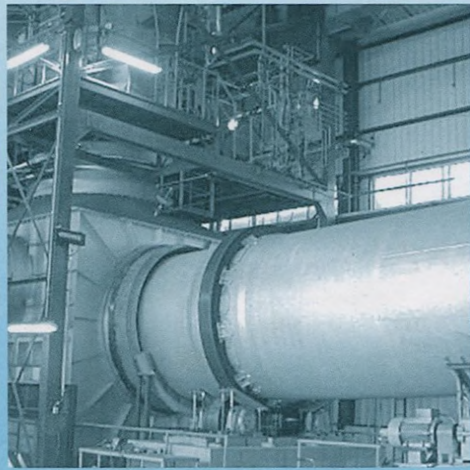


WOODHEAD PUBLISHING IN FOOD SCIENCE, TECHNOLOGY AND NUTRITION

664
H22



Handbook of water and energy management in food processing

Edited by Jiří Klemeš, Robin Smith
and Jin-Kuk Kim



WP

**Handbook of water and energy management
in food processing**

Related titles:

Handbook of waste management and co-product recovery in food processing: Volume 1

(ISBN 978-1-84569-025-0)

Millions of tonnes of waste are produced every year by the agri-food industry. Disposal by landfill or incineration is already expensive and the industry faces increasing costs for the removal of refuse and remnants. The costs of energy and water are also significant for food businesses and savings can be made in these areas if the quantity of energy and water used is limited. Methods to recycle and reduce the need for disposal are therefore increasingly of interest. This comprehensive collection reviews recent research in the field, covering optimisation of manufacturing procedures to decrease waste, reduction of energy and water expenditure, methods to valorise refuse by co-product recovery and techniques to deal with wastewater and solid waste.

Environmentally-compatible food packaging

(ISBN 978-1-84569-194-3)

Food packaging performs an essential function, but packaging materials can have a negative impact on the environment. This collection reviews bio-based, biodegradable and recycled materials and their current and potential applications for food protection and preservation. The first part of the book focuses on environmentally-compatible food packaging materials. Part II discusses drivers for using alternative packaging materials, such as legislation and consumer preference, environmental assessment of food packaging and food packaging eco-design. Chapters on the applications of environmentally-compatible materials for particular functions, such as active packaging, and in particular product sectors then follow.

Environmentally-friendly food processing

(ISBN 978-1-85573-677-1)

With increasing regulation and consumer pressure, the food industry needs to ensure that its production methods are sustainable and sensitive to environmental needs. This important collection reviews ways of analysing the impact of food processing operations on the environment, particularly life cycle assessment (LCA), and techniques for minimising that impact. The first part of the book looks at the application of LCA to the key product areas in food processing. Part II then discusses best practice in such areas as controlling emissions, waste treatment, energy efficiency and bio-based food packaging.

Details of these books and a complete list of Woodhead's titles can be obtained by:

- visiting our web site at www.woodheadpublishing.com
- contacting Customer Services (e-mail: sales@woodhead-publishing.com; fax: +44 (0) 1223 893694; tel.: +44 (0) 1223 891358 ext. 130; address: Woodhead Publishing Ltd, Abington Hall, Granta Park, Great Abington, Cambridge CB21 6AH, England)

Handbook of water and energy management in food processing

**Edited by
Jiří Klemeš, Robin Smith and Jin-Kuk Kim**



**CRC Press
Boca Raton Boston New York Washington, DC**

WOODHEAD PUBLISHING LIMITED
Cambridge, England

Published by Woodhead Publishing Limited, Abington Hall, Granta Park, Great Abington
Cambridge CB21 6AH, England
www.woodheadpublishing.com

Published in North America by CRC Press LLC, 6000 Broken Sound Parkway, NW,
Suite 300, Boca Raton, FL 33487, USA

First published 2008, Woodhead Publishing Limited and CRC Press LLC
© 2008, Woodhead Publishing Limited
The authors have asserted their moral rights.

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. Reasonable efforts have been made to publish reliable data and information, but the authors and the publishers cannot assume responsibility for the validity of all materials. Neither the authors nor the publishers, nor anyone else associated with this publication, shall be liable for any loss, damage or liability directly or indirectly caused or alleged to be caused by this book.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming and recording, or by any information storage or retrieval system, without permission in writing from Woodhead Publishing Limited.

