

Contents

Introduction	XIX
List of Contributors	XXV

I	Methodologies and Instrumentation	1
1	Theoretical Aspects of Flow Analysis	3
	<i>Fernando A. Iñón and Mabel B. Tudino</i>	
1.1	Introduction	3
1.2	Classification of Flow Systems. Fundamentals	4
1.2.1	Continuous Flow Analysis	4
1.2.2	Flow Injection Analysis	4
1.2.3	Sequential Injection Analysis	4
1.2.4	Multicommutation in Flow Injection Analysis	5
1.2.5	Stopped Flow	6
1.2.6	Batch Flow Injection Analysis (BFA)	6
1.3	Dispersion in Flow Injection Analysis: From the Movement of Fluids in Open Tubes to Controlled Dispersion	7
1.3.1	Transport of Fluids	7
1.3.1.1	Viscosity	7
1.3.1.2	Thermal Conductivity	8
1.3.1.3	Diffusivity	8
1.3.1.4	Diffusion	8
1.3.2	The Diffusion–Convection Equation in Open Conduits	9
1.3.3	The Distribution of Times of Residence	10
1.3.3.1	Characterization and Experimental Domain of Flow Systems: Dimensionless Numbers and Their Meaning	11
1.3.4	From the RTD Curve to the Generation of Signals in Flow Injection Systems	12
1.3.4.1	The Dispersion Process	12
1.3.4.2	The Concept of Controlled Dispersion and Analytical Implications	13
1.3.4.3	The Transient Profile	14

1.4	The Measurement of Dispersion	15
1.4.1	The Coefficient “D”	16
1.4.2	Peak Width and Time of Appearance	17
1.4.3	Peak Variance and Theoretical Plate Height	18
1.4.4	Degree and Intensity of Axial Dispersion	19
1.4.4.1	Degree of Axial Dispersion	19
1.4.4.2	Intensity of the Radial Dispersion	20
1.4.5	Other Approaches to the Measurement of Dispersion	21
1.5	Contribution of the Different Components of a Flow System to Dispersion	21
1.5.1	Injection	23
1.5.2	Detection	24
1.5.3	Transport: Different Models	25
1.5.3.1	Descriptive Models or “Black Boxes”	25
1.5.3.2	Deterministic Models: Dispersive Models and Tank-in-Series Model	25
1.5.4	Probabilistic Models	28
1.5.4.1	Random Walk	28
1.6	Design Equations	29
1.6.1	Influence of the Different System Variables	29
1.6.1.1	Reactor Length	29
1.6.1.2	Geometric Configuration	29
1.6.1.3	Flow Rate	30
1.6.1.4	Tube Radius	32
1.6.1.5	Injection Volume	32
1.6.2	Optimization of Flow Systems	34
1.7	Concluding Remarks	38
	References	39
2	Injection Techniques in Flow Analysis	43
	<i>Víctor Cerdà and José Manuel Estela</i>	
2.1	Introduction	43
2.2	Continuous Flow Analysis (CFA)	44
2.3	Segmented Flow Analysis (SFA)	45
2.4	Flow Injection Analysis (FIA)	46
2.4.1	Syringe-based Injection	46
2.4.2	Injection with Rotary Valves	47
2.4.3	Proportional Injection	48
2.4.4	Merged Injection	48
2.4.5	Injection Following a Prior Flow Sample Processing	49
2.4.5.1	Multiparametric Determination	49
2.4.5.2	Dialysis	50
2.4.5.3	Gas Diffusion	50
2.4.5.4	Pervaporation	52
2.4.6	Hydrodynamic Injection	53
2.5	Sequential Injection Analysis (SIA)	53

