Contents

	Contributor contact details Woodhead Publishing Series in Energy	xviii xliii
	Foreword	xlvii
Part I	Overview of Process Integration and Analysis	1
1	Process Integration (PI): An Introduction Jiři Jaromir Klemeš, University of Pannonia, Veszprém, Hungary	3
1.1	Introduction	3
1.2	A Short History of Process Integration (PI)	7
1.3	Current Centres of Expertise in PI	12
1.4	Sources of Further Information	21
1.5	References	22
2	Basic Process IntegrationTerminology Petar Sabev Varbanov, University of Pannonia, Veszprém, Hungary	28
2.1	Introduction	28
2.2	Process Integration Terms: The Importance of Context	29
2.3	Fundamental Process Integration Terms	30
2.4	Conventions: Symbols for Heaters and Coolers	74
2.5	References	75
2.6	Appendix: Nomenclature	76
3	Process Design, Integration and Optimisation: Advantages, Challenges and Drivers VASILE LAVRIC, University 'Politehnica' of Bucharest, Romania	79
3.1	Introduction	79
3.2	Grassroots Design versus Retrofit Design	84

vi	Contents	
3.3	Process Integration	90
3.4	Integration versus Intensification	97
3.5	Process Integration Techniques	98
3.6	Optimisation of Integrated Processes	102
3.7	Controllability of Integrated Processes	106
3.8	Process Integration under Disturbances	112
3.9	References	113
Part II	Heat Integration	127
4	Heat Integration: Targets and Heat Exchanger Network Design	129
	Truls Gundersen, Norwegian University of Science and Technology, Trondheim, Norway	120
4.1	Introduction	129
4.2	Stages in the Design of Heat Recovery Systems	132
4.3	Data Extraction	134
4.4	Performance Targets	138
4.5	Process Modifications	146
4.6	Network Design	153
4.7	Design Evolution	159
4.8	Conclusion	165
4.9	Sources of Further Information	166
4.10	References	166
5	Application of Process Integration to the Synthesis of Heat and Power (CHP) and Industrial Heat Pumps	168
	Heat and Power (CHP) and Industrial Heat Pumps Thore Berntsson, Simon Harvey and Matteo Morandin, Chalmers University of Technology, Gothenburg, Sweden	100
5.1	Introduction	168
5.2	Targeting Utility Loads and Temperature Levels	169
5.3	Integration of Advanced Energy Conversion Cycles as	
	Process Utilities: Basic Concepts	176
5.4	Process Integration of Heat Engines	181
5.5	Process Integration of Heat Pumps	190
5.6	Sources of Further Information and Advice	196
5.7	References	198

	Contents	vi
6	Total Site Methodology	20°
	SIMON PERRY, The University of Manchester, UK	
6.1	Introduction	201
6.2	Data Extraction for Total Sites	203
6.3	Total Site Profiles and Total Site Composite Curves	212
6.4	Site Utility Grand Composite Curve (SUGCC)	219
6.5	Conclusion	222
6.6	Sources of Further Information	223
6.7	References	224
7	Extending Total Site Methodology to Address Varying	
	Energy Supply and Demand	226
	Petar Sabev Varbanov, University of Pannonia, Veszprém	
	Hungary	
7.1	Introduction	226
7.2	Characteristics of Energy Supply and Demand	228
7.3	Thermal Energy Storage and Integrated Architecture	232
7.4	Terminology for Process Streams and Utilities	235
7.5	Identification of Time Slices	236
7.6	Heat Cascades for the Evaluation of Total Site Targets	
	When There Is Variation in Supply and Demand	239
7.7	Case Study: Integration of Solar Thermal Energy into a	
	Locally Integrated Energy Sector (LIES)	250
7.8	Conclusion	256
7.9	Sources of Further Information	256
7.10	References	258
7.11	Appendix: Nomenclature	260
8	Analysis and Design of Heat Recovery Systems for	
	Grassroots and Retrofit Situations	262
	Trues Gundersen, Norwegian University of Science and	
	Technology, Trondheim, Norway	
8.1	Introduction	262
8.2	Extended Procedures for Grassroots Analysis	264
8.3	Extended Procedures for Grassroots Design	273
8.4	Retrofit Analysis and Design	281
8.5	Use of Optimisation for Heat Exchanger Network	
	Synthesis	295