The consent of Woodhead Publishing Limited does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained in writing from Woodhead Publishing Limited for such copying.

Trademark notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation, without intent to infringe.

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library.

Library of Congress Cataloging in Publication Data
A catalog record for this book is available from the Library of Congress.

Woodhead Publishing ISBN 978-1-84569-195-0 (book)
Woodhead Publishing ISBN 978-1-84569-467-8 (e-book)
CRC Press ISBN 978-1-4200-7795-7
CRC Press order number WP7795

The publishers' policy is to use permanent paper from mills that operate a sustainable forestry policy, and which has been manufactured from pulp which is processed using acid-free and elementary chlorine-free practices. Furthermore, the publishers ensure that the text paper and cover board used have met acceptable environmental accreditation standards.

Typeset in India by Replika Press Pvt Ltd
Printed by TJ International, Padstow, Cornwall, England

Contents

<i>Contributor contact details</i>	<i>xvii</i>
<i>Preface</i>	<i>xxv</i>
Part I Key drivers to improve water and energy management in food processing	
1 Legislation and economic issues regarding water and energy management in food processing	3
<i>Peter Cooke, Water Ltd, UK</i>	
1.1 Introduction.....	3
1.2 Trends in, and overview of, legislation.....	8
1.3 Economic drivers as an alternative to prosecution.....	19
1.4 Implications of legislative and economic drivers for management.....	20
1.5 Aspects of boiler management.....	23
1.6 Generic procedure for assessing the economics of effluent treatment and water reuse projects.....	24
1.7 Summary.....	27
1.8 Sources of further information and advice.....	27
1.9 References.....	28
2 Environmental and consumer issues regarding water and energy management in food processing	29
<i>David Elkin and Chris Stevens, MSA, UK</i>	
2.1 Introduction.....	29
2.2 The scale of water and energy consumption in food processing.....	30
2.3 Financial costs to food companies.....	32
2.4 Environmental impacts and costs.....	35
2.5 Future trends.....	39
2.6 Sources of further information and advice.....	43
2.7 References.....	44

3	Towards a complex approach to waste treatment in food processing	45
	<i>Petr Stehlik, Brno University of Technology – VUT UPEI, Czech Republic</i>	
3.1	Introduction.....	45
3.2	Waste in food processing.....	46
3.3	Approaches to food waste treatment.....	50
3.4	Selection of waste treatment technology.....	55
3.5	Examples of efficient approaches.....	60
3.6	Life-cycle analysis.....	73
3.7	Future trends.....	77
3.8	Conclusions.....	79
3.9	Sources of further information and advice.....	80
3.10	References.....	80
	Part II Assessing water and energy consumption and designing strategies for their reduction	
4	Auditing energy and water use in the food industry	85
	<i>Philippe Navarri and Serge Bedard, Natural Resources Canada, Canada</i>	
4.1	Introduction to energy and water auditing.....	85
4.2	Process mapping and energy and water use inventories	89
4.3	Identification of energy and water saving opportunities.....	93
4.4	Cost-benefit analysis.....	106
4.5	Conclusion.....	110
4.6	Sources of further information and advice.....	110
4.7	References.....	111
5	Methods to minimise water use in food processing	113
	<i>Jin-Kuk Kim and Robin Smith, The University of Manchester, UK</i>	
5.1	Introduction.....	113
5.2	Water minimisation.....	114
5.3	Water reuse and recycling.....	121
5.4	Process changes for water minimisation.....	124
5.5	Application in the food industry.....	126
5.6	Summary.....	132
5.7	Sources of further information and advice.....	132
5.8	References.....	134
6	Methods to minimise energy use in food processing	136
	<i>Jiří Klemeš, University of Pannonia, Hungary (formerly of The University of Manchester, UK) and Simon Perry, The University of Manchester, UK</i>	
6.1	Introduction: energy use in food processing.....	136