2.5.1	Original Procedures	53
2.5.2	Conventional Injection	54
2.5.3	Controlled Variable Volume Injection	54
2.5.4	Cumulative Injection	55
2.5.5	The Sandwich Technique	55
2.5.6	Multiparametric Analysis	57
2.5.7	Gas Diffusion	57
2.5.8	Dialysis	59
2.5.9	Mixing Chamber-Based Injection	60
2.5.10	Bead Injection	60
2.5.11	Hydrodynamic Injection	61
2.6	Multicommutated Flow Injection Analysis (MCFIA)	61
2.6.1	Time-based Injection	61
2.6.2	Tandem Streams	62
2.7	Multisyringe Flow Injection Analysis (MSFIA)	63
2.7.1	Injection with Rotary Valves	64
2.7.2	Time-based Injection	65
2.7.3	Controlled Variable Volume Injection	66
2.7.4	Synchronous Injection with Two Valves	66
2.7.5	Synchronous Injection	67
2.7.6	Injection with a Dual Module	68
2.7.7	Bead Injection	69
2.8	Multipumping Flow Systems (MPFS)	69
2.8.1	Pulse-based Injection	70
2.8.2	Merged Injection	70
2.9	Combined Injection Methods	70
2.9.1	Dual Sequential Injection Analysis	71
2.9.2	Sequential Injection-multisyringe Flow Injection Systems	71
2.9.3	Multisyringe Flow Injection-multipumping Flow Systems	72
2.10	Concluding Remarks	73
	References	74
3	Application of Moveable Suspensions of Solid Particles in Flow Analysis	79
	<i>Marek Trojanowicz</i>	
3.1	Introduction	79
3.2	Solid Microparticles Used in Suspensions in Flow Analysis	81
3.3	Handling Suspensions of Particles in Flow Systems	82
3.4	Detection Methods Employed in Flow Systems with Particle Suspensions	86
3.5	Renewable Columns in Flow Systems	91
3.6	Microfluidics with Processing of Particle Suspensions	94
3.7	Nanoparticles in Flow Systems	98
3.8	Conclusions	100
	References	101

4	Batch Injection Analysis	107
	<i>Christopher M.A. Brett</i>	
4.1	Introduction	107
4.2	Theory of Batch Injection Analysis	108
4.3	Experimental Aspects – Cell Design and Detection Strategies	110
4.4	Applications of Batch Injection Analysis	114
4.4.1	Stripping Voltammetry of Trace Metal Ions and Applications in Environmental Monitoring	115
4.4.2	Other BIA Environmental Monitoring Applications	116
4.4.3	Analysis of Foodstuffs, Pharmaceuticals and Clinical Analysis	117
4.4.4	Capillary Batch Injection Analysis	119
4.4.5	Non-Electrochemical Methodologies and Detection Strategies	119
4.5	Comparison of BIA with Flow Injection Techniques	120
4.6	Future Perspectives	121
	References	121
5	Electroosmosis-Driven Flow Analysis	127
	<i>Petr Kubáň, Shaorong Liu, and Purnendu K. Dasgupta</i>	
5.1	Introduction	127
5.2	Pumping Systems	128
5.2.1	Pressure Pumping Systems	128
5.2.2	Electroosmosis-Driven Pumping Systems	129
5.2.2.1	Theoretical Considerations	129
5.2.2.2	Theoretical Considerations for an EOF-Induced Pumping System	130
5.3	EOF Pumping Systems	133
5.3.1	EOF Pumping Without Electric Isolation	133
5.3.2	Electrically Isolated EOF Pumps	136
5.3.2.1	Open Tubular Electrically Isolated EOF Pumps	136
5.3.2.2	Microchannel-based Electrically Isolated EOF Pumps	138
5.3.2.3	Electrically Isolated EOF Pumps Based on Packed Columns	139
5.3.2.4	Electrically Isolated EOF Pumps Based on Porous Media and Monoliths	141
5.4	EOF Injection Methods Utilized in FIA, SIA and Micro Total Analysis Systems (μ -TAS)	142
5.5	Applications of EOF-Driven Pumping in Flow Analysis	143
5.6	Future Prospects	145
	References	145
6	Flow Analysis in Microfluidic Devices	149
	<i>Manabu Tokeshi and Takehiko Kitamori</i>	
6.1	Introduction	149
6.2	Continuous Flow Chemical Processing in Microfluidic Devices	149
6.2.1	Integration of Heavy Metal Analysis System	149
6.2.2	Integration of Multi-Ion Sensing System	152
6.2.3	Integration of a Bioassay System	155