viii	Contents	
8.6	Conclusion	303
8.7	Sources of Further Information	304
8.8	References	306
9	Heat Integration in Batch Processes Thokozani Majozi, University of Pretoria, South Africa and Council for Scientific and Industrial Research, South Africa	310
9.1	Introduction	310
9.2	Graphical Technique for Heat Integration in Batch Process	313
9.3	Mathematical Technique for Heat Integration of Batch	224
0.4	Plants Constitution of a Multipurpose Batch Facility	324 335
9.4	Case Study of a Multipurpose Batch Facility	339 339
9.5	Industrial Case Study Conclusion	339 346
9.6 9.7	Sources of Further Information	346
9.7 9.8	References	347
9.9	Appendix: Glover Transformation	349
	2 - P P Committee	
Part III	Mass Integration	351
10	Water Pinch Analysis for Water Management and	
	Minimisation: An Introduction	353
	SHARIFAH RAFIDAH WAN ALWI AND ZAINUDDIN ABDUL MANAN,	
	Process Systems Engineering Centre (PROSPECT),	
	Faculty of Chemical Engineering, Universiti Teknologi	
	Malaysia, Johor Bahru, Malaysia	
10.1	Approaches for Water Management and Minimisation	353
10.2	Water Integration and Water Pinch Analysis	355
10.3	Water Pinch Analysis Steps	357
10.4	Examples of Successful Case Studies	374
10.5	Sources of Further Information and Advice	378
10.6	References	379
10.7	Appendix: Nomenclature	381
11	Using Systematic Design Methods to Minimise Water	
	Use in Process Industries	383
44.4	JIN-KUK KIM, Hanyang University, Seoul, South Korea	
11.1	Introduction	383
11.2	Water Use in Process Industries	386
11.3	Process Integration for Water Systems	388

	Contents	ix
11.4	Conclusion and Future Trends	397
11.5	Sources of Further Information	398
11.6	References	399
12	Synthesis of Water Networks with Water Loss and	
	Gain via an Extended Pinch Analysis Technique	401
	XIAO FENG and CHUN DENG, China University of Petroleum, Beijing, China	
12.1	Introduction	401
12.2	Targeting a Single Water-Using Process	405
12.3	Process-based Graphical Approach (PGA) for Synthesis of	
	Direct Reuse Water Networks	411
12.4	Conclusion	419
12.5	Sources of Further Information and Advice	419
12.6	Acknowledgements	419
12.7	References	420
12.8	Appendix: Nomenclature	421
13	Conserving Material Resources through Process	
	Integration: Material Conservation Networks	422
	MAHMOUD M. EL-HALWAGI, Texas A&M University, USA	
13.1	Introduction	422
13.2	Overall Targeting of Material Conservation Networks	424
13.3	Mass Exchange Networks	426
13.4	Water-Pinch Analysis	429
13.5	Direct Recycle and Material Recycle Pinch Diagram	431
13.6	Property-Based Material Recycle Pinch Diagram	433
13.7	References	437
13.8	Appendix: Nomenclature	439
Part IV	Extended Process Integration	441
14	Process Integration for Cleaner Process Design	443
	Dominic C. Y. Foo and Denny K. S. Ng, University of	
	Nottingham Malaysia, Selangor, Malaysia	
14.1	Introduction	443
14.2	A Revised 'Onion Diagram'	443
14.3 14.4	Different Models for Total Material Network (TMN) Case Study: Water Minimisation in a Water Fabrication	446
	Plant	451