6.2	Minimising energy use in food processing.....	144
6.3	Energy saving and minimisation: process integration/pinch technology, combined heat and power, combined energy and water minimisation.....	145
6.4	Overview of selected case studies.....	156
6.5	Case studies and examples of energy saving using pinch technology and heat integration.....	157
6.6	Further studies.....	187
6.7	Sources of further information and advice.....	194
6.8	References.....	196
7	Modelling and optimisation tools for water minimisation in the food industry.....	200
	<i>Ferenc Friedler and Petar Varbanov, University of Pannonia, Hungary</i>	
7.1	Introduction.....	200
7.2	Framework for model building and optimisation.....	201
7.3	Optimisation: meaning and mathematical formulation.....	202
7.4	Creating models.....	204
7.5	Example: an overview of an industrial case study.....	216
7.6	Sources of further information and advice.....	217
7.7	References.....	219
8	Energy management methods for the food industry.....	221
	<i>François Marechal and Damien Muller, Ecole Polytechnique Fédérale de Lausanne, Switzerland</i>	
8.1	Introduction.....	221
8.2	The top-down approach: from the bill to the production.....	225
8.3	The bottom-up approach: from efficient production to the bill.....	236
8.4	Assessing the energy savings options.....	249
8.5	Conclusions.....	251
8.6	Future trends.....	252
8.7	Sources of further information and advice.....	253
8.8	Acknowledgements.....	253
8.9	References.....	254
9	Minimizing water and energy use in the batch and semi-continuous processes in the food and beverage industry.....	256
	<i>Luis Puigjaner, Antonio Espuña and Maria Almató, Universitat Politècnica de Catalunya, Spain</i>	
9.1	Introduction.....	256
9.2	Method for water use minimization.....	258
9.3	General modeling framework.....	260

viii Contents

9.4	Mathematical formulation.....	261
9.5	Energy integration opportunities.....	272
9.6	Solving the model.....	273
9.7	Model optimization.....	274
9.8	Software prototype.....	276
9.9	Industrial applications.....	277
9.10	Final considerations and future trends.....	293
9.11	Nomenclature.....	298
9.12	Sources of further information and advice.....	302
9.13	Acknowledgments.....	302
9.14	References.....	302
10	Novel methods for combined energy and water minimisation in the food industry.....	304
	<i>Luciana Savulescu, Natural Resources Canada, Canada, and Jin-Kuk Kim, The University of Manchester, UK</i>	
10.1	Introduction.....	304
10.2	Literature review on simultaneous energy and water minimisation.....	307
10.3	Conceptual understanding and physical insights.....	311
10.4	Design methodology.....	316
10.5	Summary.....	324
10.6	Sources of further information and advice.....	327
10.7	References.....	328
	Part III Good housekeeping procedures, measurement and process control to minimise water and energy consumption	
11	Good housekeeping procedures to improve efficiency of water use in food processing plants.....	335
	<i>Robert Pagan and Nicole Price, The University of Queensland, Australia</i>	
11.1	Introduction.....	335
11.2	Better management practices.....	339
11.3	Monitoring water use.....	341
11.4	Cleaning.....	343
11.5	Utilities.....	352
11.6	Auxiliaries.....	356
11.7	Unit operations.....	358
11.8	Trends in food processing.....	361
11.9	Sources of further information and advice.....	362
11.10	References.....	364

12	Housekeeping measures to reduce energy consumption in food processing plants	367
	<i>Robert Pagan, Nicole Price and Jane Gaffel, The University of Queensland, Australia</i>	
12.1	Introduction.....	367
12.2	Reducing cleaning requirements to save energy.....	367
12.3	Reducing waste to save energy.....	369
12.4	Maintenance and monitoring of unit operations to save energy.....	371
12.5	Future trends.....	381
12.6	Sources of further information and advice.....	382
12.7	References.....	384
13	Measurement and process control for water and energy use in the food industry	387
	<i>Panos Seferlis, Aristotle University of Thessaloniki, Greece, and Spyros Voutetakis, Centre for Research and Technology – Hellas, Greece</i>	
13.1	Introduction.....	387
13.2	Measurements and sensors in the food industry.....	389
13.3	Process control for water and energy in the food industry.....	394
13.4	System integration.....	406
13.5	Conclusions and future trends - sources of further information and advice.....	414
13.6	References.....	416
14	Monitoring and intelligent support systems to optimise water and energy use	419
	<i>Toshko Zhelev, University of Limerick, Ireland</i>	
14.1	Introduction.....	419
14.2	Intelligent systems for process operation support.....	420
14.3	Diagnostics.....	421
14.4	Monitoring for better control.....	423
14.5	Agent-based monitoring.....	424
14.6	Links to supply chain management.....	425
14.7	Links with life-cycle management.....	425
14.8	Monitoring and analysis.....	426
14.9	Monitoring and forecasting for energy efficiency improvement.....	430
14.10	Tendencies.....	431
14.11	Application of monitoring and intelligent support for decision making.....	433
14.12	Monitoring for optimal energy and water consumption....	434
14.13	Introducing integrated management of resources and finances.....	437