6.2.4	Real-time Monitoring of a Chemical Reaction	157
6.3	Flow Injection Analysis in Microfluidic Devices	159
6.3.1	Flow Injection Analysis System: On-Chip PDMS Valve	159
6.3.2	Flow Injection Analysis System: Chip-based Slide Valve	160
6.3.3	Flow Injection Analysis System: Immunoassay	162
6.4	Perspectives	163
	References	165
7	The Concept of Multi-commutation in Flow Analysis	167
	<i>Mário A. Feres, Elias A.G. Zagatto, João L.M. Santos, and José L.F.C. Lima</i>	
7.1	Introduction	167
7.2	Concepts	169
7.3	The Discretely Operated Devices	171
7.3.1	Passively Operated Devices	171
7.3.2	Actively Operated Devices	172
7.4	System Design	172
7.5	Tandem Streams	174
7.6	Processes Involving Multi-Commutation	175
7.6.1	Sample Introduction	175
7.6.2	Sample Dispersion	176
7.6.3	Solution Additions to the Sample	178
7.6.4	Sample Incubation	178
7.6.5	Analyte Separation/Concentration	179
7.7	Applications	180
7.7.1	Selection Criteria	180
7.7.2	Selected Applications	180
7.8	Conclusions	181
7.9	Trends	181
	References	192
8	Advanced Calibration Methods in Flow Injection Analysis	203
	<i>Paweł Kościelniak</i>	
8.1	Introduction	203
8.2	Advanced Calibration Procedures	205
8.2.1	Preparation Stage	205
8.2.2	Reconstruction Stage	208
8.2.3	Transformation Stage	211
8.2.4	Critical View	212
8.3	Advanced Calibration Concepts	214
8.3.1	Integrated Calibration	214
8.3.2	Gradient Dilution Calibration	216
8.3.3	Reaction-based Calibration	217
8.3.4	Multi-Component FIA Calibration	218
8.4	Trends and Perspectives	219
	References	221

9	Multicomponent Flow Injection Analysis	227
	<i>Javier Saurina</i>	
9.1	Introduction	227
9.2	Principal Strategies for Multicomponent Analysis	229
9.2.1	Optimization of FI Multicomponent Methods	229
9.2.1.1	Types of Objective Functions in Optimization	230
9.2.1.2	Univariate versus Multivariate Optimization	231
9.2.1.3	A Practical Case	232
9.2.2	Reagents	234
9.2.3	Manifolds for Multicomponent Determinations	239
9.2.3.1	Sequential Configurations	240
9.2.3.2	Parallel Configurations	241
9.2.3.3	Serial Configurations	242
9.2.4	Detectors	242
9.2.5	Chemometric Techniques for Data Analysis	245
9.2.5.1	Data Sets from Flow Systems	245
9.2.5.2	Calibration Methods Applied to Flow Data	247
9.2.5.3	A Practical Example of Second-Order Calibration	252
9.3	Trends and Perspectives	254
	References	256
10	Flow Processing Devices Coupled to Discrete Sample Introduction Instruments	265
	<i>M. Valcárcel, S. Cárdenas, B.M. Simonet, and R. Lucena</i>	
10.1	Introduction: The Problem of Sample Treatment	265
10.2	Roles of Flow Processing Devices	265
10.3	Ways of Coupling Flow Processing Devices to Discrete Sample Introduction Instruments	266
10.4	Coupling Flow Processing Devices to Gas Chromatographs	267
10.4.1	Interfaces and Types of Coupling	267
10.4.2	Analytical Uses	268
10.4.3	Critical Discussion	270
10.5	Coupling Flow Processing Devices to Liquid Chromatographs	271
10.5.1	Interfaces and Types of Coupling	271
10.5.2	Analytical Uses	274
10.5.3	Critical Discussion	274
10.6	Coupling Flow Processing Devices to Capillary Electrophoresis Equipment	274
10.6.1	Interfaces and Types of Coupling	275
10.6.2	Analytical Uses	280
10.6.3	Critical Discussion	281
10.7	Future Prospects	283
	References	283