X	Contents	
14.5	Conclusion	457
14.6	Sources of Further Information	457
14.7	References	458
14.8	Appendix: Nomenclature	459
15	Process Integration Concepts for Combined Energy	
	and Water Integration	461
	Luciana Elena Savulescu, Natural Resources Canada –	
	Varennes, Canada and Alberto Alva-Argaez, Process	
	Ecology Inc., Canada	
15.1	Introduction	461
15.2	Water-Energy Specifics and Challenges	463
15.3	Water Path Concept	466
15.4	State-of-the-Art Methodology for Combined Energy and	
4 = =	Water Integration	468
15.5	Sequential, Simultaneous, Mathematical Programming	476
15.6	Conclusion Sources of Further Information	478 479
15.7 15.8	References	480
13.6	References	400
16	Process Integration Techniques for Cogeneration and	
	Trigeneration Systems	484
	Martín Picón-Núñez, University of Guanajuato, México	
	and José Martín Medina-Flores, Polytechnic University of	
	Guanajuato, México	
16.1	Introduction	484
16.2	Combined Heat and Power	485
16.3	Heat Integration of Trigeneration Systems	488
16.4	Conclusions	500
16.5	Sources of Further Information	501
16.6 16.7	References Appendix Nemeraleture	501 502
10.7	Appendix: Nomenclature	302
17	Pinch Analysis for Sustainable Energy Planning Using	
	Diverse Quality Measures	505
	RAYMOND R. TAN, De La Salle University, Manila, Philippines	
	and Dominic C.Y. Foo, University of Nottingham, Selangor,	
	Malaysia	
17.1	Introduction	505
17.2	Generalised Problem Statement	508

	Contents	xi
17.3	Graphical Targeting Procedure	510
17.4	Case Studies	513
17.5	Conclusion	519
17.6	Sources of Further Information	519
17.7	References	520
17.8	Appendix	522
18	A Unified Targeting Algorithm for Diverse Process	
	Integration Problems	524
	UDAY V. SHENOY, Synew Technologies, India	
18.1	Introduction to Targeting Algorithms	524
18.2	Unified Approach to Diverse Resource Optimisation	
	Problems	525
18.3	Basis for Unification	527
18.4	Unified Targeting Algorithm (UTA)	532
18.5	Heat Exchange Networks (HENs) and Mass Exchange	
	Networks (MENs)	541
18.6	Water Networks: Case Study of a Specialty	
	Chemical Plant	548
18.7	Hydrogen and Other Gas Networks	550
18.8	Property-Based Material Reuse Networks	558
18.9	Alternative Approaches to Targeting	561
18.10	Conclusion	564
18.11	Sources of Further Information	565
18.12	References	565
18.13	Appendix: Nomenclature	569
19	A Process Integration Approach for Supply Chain	
	Development	571
	Hon Loong Lam and W. P. Q. Ng, The University of	
	Nottingham, Malaysia, Selangor, Malaysia	
19.1	Introduction	571
19.2	Supply Chain Characteristics and Performance	
	Measurement	572
19.3	Supply Chain Development with Process	
	Integration	576
19.4	Case Studies	584
19.5	Future Trends	592
19.6	Sources of Further Information	592
19.7	References	593

xii	Contents	
20	Application of Heat Recovery Loops to Semicontinuous Processes for Process Integration Michael R. W. Walmsley, Martin John Atkins and Timothy G. Walmsley, University of Waikato, New Zealand	594
20.1	Introduction	594
20.2	Indirect Heat Recovery Systems	595
20.3	Application of Heat Recovery Loops to Semi-continuous	600
20.4	Plants A Mary Country Every leaf a Heat Recovery Leap	600
20.4	A More Complex Example of a Heat Recovery Loop	613
20.5	(HRL) Case Study: Semi-continuous Multi-plant Dairy Factory	618
20.6	Conclusion and Future Trends	626
20.7	Sources of Further Information	627
20.8	References	627
Part V	Applications and Case Studies	631
21	Applications of Energy and Water Process Integration Methodologies in Oil Refineries and Petrochemical	
	Complexes M. Hassan Panjeshahi, University of Tehran, Iran	633
21.1	Introduction	633
21.2	Heat and Power Integration	634
21.3	Water and Wastewater Minimisation	667
21.4	Effluent Treatment and Regeneration	686
21.5	Conclusion	699
21.6	Sources of Further Information	701
21.7	References	702
22	Process Integration of an Oil Refinery Hydrogen Network	705
	Nan Zhang, Process Integration Limited Manchester, UK	705
22.1	Introduction	705
22.2	Technology Review	706
22.3	An Industrial Case Study	711
22.4	Hydrogen Management in the Wider Context of Process	
	Integration: Future Trends	718
22.5	Conclusion	722
22.6	Sources of Further Information	722
22.7	References	723