14.14	Concluding remarks.....	443
14.15	Sources of further information and advice.....	443
14.16	References.....	444
Part IV Methods to minimise energy consumption in food processing, retail and waste treatment		
15	Minimising energy consumption associated with chilling, refrigerated storage and cooling systems in the food industry.....	449
	<i>Judith Evans, University of Bristol, UK</i>	
15.1	Introduction.....	449
15.2	Energy used in chilling/freezing and storage of food.....	450
15.3	Refrigeration system efficiency.....	450
15.4	Refrigeration system component efficiency.....	453
15.5	Efficiency of heat extraction from food and temperature maintenance during storage.....	459
15.6	Construction and usage of refrigerated areas.....	465
15.7	Life-cycle costs and analysis.....	468
15.8	Energy target and monitoring.....	469
15.9	Energy minimisation through integrated heating and cooling systems.....	471
15.10	Future trends.....	478
15.11	Sources of further information and advice.....	478
15.12	References.....	479
16	Minimising energy consumption associated with drying, baking and evaporation.....	481
	<i>Michele Marcotte and Stefan Grabowski, Agriculture and Agri-Food Canada, Canada</i>	
16.1	Introduction.....	481
16.2	General energy accounting methods.....	483
16.3	Drying.....	486
16.4	Baking.....	503
16.5	Evaporation.....	513
16.6	Final remarks - sources of further information and advice.....	517
16.7	References.....	518
17	Minimising energy consumption associated with retorting.....	523
	<i>Ricardo Simpson and Sergio Almonacid, Universidad Técnica Federico Santa María, Chile</i>	
17.1	Introduction.....	523
17.2	Retort operation.....	526
17.3	Modeling and optimization of energy consumption.....	527

17.4	Simultaneous processing of different product lots in the same retort.....	536
17.5	New package systems and their impact on energy consumption.....	537
17.6	Future trends.....	539
17.7	Nomenclature.....	540
17.8	Sources of further information and advice.....	541
17.9	References.....	541
18	Heat recovery in the food industry.....	544
	<i>David Reay, David Reay & Associates, UK</i>	
18.1	Introduction.....	544
18.2	Chapter themes.....	545
18.3	Recovering waste heat at source.....	549
18.4	The uses for waste heat - the sink.....	551
18.5	The site survey – quantifying waste heat.....	553
18.6	Types of heat recovery equipment.....	555
18.7	Heat/cold storage (or thermal energy storage – TES).....	562
18.8	Process integration.....	563
18.9	Case studies.....	563
18.10	Summary.....	568
18.11	Sources of further information and advice.....	568
18.12	References.....	569
19	Fouling of heat transfer equipment in the food industry.....	570
	<i>Bernard Thonon, Greth, France</i>	
19.1	Introduction.....	570
19.2	Fouling mechanisms.....	570
19.3	Waterside fouling.....	575
19.4	Process-side fouling.....	578
19.5	Conclusion.....	582
19.6	Nomenclature.....	582
19.7	Sources of further information and advice.....	583
19.8	References.....	583
20	Reduction of refrigeration energy consumption and environmental impacts in food retailing.....	585
	<i>Savvas Tassou and Yunting Ge, Brunel University, UK</i>	
20.1	Introduction.....	585
20.2	Refrigeration systems in food retailing.....	587
20.3	Recent research and development to reduce the environmental impacts of supermarket refrigeration systems.....	590
20.4	CO ₂ refrigeration systems for supermarket applications.....	599
20.5	Opportunities for energy savings in supermarket refrigeration.....	604