11	On-line Sample Processing Methods in Flow Analysis	291
	<i>Manuel Miró and Elo Harald Hansen</i>	
11.1	Introduction	291
11.2	On-line Sample Pretreatment Protocols for Aqueous and Air Samples	292
11.2.1	On-line Dilution	292
11.2.2	Derivatization Reactions	293
11.2.3	Solvent Extraction	294
11.2.4	Sorbent Extraction	297
11.2.5	Precipitation/Co-Precipitation	300
11.2.6	Gas–Liquid Separation	301
11.2.7	Membrane-based Separation	302
11.2.7.1	Gas Diffusion	302
11.2.7.2	Dialysis	304
11.2.7.3	Pervaporation	305
11.2.8	Digestion Protocols	305
11.3	On-line Processing of Solid Samples: Leaching/Extraction Methods	306
11.4	Trends and Perspectives	307
	References	311
12	Flow Analysis and the Internet – Databases, Instrumentation, and Resources	321
	<i>Stuart J. Chalk</i>	
12.1	Introduction	321
12.2	Databases	321
12.2.1	Dr. Elo Hansen’s Flow Bibliography	322
12.2.2	Google Scholar Beta	322
12.2.3	The Flow Analysis Database	323
12.3	Journals	323
12.3.1	Analytica Chimica Acta (Elsevier)	326
12.3.2	Talanta (Elsevier)	326
12.3.3	Analytical Chemistry (American Chemical Society – ACS)	327
12.3.4	The Analyst (Royal Society of Chemistry – RSC)	327
12.3.5	Journal of Flow Injection Analysis (Japanese Association of Flow Injection Analysis)	327
12.3.6	Journal of Automatic Methods and Management in Chemistry (Hindawi)	327
12.3.7	Analytical and Bioanalytical Chemistry (Springer)	327
12.3.8	Analytical Sciences (Japanese Society for Analytical Chemistry)	328
12.3.9	Analytical Letters (Taylor and Francis)	328
12.3.10	Journal of Chromatography A (Elsevier)	328
12.3.11	Electroanalysis (Wiley)	328
12.3.12	Journal of Analytical Atomic Spectrometry (RSC)	328
12.3.13	Fenxi Huaxue (Wanfang Data)	329

12.3.14	Bunseki Kagaku (Japanese Society for Analytical Chemistry)	329
12.3.15	Clinical Chemistry (American Association for Clinical Chemistry)	329
12.4	Instrumentation	330
12.5	Standard Methods	330
12.5.1	International Standards Organization	330
12.5.2	US Environmental Protection Agency	332
12.5.3	American Society for Testing and Materials	334
12.5.4	APHA/AWWA/WEF Standard Methods	334
12.5.5	US Geological Survey Standard Methods	336
12.6	Other Useful Websites	337
12.6.1	Tutorials	337
12.6.2	Books (Chronological Order)	337
12.6.3	Webpages of Prominent Researchers (Alphabetical)	338
12.6.4	Other	339
12.7	Future Directions	339
12.7.1	The Semantic Web	339
12.7.2	Extensible Markup Language (XML)	340
	References	341