	Contents	xiii
23	Retrofit Mass Integration of Acid Gas Removal	725
	Systems in Petrochemical Plants Duncan McKenzie Fraser, University of Cape Town, South Africa	725
23.1	Introduction	725
23.2	Review of Previous Work on Mass Exchanger Network	
	Synthesis (MENS) and Retrofit of Existing Systems	727
23.3	Systems Studied: Venturi Scrubber System and	70.4
	Ethanolamine Absorber System	734
23.4	Pinch Approach	736
23.5	Hybrid Approach	741
23.6	Solution Equilibria	744
23.7	Results and Discussion Constraint and Sources of Further Information	746 749
23.8	Conclusions and Sources of Further Information	749 749
23.9 23.10	Acknowledgements References	750
23.10 23.11	Appendix: Nomenclature	750 751
23.11	Appendix. Nomenciature	7.51
24	Applications of Pinch Technology to Total Sites: A	
	Heavy Chemical Industrial Complex and a Steel Plant	752
	Kazuo Marsuda, Chiyoda Corporation, Japan	
24.1	Introduction	752
24.2	Case Study of a Heavy Chemical Complex	753
24.3	Case Study of a Steel Plant	757
24.4	Conclusion	761
24.5	Sources of Further Information	762
24.6	Acknowledgements	762
24.7	References	762
25	Applications of Process Integration Methodologies in	
	the Pulp and Paper Industry	765
	JEAN-CHRISTOPHE BONHIVERS and PAUL R. STUART, École	
	Polytechnique – Montreal, Canada	
25.1	Introduction	765
25.2	Energy Demands and Sources in the Kraft Pulping	
	Process	767
25.3	Relations between the Heat Exchanger and Water	
	Networks	773
25.4	Increasing Energy Efficiency in Existing Mills	777
25.5	Methodological Developments for Heat Integration in	
	Existing Mills	783

xiv	Contents	
25.6	Evolution of Pulp and Paper Mills	789
25.7	Conclusion	794
25.8	Sources of Further Information	796
25.9	References	797
26	Application of Process Integration Methodologies to the Thermal Processing of Waste Petr Stehlík, Brno University of Technology, Czech Republic	799
26.1	Introduction	799
26.2	Types of Waste Thermal Processing Plants	802
26.3	Analysis of Energy Efficiency in the TERMIZO Plant	804
26.4	Application of Heat Integration Technology	811
26.5	Conclusion	816
26.6	Sources of Further Information and Advice	816
26.7	References	817
26.8	Appendix: Nomenclature	818
27	Application of Process Integration Methodologies in the Brewing Industry François Marechal, Anurag Kumar Sachan and Leandro Salgueiro, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland	820
27.1	Introduction	820
27.2	Process Flowsheet Analysis	823
27.3	Calculating Maximum Heat Recovery in the System	837
27.4	Defining the Energy Conversion System	839
27.5	Conclusion	858
27.6	Sources of Further Information	860
27.7	References	860
27.8	Appendix A: Complementary Tables	861
27.9	Appendix B: Nomenclature	862
28	Applications of Process Integration Methodologies in Dairy and Cheese Production Martin John Atkins and Michael R. W. Walmsley, University of Waikato, New Zealand	864
28.1	Introduction	864
28.2	Application of Process Integration Methodologies	866
28.3	Selected Case Studies	873
28.4	Future Trends	879

