

Contents

Preface XXVII
List of Contributors XXIX

| | | |
|----------|--|----------|
| 1 | A Comprehensive History of Beer Brewing | 1 |
| | <i>Franz G. Meussdoerffer</i> | |
| 1.1 | Introduction | 1 |
| 1.2 | 'The Truly Happy Man Has His Mouth Full of Beer': From Prehistory to the End of the Roman Empire | 2 |
| 1.2.1 | Advent of Agrarian Societies | 2 |
| 1.2.2 | Mesopotamia and Egypt | 5 |
| 1.2.3 | Hellenistic Period: Greeks, Romans and Their Neighbors | 7 |
| 1.2.4 | Celts and the Germans | 8 |
| 1.3 | 'I Would Like to Have a Great Lake of Beer for Christ the King': The Christian Middle Ages | 9 |
| 1.3.1 | Monasteries | 9 |
| 1.3.2 | Beginnings of Professionalism | 12 |
| 1.4 | 'Woar Volk Is, Bint Klaantr': Hopped Beer and the Seaports | 16 |
| 1.4.1 | Hanseatic League | 16 |
| 1.4.2 | Rise and Decline of the Cities in Central Europe | 18 |
| 1.4.3 | Rise of Dutch Brewing | 20 |
| 1.5 | 'For a Quart of Ale is a Dish for a King': John Bull and the Industrialization of Brewing | 21 |
| 1.6 | 'We Live in a Country Where Beer Constitutes Quasi the Fifth Element': Advent of Lager and the Internationalization of Brewing | 25 |
| 1.6.1 | Bavaria and the Rise of Lager Beer | 25 |
| 1.6.2 | Spread of Lager Brewing | 27 |
| 1.6.3 | From Alchemy to Biochemistry: The Science of Brewing | 30 |
| 1.6.4 | Europe, the United States and the Internationalization of Beer Brewing | 33 |
| | References | 37 |

| | | |
|----------|---|-----------|
| 2 | Starchy Raw Materials | 43 |
| | <i>Franz Meussdoerffer and Martin Zarnkow</i> | |
| 2.1 | Introduction | 43 |
| 2.2 | Principles of Structure and Metabolism | 44 |
| 2.2.1 | Grain Structure | 44 |
| 2.2.2 | Basic Anabolic Processes | 46 |
| 2.2.2.1 | Starch Formation | 47 |
| 2.2.2.2 | Storage Proteins | 50 |
| 2.2.2.3 | Regulation of Grain Filling and Impact of Environmental Factors | 52 |
| 2.2.3 | Catabolic Processes | 53 |
| 2.3 | Major Brewing Cereals | 55 |
| 2.3.1 | Introductory Remarks | 55 |
| 2.3.2 | Selected Cereals | 59 |
| 2.3.2.1 | Barley (<i>H. vulgare</i> L.) | 59 |
| 2.3.2.2 | Oats (<i>Avena sativa</i> L.) | 60 |
| 2.3.2.3 | Short-Grain Millet | 61 |
| 2.3.2.4 | Maize (<i>Zea mays</i> L.) | 63 |
| 2.3.2.5 | Rice (<i>Oryza sativa</i> L.) | 64 |
| 2.3.2.6 | Rye (<i>Secale cereale</i> L.) | 65 |
| 2.3.2.7 | Sorghum (<i>Sorghum bicolor</i> L.) | 65 |
| 2.3.2.8 | Wheat Group (<i>Triticum</i> L.) | 66 |
| 2.3.3 | Pseudocereals | 69 |
| 2.3.3.1 | Grain Amaranth (Main Sorts: <i>Amaranthus cruentus</i> , <i>Amaranthus hypochondriacus</i> and <i>Amaranthus caudatus</i>) | 69 |
| 2.3.3.2 | Buckwheat (<i>Fagopyrum esculentum</i> Moench) | 70 |
| 2.3.3.3 | Quinoa (<i>Chenopodium quinoa</i> Willd.) | 70 |
| 2.4 | Concluding Remarks | 71 |
| | References | 71 |
| 3 | Hops | 85 |
| | <i>Martin Krottenthaler</i> | |
| 3.1 | Introduction | 85 |
| 3.2 | Cultivation of Hops | 85 |
| 3.3 | Components of Hops | 87 |
| 3.3.1 | Bitter Acids | 87 |
| 3.3.2 | Aroma Substances | 88 |
| 3.3.3 | Polyphenols | 89 |
| 3.4 | Hop Products | 90 |
| 3.5 | Analytics | 91 |
| 3.6 | Hopping Technology | 91 |
| 3.6.1 | General Aspects of Hop Addition | 91 |
| 3.6.2 | Beer with Hop Flavor | 94 |
| 3.6.3 | Beer with a Hop Flavor | 95 |
| 3.6.4 | Beer Enriched with Xanthohumol | 97 |