II Advances in Detection Methods in Flow Analysis 343

13 Luminescence Detection in Flow Analysis 345

Antonio Molina-Díaz and Juan Francisco García-Reyes

13.1	Introduction	345
13.2	Luminescence Detection in Continuous Flow Systems	346
13.2.1	Fluorescence	346
13.2.1.1	Introduction	346
13.2.1.2	Fluorescence Detection in Flow Methods	347
13.2.2	Phosphorescence	355
13.2.2.1	Introduction	355
13.2.2.2	Room Temperature Phosphorescence in Ordered Media	356
13.2.2.3	Non-Protected Room Temperature Phosphorescence	356
13.2.3	Chemiluminescence	357
13.2.3.1	Introduction	357
13.2.3.2	CL Flow Methods	359
13.2.3.3	Bioluminescence	365
13.2.4	Solid-phase Luminescence Based Detection in Flowing Streams	366
13.2.4.1	Solid-phase Fluorescence Detection	366
13.2.4.2	RTP-Based Optosensing	371
13.2.4.3	Solid-phase Chemiluminescence Detection	372
13.3	Recent Trends and Perspectives	374
13.3.1	Miniaturization	374
13.3.2	Molecularly Imprinted Materials	375
13.3.3	Quantum Dots	375
	References	377

14	Enzymes in Flow Injection Analysis	395
	<i>Robert Koncki, Łukasz Tymecki, and Beata Rozum</i>	
14.1	Introduction	395
14.2	Enzyme Substrates as Analytes	396
14.2.1	Biosensor-based FIA Systems	397
14.2.2	Bioreactor-based FIA Systems	403
14.2.3	Additional Benefits Offered by FIA	403
14.2.4	Analytical Applications. FIA Systems as Monitors	411
14.3	Methods Based on Enzyme Activity Measurements	412
14.3.1	Enzyme Activity Detection	413
14.3.2	Enzyme Inhibitor Detection	415
14.3.3	Enzyme Cofactor Detection	416
14.4	Conclusions	416
	References	417
15	Flow Potentiometry	425
	<i>M. Conceição B.S.M. Montenegro and Alberto N. Araújo</i>	
15.1	Introduction	425
15.2	Background Concepts	425
15.3	Electrode Developments and Detector Cell Designs	428
15.4	Flow Analytical Techniques Based on Potentiometry	436
15.5	Trends and Future Prospects	443
	References	443
16	Flow Voltammetry	455
	<i>Ivano G.R. Gutz, Lúcio Angnes, and Andrea Cavicchioli</i>	
16.1	Introduction	455
16.2	Voltammetric/Amperometric Flow Analysis	456
16.2.1	Principles and Techniques	456
16.2.2	Electrode Materials	460
16.2.3	Commercial Flow Cells	461
16.2.4	Adaptors for Commercial Batch Cells	463
16.2.5	Specially Designed Flow Cells and Systems	465
16.3	Strategies for Improving Selectivity, Sensitivity, and Durability	467
16.3.1	Preconcentration	467
16.3.2	Medium Exchange	468
16.3.3	Oxygen Removal	469
16.3.4	Catalytic Electrode Processes	469
16.3.5	Spectroelectrochemistry	470
16.3.6	Modified Electrodes	471
16.4	Trends and Perspectives	472
	References	473