xii Contents

20.6	Sources of further information and advice.....	608
20.7	Conclusions.....	608
20.8	Acknowledgements.....	609
20.9	References.....	610
21	Dewatering for food waste.....	612
	<i>Valérie Orsat and G S Vijaya Raghavan, McGill University, Canada</i>	
21.1	Introduction.....	612
21.2	Waste conditioning.....	613
21.3	Thickening.....	613
21.4	Dewatering methods.....	614
21.5	Combining dewatering methods.....	620
21.6	An environmental and economic choice.....	621
21.7	Conclusion and future trends.....	622
21.8	Sources of further information and advice.....	623
21.9	References.....	623
Part V Water reuse and wastewater treatment in the food industry		
22	Feedwater requirements in the food industry.....	629
	<i>Peter Glavic and Marjana Simonič, University of Maribor, Slovenia</i>	
22.1	Introduction.....	629
22.2	Future trends.....	630
22.3	Water supply.....	631
22.4	Feedwater pre-treatment processes.....	633
22.5	Summary.....	643
22.6	Sources of further information and advice.....	643
22.7	References.....	645
23	Water recycling in the food industry.....	647
	<i>Vasanthi Sethu and Vijai Ananth Viramuthu, University of Nottingham, Malaysia Campus, Malaysia</i>	
23.1	Introduction.....	647
23.2	The food processing industry.....	648
23.3	Water in food processing plants.....	648
23.4	Water recycling technologies.....	649
23.5	Water purity standards.....	651
23.6	Water recycling opportunities.....	652
23.7	Water conservation measures.....	654
23.8	Designing a water recycling scheme.....	656
23.9	Benefits and drawbacks of water recycling.....	658
23.10	Case studies.....	658
23.11	Conclusions and future trends.....	661
23.12	Sources of further information and advice.....	661
23.13	References.....	662

24	Advances in membrane technology for the treatment and reuse of food processing wastewater.....	663
	<i>Endre Nagy, University of Pannonia, Hungary</i>	
24.1	Introduction.....	663
24.2	Membrane separation processes.....	664
24.3	Membrane bioreactor.....	682
24.4	Biofilm membrane bioreactor.....	686
24.5	Applications in food processing wastewater treatment.....	687
24.6	Conclusions and future trends.....	690
24.7	Sources of further information and advice.....	691
24.8	Acknowledgement.....	693
24.9	Appendix.....	694
24.10	References.....	695
25	Advances in disinfection techniques for water reuse.....	700
	<i>Larry Forney, Georgia Institute of Technology, USA</i>	
25.1	Introduction.....	700
25.2	Continuous disinfection process.....	701
25.3	Chemical and physical disinfection.....	710
25.4	Future trends.....	716
25.5	Sources of further information and advice.....	717
25.6	References.....	718
26	Advances in aerobic systems for treatment of food processing wastewater.....	720
	<i>Jerry R Taricska, Hole Montes Inc., USA, Yung-Tse Hung, Cleveland State University, USA, Kathleen Hung Li, Texas Hospital Association, USA</i>	
26.1	Introduction.....	720
26.2	Characteristics of food processing wastewater.....	721
26.3	Aerobic treatment.....	736
26.4	Future trends.....	749
26.5	Sources of further information and advice.....	751
26.6	References.....	752
27	Advances in anaerobic systems for organic pollution removal from food processing wastewater.....	755
	<i>Yung-Tse Hung, Cleveland State University, USA, Puangrat Kajitvichyanukul, King Mongkut's University of Technology Thonburi, Thailand, Lawrence K. Wang, Lenox Institute of Water Technology, USA</i>	
27.1	Introduction.....	755
27.2	Food processing wastewater characteristics.....	756
27.3	Anaerobic treatment for food processing wastewater.....	757
27.4	Types of anaerobic treatment for food processing wastewater.....	761

27.5	Controlling the anaerobic digestion process.....	767
27.6	Modelling of the anaerobic process for food processing wastewater.....	769
27.7	Future trend: methane and hydrogen production from anaerobic process using food processing wastewater.....	771
27.8	Sources of further information and advice.....	771
27.9	References.....	773
28	Seafood wastewater treatment.....	776
	<i>Kuan-Yeow Show, University Tunku Abdul Rahman, Malaysia</i>	
28.1	Introduction.....	776
28.2	Characteristics of seafood wastewater.....	777
28.3	Primary treatment.....	781
28.4	Biological treatment.....	784
28.5	Physicochemical treatment.....	793
28.6	Land application of seafood wastewater.....	796
28.7	Future trends.....	798
28.8	Sources of further information and advice.....	798
28.9	References.....	799
 Part VI Water and energy minimisation in particular industry sectors		
29	Water and energy management in the slaughterhouse.....	805
	<i>Inge Genné and An Derden, VITO, Belgium</i>	
29.1	Introduction.....	805
29.2	Water and energy use in slaughterhouses.....	806
29.3	Water and energy saving options.....	809
29.4	Sources of further information and advice.....	814
29.5	References.....	815
30	Water and energy management in poultry processing.....	816
	<i>Colin Burton, Cemagref, France, and Dave Tinker, David Tinker and Associates, UK</i>	
30.1	Current water and energy uses in the industry.....	816
30.2	Current water and energy use: how much water and energy is used and why.....	822
30.3	Measuring, monitoring, analysis and strategies.....	824
30.4	Reducing energy consumption in each part of the process.....	827
30.5	Waste management and renewable energy.....	831
30.6	Reducing water consumption in each part of the process.....	833
30.7	Water recycling.....	835
30.8	Conclusions.....	838
30.9	Sources of further information and advice.....	839
30.10	References.....	840