	Contents	XV
28.5 28.6	Sources of Further Information References	879 880
29	Applications of Process Integration Methodologies in Beet Sugar Plants	883
	Krzysztof Urbaniec, Mirosław Grabowski and Jacek Wernik, Warsaw University of Technology, Plock Campus, Poland	
29.1	Introduction	883
29.2	Sugar Production from Sugar Beet	884
29.3	Identification of Opportunities to Improve Energy and Water Use in Sugar Plants	885
29.4	Reduction of Energy Consumption	887
29.5	Reduction of Water Consumption	893
29.6	Energy and Water Use in Sugar Production Directly from	
20.7	Raw Beet Juice	898
29.7 29.8	Future Trends Sources of Further Information and Advice	909 911
29.6 29.9	References	911
30	Application of Process Integration Techniques for the	
	Efficient Use of Energy in a Urea Fertiliser Plant:	
	A Case Study	914
	Martín Picón-Núñez, University of Guanajuato, Mexico	
30.1	Introduction	914
30.2	Process Description	916
30.3	Opportunities for the Reduction of Energy Consumption	924
30.4	Conclusion	932
30.5	Sources of Further Information	934
30.6	References	935
30.7	Appendix: Nomenclature	936
31	Process Integration for Energy Saving in	
	Buildings and Building Complexes	938
	Petro O. Kapustenko and Olga P. Arsenyeva, National	
	Technical University – Kharkiv Polytechnical Institute, Ukraine	
31.1	Introduction	938
31.2	Buildings as Consumers and Producers of Energy	939
31.3	Commercial and Public Buildings and Building Complexes	942
31.4	District Energy (DE) Systems and Total Site Analysis (TSA)	947
31.5	The Use of Industrial Waste Heat	951

xvi	Contents	
31.6	Renewable Energy for Buildings	956
31.7	Conclusion	961
31.8	Sources of Further Information and Advice	961
31.9	References	962
32	Heat Transfer Enhancement in Heat Exchanger Networks	966
	ROBIN SMITH, MING PAN and IGOR BULATOV, The University of Manchester, UK	
32.1	Introduction to Shell-and-Tube Heat Exchangers	966
32.2	Heat Transfer Enhancement Techniques	979
32.3	Heat Transfer Enhancement in Heat Exchanger Network	
32.4	Retrofit Heat Transfer Enhancement in Heat Exchanger Network	996
	Retrofit with Fouling Consideration	1017
32.5	Sources of Further Information	1027
32.6	Nomenclature	1029
32.7	References	1033
33	Applications of Pinch Analysis in the Design of	
	Isolated Energy Systems	1038
	Santanu Bandyopadhyay, Indian Institute of Technology, Bombay, India	
33.1	Introduction	1038
33.2	Isolated Energy Systems: Descriptions and Models	1040
33.3	Grand Composite Curve and Storage Sizing	1043
33.4	Design Space	1046
33.5	Illustrative Applications	1048
33.6	Sources of Further Information and Advice	1053
33.7	References	1054
Part VI	Software Tools and Epilogue	1057
34	Software Tools for Heat Integration IGOR BULATOV, The University of Manchester, UK	1059
34.1	Heat Integration Software Tools	1059
34.2	Sources of Further Information and Advice	1033
34.3	References	1084

		Contents	xvii
35	Mass and Water Integration Software Tools IGOR BULATOV, The University of Manchester, UK		1086
35.1 35.2 35.3	Mass and Water Integration Software Tools Sources of Further Information and Advice References		1086 1095 1096
36	Epilogue: The Importance of Problem Formuland Data Extraction in Process Integration Jiří Jaromer Klemeš, University of Pannonia, Vesz Hungary		1099
36.1	Introduction: Process Integration – from its Roo	ts to its	
	Present Strong Position		1099
36.2	Successful Applications of Process Integration	/·	1101
36.3	Methods of Obtaining Credible High Integration	n (HI)	
	Solutions		1103
36.4	Data Extraction		1104
36.5	Integration of Renewables – Fluctuating Deman	d and	
	Supply		1109
36.6	Results Interpretation		1110
36.7	Conclusion: Making It Happen		1110
36.8	Sources of Further Information		1111
36.9	Acknowledgements		1111
36.10	References		1112
	Index		1117