17	Affinity Interaction Profiling of Protein–Protein and Protein–Ligand Interactions Using Flow Analysis	483
	<i>J. Kool, N.P.E. Vermeulen, H. Lingeman, R.J.E. Derks, and H. Irth</i>	
17.1	Introduction	483
17.2	Profiling of Noncovalent Protein–Protein and Protein–Ligand Interactions Based on Mass Spectrometry Flow Analysis	485
17.2.1	Flow Injection and Continuous Infusion Mass Spectrometry of Noncovalent Complexes Using Electrospray Ionization	485
17.2.1.1	Introduction	485
17.2.1.2	Electrospray Ionization Mass Spectrometry of Noncovalent Complexes	485
17.2.1.3	Limitations of Electrospray Ionization Mass Spectrometry for the Study of Noncovalent Complexes	486
17.2.2	Flow Injection Mass Spectrometry Assays Using Reporter Molecules	487
17.2.2.1	Introduction	487
17.2.2.2	Requirements for Mass Spectrometry-Based Biochemical Assays	488
17.2.2.3	Flow Injection Ligand-Binding Assays Using Mass Spectrometry as Readout	488
17.2.2.4	Flow Injection Enzyme Assays Using Mass Spectrometry as Readout	488
17.2.3	Reporter-Free Assays after Dissociation of Protein–Ligand Complexes	489
17.3	Integration of Flow Analysis and High-Performance Liquid Chromatography for the Bioaffinity Screening of Mixtures	490
17.3.1	Introduction	490
17.3.2	On-line Coupling of Flow Biochemical Assays to HPLC	491
17.3.2.1	General Principles	492
17.3.2.2	On-line Ligand-Binding Flow Assays Coupled to HPLC	493
17.3.2.3	On-line Enzyme Flow Assays Coupled to HPLC	498
17.4	Conclusions	502
	References	503
18	Atomic Spectroscopy in Flow Analysis	511
	<i>José L. Burguera and Marcela Burguera</i>	
18.1	Introduction	511
18.2	Flame Atomic Absorption Spectrometry	512
18.2.1	Preconcentration/Separation Systems Using FAAS Detection	512
18.2.1.1	Chemical Vapor Generation	512
18.2.1.2	Preconcentration of Trace Elements by Solid-phase Extraction	514
18.2.1.3	Other Preconcentration Systems for FAAS Detection	514
18.2.1.4	Indirect Determinations	519
18.3	Sample Dilution	519
18.4	Electrothermal Atomic Absorption Spectrometry	520

18.4.1	Analyte Preconcentration for ET AAS Detection	520
18.4.1.1	Precipitation or Coprecipitation/Dissolution Reactions	520
18.4.1.2	Sorption on Columns	521
18.4.1.3	Solvent Extraction	523
18.4.2	Analyte Separation Prior to ET AAS Detection	524
18.4.3	Miscellaneous	526
18.5	Atomic Fluorescence Spectrometry	527
18.5.1	Preconcentration of the Analyte for AFS Detection	527
18.5.2	Hyphenated Techniques for Speciation Studies with AFS Detection	529
18.6	Conclusions and Further Developments	531
	References	532
19	Flow Injection Mass Spectrometry	545
	<i>Maria Fernanda Giné</i>	
19.1	Introduction	545
19.1.1	The Role and Importance of Flow Injection Analysis Mass Spectrometry	545
19.1.2	Mass Spectrometry	545
19.1.2.1	Quadrupole Mass Spectrometers (QMS)	547
19.1.2.2	Sector Field Mass Spectrometers	547
19.1.2.3	Multicollector Mass Spectrometer	548
19.1.2.4	Time of Flight Mass Spectrometers (TOFMS)	549
19.2	FIA-MS Sample Introduction Devices	550
19.2.1	Transient Sample Introduction into the MS Ionization Chamber	551
19.2.2	FI Sample Introduction to External Ionization Sources – MS	553
19.3	Flow Systems Coupled to External Ionization Sources – MS	553
19.3.1	FIA-ICP-MS	553
19.3.1.1	The ICP Source	554
19.3.1.2	FIA-ICP-MS for Reducing Matrix Effects	555
19.3.1.3	FIA Systems to Perform Isotope Dilution (ID)	556
19.3.1.4	FIA Applications of ID-ICP-MS	560
19.3.1.5	FIA Coupled with Hyphenated Techniques to ICP-MS	561
19.3.2	FIA-Thermospray MS	563
19.3.3	Electrospray Ionization (ESI – MS)	564
19.3.3.1	Electrospray Ionization	564
19.3.3.2	FIA-ESI-MS	564
19.4	Conclusions	566
	References	566
III	Applications	575
20	Environmental Applications of Flow Analysis	577
	<i>Shoji Motomizu</i>	
20.1	Introduction	577