31	Water and energy management in cereals processing	842
	<i>Grant Campbell and Fernán Mateos-Salvador,</i> <i>The University of Manchester, UK</i>	
31.1	Introduction.....	842
31.2	Overview of water and energy use in the cereals processing industries.....	845
31.3	Mixing, baking, drying and cooling of farinaceous products.....	853
31.4	Corn wet milling and starch processing.....	854
31.5	Future trends.....	858
31.6	Sources of further information and advice.....	859
31.7	References.....	859
32	Water and energy management in the sugar industry	863
	<i>Krzysztof Urbaniec, Warsaw University of Technology, Poland,</i> <i>and Jiří Klemeš, University of Pannonia, Hungary</i> <i>(formerly of The University of Manchester, UK)</i>	
32.1	Introduction.....	863
32.2	Sugar production from sugar beet and sugar cane.....	864
32.3	Identification of opportunities to improve energy and water use in sugar production.....	865
32.4	Energy and water minimisation: process integration/pinch technology and other optimisation techniques.....	868
32.5	Retrofitting the energy sub-system for reduced energy consumption.....	869
32.6	Retrofitting the water and wastewater sub-system for reduced water consumption.....	875
32.7	Future trends.....	881
32.8	Sources of further information and advice.....	882
32.9	References.....	883
33	Improving energy efficiency in sugar processing	885
	<i>Frieder Lorenz, Südzucker, Germany</i>	
33.1	Introduction.....	885
33.2	The sugar industry.....	885
33.3	What are the reasons for energy demand?.....	890
33.4	Combined heat and power station.....	892
33.5	Heat losses.....	892
33.6	Heating.....	893
33.7	Evaporation.....	895
33.8	Drying.....	898
33.9	Limits.....	899
33.10	Output/input ratio.....	900
33.11	Future trends.....	901
33.12	Sources of further information and advice.....	902
33.13	References.....	902

34	Water minimization in the soft drinks industry	904
	<i>Thokozani Majazi, University of Pretoria, South Africa, and Dominic Chwan Yee Foo, University of Nottingham, Malaysia Campus, Malaysia</i>	
34.1	Introduction.....	904
34.2	Current trends in wastewater minimization in the continuous processing industry.....	905
34.3	Current trends in wastewater minimization in the batch processing industry.....	906
34.4	Background on water usage in soft drinks industries.....	908
34.5	Case study 1: case study on amalgamated beverage industries (ABI), South Africa.....	909
34.6	Case study 2: water recycling by floating media filtration and nanofiltration at a Japanese soft drink factory.....	918
34.7	Conclusions.....	921
34.8	Sources of further information and advice.....	925
34.9	Acknowledgements.....	926
34.10	References.....	926
35	Brewing, winemaking and distilling: an overview of wastewater treatment and utilisation schemes	929
	<i>Luc Fillaudeau, LISBP INRA UMR792, France, André Bories, INRA UE999, France, and Martine Decloux, AgroParisTech, UMR1145 France</i>	
35.1	Introduction.....	929
35.2	Water use: the origin and nature of effluents in the brewing, wine and distilling industries.....	932
35.3	Most widely used treatment methods: livestock feed, discharge, anaerobic and aerobic treatments, incineration	950
35.4	Alternative treatments and re-engineering processes with the best available techniques (BAT) approach: industrial reality and alternative treatments.....	969
35.5	Acknowledgements.....	982
35.6	Nomenclature.....	983
35.7	References.....	983
	<i>Index</i>	996