| | | |
|----------|--|------------|
| 3.6.5 | Yield of Bitter Principles | 97 |
| 3.6.6 | Foam | 98 |
| 3.6.7 | Microbiology | 99 |
| 3.6.8 | Addition of ‘Downstream Products’ | 99 |
| 3.7 | Storage of Hops | 100 |
| | References | 101 |
| 4 | Brew Water | 105 |
| | <i>Martin Krottenthaler and Karl Glas</i> | |
| 4.1 | General Requirements | 105 |
| 4.2 | Characteristics of Constituents Relevant for Brewing | 105 |
| 4.3 | Quality Criteria for Brew Water | 108 |
| 4.4 | Water Treatment | 110 |
| 4.4.1 | Removal of Problematic Inorganic Substances | 110 |
| 4.4.1.1 | Deferrization and Demanganization | 110 |
| 4.4.1.2 | Nitrate Reduction | 111 |
| 4.4.2 | Removal of Problematic Organic Substances | 112 |
| 4.4.2.1 | Aeration | 112 |
| 4.4.2.2 | Activated-Carbon Filtration | 112 |
| 4.4.2.3 | Combination Processes Using Oxidation/UV Irradiation | 112 |
| 4.4.3 | Common Processes for Brew Water Treatment | 112 |
| 4.4.3.1 | Lime Softening | 112 |
| 4.4.3.2 | Ion Exchange | 113 |
| 4.4.3.3 | Membrane Processes | 115 |
| | References | 117 |
| 5 | Yeast | 119 |
| | <i>Christoph Tenge</i> | |
| 5.1 | Brewing Yeast | 119 |
| 5.1.1 | History of Yeast Research | 119 |
| 5.1.2 | Yeast for Brewing Applications | 120 |
| 5.1.2.1 | Flocculation | 123 |
| 5.1.3 | Yeast Morphology and Chemical Composition | 124 |
| 5.1.3.1 | Cell Wall | 124 |
| 5.1.3.2 | Periplasm | 125 |
| 5.1.3.3 | Cell Membrane | 125 |
| 5.1.3.4 | Cytoplasm | 126 |
| 5.1.3.5 | Mitochondria | 126 |
| 5.2 | Yeast Management | 127 |
| 5.2.1 | Nutrient Requirements and Intake | 127 |
| 5.2.1.1 | Carbohydrates and Fermentable Sugars | 127 |
| 5.2.1.2 | Nitrogen Sources | 128 |
| 5.2.1.3 | Oxygen | 129 |
| 5.2.1.4 | Minerals and Trace Elements | 129 |
| 5.2.1.5 | Vitamins and Other Growth Factors | 130 |

