company's Business Fall within ISO 9000 and/or ISO 17025?	636
24.4	What are the New Flow Measurement Challenges?	637
24.5	What Developments Should We Expect in Micro-Engineering Devices?	638

<i>Contents</i>	xxi
24.6 Which Techniques for Existing and New Flow Metering Concepts Should Aid Developments?	639
24.7 Closing Remarks	641
<i>References</i>	643
<i>Main Index</i>	735
<i>Flowmeter Index</i>	739
<i>Flowmeter Application Index</i>	743