20.2	Analysis of the Aquatic Environment by Flow Methods	577
20.2.1	Substances Related to Eutrophication	577
20.2.1.1	Nitrogen Compounds	578
20.2.1.2	Phosphorus Compounds	582
20.2.2	Organic Compounds Related to Water Pollution	584
20.2.2.1	Surfactants	584
20.2.2.2	Chemical Oxygen Demand (COD)	585
20.2.3	Organic Compounds Related to Toxic/Hazardous Problems	586
20.2.4	Metals and Metal Compounds Related to Water Pollution and Toxic/Hazardous Problems	587
20.2.4.1	Spectroscopic Detection	587
20.2.4.2	Other Detection Methods	590
20.3	Analysis of an Atmospheric Environment by Flow Methods	590
20.3.1	Denuder (DN) and Gas Diffusion Scrubber (GDS)	590
20.3.2	Chromatomembrane Cell (CMC)	591
20.3.3	Simple Batchwise Collection/Concentration Method for Substances in Air	593
20.4	Analysis of the Geosphere Environment by Flow Methods	594
20.5	Future of Environmental Analysis	595
	References	596
21	Flow Methods in Pharmaceutical Analysis	601
	<i>J. Martínez Calatayud and J.R. Albert-García</i>	
21.1	Introduction	601
21.2	Analysis of Pharmaceutical Formulations	602
21.2.1	Spectrophotometry (UV-vis and IR). Homogeneous Systems	602
21.2.1.1	Applications of Flow-Based Molecular Absorption Spectrophotometry to the Determination of Drugs	602
21.2.1.2	UV-vis Heterogeneous Systems (Turbidimetry, Solid-Liquid and Liquid-Liquid)	606
21.2.1.3	Infrared Absorption	607
21.2.1.4	Flame Atomic Absorption Spectrometry	608
21.2.1.5	Liquid-Liquid (Extraction) Systems Involving the Formation of Ion-Pairs or Neutral Chelates with the Analyte	609
21.2.2	Luminescence	610
21.2.2.1	Flow-Fluorimetry in Drug Analysis	611
21.2.2.2	Phosphorimetry	614
21.2.2.3	Chemiluminescence	614
21.2.3	Electrochemistry	619
21.2.3.1	Conductimetry	619
21.2.3.2	Potentiometry	619
21.2.3.3	Polarography	621
21.2.3.4	Amperometry	622
21.2.3.5	Continuous Flow Voltammetry	624
21.2.3.6	Continuous Flow Amperometry	625

21.3	Flow Process Analyzers in the Pharmaceutical Industry	626
21.3.1	Process Analysis in Pharmaceutical Production	626
21.3.2	Automated Drug Dissolution and Drug Release Testing	628
21.3.3	Membrane Diffusion	631
21.3.4	Functional Cellular Assays for Screening Potential Drugs	633
	References	635

22 Industrial and Environmental Applications of Continuous Flow Analysis 639

Kees Hollaar and Bram Neele

22.1	Introduction	639
22.2	Overview of Environmental and Industrial Fields	640
22.2.1	Environmental Applications	640
22.2.2	Plant and Soil Applications	641
22.2.3	Pharmaceutical Applications	642
22.2.4	Beer and Wine Applications	643
22.2.5	Tobacco Applications	644
22.2.6	Food Applications	645
22.3	Applications and Their Ranges	645
22.3.1	Total Nitrogen	647
22.3.2	Total Phosphate	649
22.3.3	Cyanides	650
22.3.3.1	Total Cyanide	651
22.3.3.2	Free Cyanide	651
22.3.4	Phenol Index	651
22.3.5	Total Reducing Sugars	653
22.3.6	Bitterness	656
22.4	Development of Flow Analysis Applications	658
22.5	Trends in Continuous Flow Analysis	659
	References	661

Index 663