| | | |
|----------|--|------------|
| 5.2.2 | Metabolic Pathways during Propagation and Fermentation | 131 |
| 5.2.2.1 | Carbohydrate Metabolism for Cell Growth and Energy Generation | 131 |
| 5.2.2.2 | Formation of Vicinal Diketones | 132 |
| 5.2.2.3 | Formation of Higher Alcohols | 132 |
| 5.2.2.4 | Formation of Esters | 134 |
| 5.2.2.5 | Phenolic Compounds | 134 |
| 5.2.2.6 | Formation of Sulfur Dioxide | 135 |
| 5.2.3 | Yeast Cultivation, Propagation and Post-Fermentation Treatment | 135 |
| 5.2.3.1 | Yeast Cultivation in the Laboratory | 136 |
| 5.2.3.2 | Yeast Propagation in the Yeast Cellar | 138 |
| 5.2.3.3 | Post-Fermentation Treatment of Yeast | 140 |
| 5.2.3.4 | Yeast Crop | 140 |
| 5.2.3.5 | Yeast Treatment after Cropping and Yeast Storage | 141 |
| | References | 142 |
| 6 | Malting | 147 |
| | <i>Stefan Kreisz</i> | |
| 6.1 | Brewing Barley | 147 |
| 6.2 | Barley Intake and Storage | 149 |
| 6.2.1 | Barley Cleaning | 149 |
| 6.2.2 | Steeping | 150 |
| 6.2.3 | Germination | 152 |
| 6.2.4 | Kilning | 155 |
| 6.2.5 | Cleaning, Storage and Polishing of the Malt | 156 |
| 6.2.6 | Malt Yield | 157 |
| 6.2.7 | Malt Quality | 157 |
| 6.2.8 | Quality Criteria of Barley Malt | 158 |
| 6.2.8.1 | Cytolysis | 158 |
| 6.2.8.2 | Proteolysis | 160 |
| 6.2.8.3 | Amylolysis | 160 |
| 6.2.8.4 | Enzymes | 161 |
| 6.2.8.5 | Further Malt Quality Criteria | 161 |
| 6.3 | Special Malts | 163 |
| 6.3.1 | Dark Malt (Munich Type) | 163 |
| 6.3.2 | Caramel (Crystal) Malt | 163 |
| 6.3.3 | Roasted Malt | 164 |
| 6.3.4 | Wheat Malt and Malt Made from Other Cereals | 164 |
| 6.3.5 | Other Special Malt | 164 |
| | References | 164 |
| 7 | Wort Production | 165 |
| | <i>Martin Krottenthaler, Werner Back, and Martin Zarnkow</i> | |
| 7.1 | Introduction | 165 |
| 7.2 | Technology of Grinding | 165 |

| | | |
|----------|--|-----|
| 7.3 | Mashing Technology | 168 |
| 7.3.1 | Mashing Parameters | 169 |
| 7.3.2 | Selected Mashing Processes | 173 |
| 7.3.2.1 | Step-Mashing Process | 173 |
| 7.3.2.2 | Maltase Process | 174 |
| 7.3.2.3 | Dark Beer Varieties | 175 |
| 7.3.2.4 | Adjunct Mashing | 176 |
| 7.4 | Technology of Lautering | 181 |
| 7.4.1 | Lauter Tun | 182 |
| 7.4.2 | Mash Filter | 184 |
| 7.4.3 | Strainmaster | 186 |
| 7.5 | Technological Basics of Wort Boiling | 186 |
| 7.5.1 | Hot Holding | 186 |
| 7.5.2 | Evaporation | 187 |
| 7.5.3 | Modern Boiling Systems | 190 |
| 7.5.3.1 | Internal Boilers | 190 |
| 7.5.3.2 | Optimized Internal Boiler ‘Stromboli’ | 190 |
| 7.5.3.3 | Optimized Internal Boiler Subjet | 191 |
| 7.5.3.4 | External Boiler | 192 |
| 7.5.3.5 | High-Temperature Wort Boiling | 194 |
| 7.5.3.6 | Dynamic Low-Pressure Boiling | 194 |
| 7.5.3.7 | Soft Boiling Method ‘SchoKo’ | 194 |
| 7.5.3.8 | Wort Stripping | 196 |
| 7.5.3.9 | Vacuum Evaporation | 197 |
| 7.5.3.10 | Flash Evaporation ‘Varioboil’ | 197 |
| 7.5.3.11 | Thin Film Evaporator ‘Merlin’ | 199 |
| 7.5.4 | Vapor Condensate | 201 |
| 7.5.5 | Cold Trub | 202 |
| | References | 202 |
| 8 | Fermentation, Maturation and Storage | 207 |
| | <i>Hans Michael Eßlinger</i> | |
| 8.1 | Pitching | 207 |
| 8.2 | Aeration | 209 |
| 8.3 | Topping-up | 209 |
| 8.4 | Changes during Fermentation | 209 |
| 8.4.1 | Changes in the Composition of Nitrogen Compounds | 211 |
| 8.4.2 | pH Drop | 211 |
| 8.4.3 | Changes in the Redox Properties of Beer | 212 |
| 8.4.4 | Beer Color | 212 |
| 8.4.5 | Precipitation of Bitter Substances and Polyphenols | 212 |
| 8.4.6 | CO ₂ Content | 212 |
| 8.4.7 | Clarification and Colloidal Stabilization | 213 |
| 8.5 | Appearance during Fermentation | 213 |
| 8.6 | Fermentation Parameters | 213 |
| 8.7 | Control of Fermentation | 214 |

| | | |
|-----------|---|------------|
| 8.8 | Fermenters | 214 |
| 8.9 | Maturation | 215 |
| 8.10 | Storage | 215 |
| 8.11 | Bottom Fermentation in Practice | 216 |
| 8.11.1 | Cold Fermentation with Conventional Storage | 216 |
| 8.11.2 | Cold Fermentation with Well-Directed Maturation in a Cylindroconical Vessel (CCV) | 217 |
| 8.11.3 | Pressureless Warm Fermentation | 217 |
| 8.11.4 | Accelerated Fermentation under CO ₂ Pressure | 217 |
| 8.11.5 | Cold Fermentation with Integrated Maturation at 12 °C | 218 |
| 8.11.6 | Cold Fermentation with Programmed Maturation at 20 °C | 219 |
| 8.11.7 | Accelerated Fermentation and/or Maturation | 219 |
| 8.12 | Yeast Crop and Yeast Storage | 220 |
| 8.13 | Beer Recovery from Yeast | 221 |
| 8.14 | CO ₂ Recovery | 221 |
| 8.15 | Types of Bottom-Fermented Beers | 222 |
| 8.16 | Top Fermentation | 222 |
| 8.17 | Types and Production of Top-Fermented Beers | 223 |
| 8.17.1 | Wheat Beer | 223 |
| 8.17.2 | Alt Beer | 223 |
| 8.17.3 | Kölsch Beer | 224 |
| | References | 224 |
| 9 | Filtration and Stabilization | 225 |
| | <i>Bernd Lindemann</i> | |
| 9.1 | Introduction | 225 |
| 9.2 | Purpose of Filtration | 225 |
| 9.3 | Theoretical Considerations of Cake Filtration | 225 |
| 9.4 | Filtration Techniques | 226 |
| 9.4.1 | Kieselguhr Filtration | 226 |
| 9.4.1.1 | Plate and Frame Filter | 227 |
| 9.4.1.2 | Horizontal Leaf Filter | 227 |
| 9.4.1.3 | Metal Candle Leaf Filter | 229 |
| 9.4.2 | Filter Aids for Pre-coating | 230 |
| 9.4.3 | Methods in Kieselguhr Pre-coating Filtration | 230 |
| 9.4.4 | Membrane Filtration | 230 |
| 9.5 | Variables Influencing Beer Filtration | 231 |
| 9.6 | Beer Stabilization | 231 |
| 9.7 | Technical Design of a Filtration and Stabilization Plant | 232 |
| | References | 234 |
| 10 | Special Production Methods | 235 |
| | <i>Felix Burberg and Martin Zarnkow</i> | |
| 10.1 | Alcohol-Free Beers | 235 |
| 10.1.1 | Introduction | 235 |

| | | |
|-----------|---|-----|
| 10.1.2 | Techniques for the Production of Alcohol-Free Beers | 236 |
| 10.1.2.1 | Physical Techniques | 236 |
| 10.1.2.2 | Biological Methods | 238 |
| 10.1.2.3 | Combination Physical-Biological Processes | 240 |
| 10.2 | Dietetic Beer | 240 |
| 10.2.1 | Introduction | 240 |
| 10.2.2 | Methods for the Production of Dietetic Beers | 241 |
| 10.3 | 'Nährbier' and 'Malzbier' ('Malztrunk') | 242 |
| 10.3.1 | Introduction | 242 |
| 10.3.2 | Methods for the Production of 'Nährbier' and 'Malzbier' ('Malztrunk') | 242 |
| 10.4 | XAN™ Wheat Beer | 243 |
| 10.4.1 | Introduction | 243 |
| 10.4.2 | Methods of Production of XAN™ Wheat Beer | 243 |
| 10.5 | Gluten-Free Beer | 244 |
| 10.5.1 | Introduction | 244 |
| 10.5.2 | Production Methods for Gluten-Free Beer | 244 |
| 10.5.2.1 | Conventional 'Gluten-Containing' Raw Material | 245 |
| 10.5.2.2 | Sources of Gluten-Free Sugars and Starch | 245 |
| 10.6 | Brewing with High Original Wort | 246 |
| 10.6.1 | Introduction | 246 |
| 10.6.2 | Methods for Beer Production with High Original Wort | 247 |
| 10.7 | Ale and Cask-Conditioned Ale | 248 |
| 10.7.1 | Introduction | 248 |
| 10.7.2 | Methods for the Production of Cask-Conditioned Ale | 249 |
| 10.8 | Lambic, Gueuze and Fruit Lambic | 250 |
| 10.8.1 | Introduction | 250 |
| 10.8.2 | Method for the Production of Lambic and Gueuze | 251 |
| 10.8.2.1 | Wort Production | 251 |
| 10.8.2.2 | Beer Production | 251 |
| 10.8.3 | Method for the Production of Fruit Lambic | 252 |
| 10.9 | Berliner Weisse | 253 |
| 10.9.1 | Introduction | 253 |
| 10.9.2 | Method for the Production of Berliner Weisse | 254 |
| 10.10 | Porter | 254 |
| 10.10.1 | Introduction | 254 |
| 10.10.2 | Method for the Production of Porter Bier | 255 |
| 10.11 | Summary | 255 |
| | References | 255 |
| 11 | Beer-Based Mixed Drinks | 257 |
| | <i>Oliver Franz, Martina Gastl, and Werner Back</i> | |
| 11.1 | Development of Beer-Based Mixed Drinks | 258 |
| 11.2 | Ingredients and Mixing Formulations | 260 |
| 11.2.1 | Constituent Beer | 260 |

| | | |
|-----------|--|------------|
| 11.2.2 | Water Quality | 261 |
| 11.2.3 | Sweetening | 261 |
| 11.2.3.1 | Sweetening Agents | 261 |
| 11.2.4 | Food Acids | 262 |
| 11.2.5 | Flavor and Juices | 263 |
| 11.3 | Quality Control of Beer-Based Mixed Drinks | 263 |
| 11.3.1 | Wet Chemical Analysis | 263 |
| 11.3.2 | Sensory Assessment of Beer-Based Mixed Drinks | 264 |
| 11.3.3 | Assessment by the Deutsche Landwirtschafts-Gesellschaft (DLG) (German Agricultural Society) | 264 |
| 11.3.4 | Off-flavors | 266 |
| 11.4 | Microbiology of Beer-Based Mixed Drinks | 268 |
| 11.5 | Preservation of the Final Beverage | 269 |
| 11.5.1 | Use of Antioxidants | 269 |
| 11.5.2 | Use of Preserving Agents | 269 |
| 11.5.3 | Thermal Processes – Pasteurization | 269 |
| 11.6 | Technological Aspects for the Production of Beer-Based Mixed Drinks | 270 |
| 11.6.1 | Mixing | 270 |
| 11.6.2 | Filtration | 271 |
| 11.6.3 | Filling | 272 |
| 11.6.4 | Influence of the Packaging | 272 |
| 11.7 | Technical Equipment for the Production of Beer-Based Mixed Drinks | 273 |
| | References | 273 |
| 12 | Filling | 275 |
| | <i>Susanne Blüml</i> | |
| 12.1 | Choice of Packaging | 275 |
| 12.1.1 | Glass Bottles | 275 |
| 12.1.2 | Cans | 277 |
| 12.1.3 | Plastic Bottles | 278 |
| 12.1.4 | Kegs | 280 |
| 12.2 | Framework Conditions for Filling Beer | 281 |
| 12.2.1 | Significance of the Gases | 282 |
| 12.2.1.1 | Oxygen Content | 282 |
| 12.2.1.2 | CO ₂ Content | 283 |
| 12.2.2 | Filling Pressure | 284 |
| 12.2.3 | Temperature | 285 |
| 12.3 | Process Steps When Filling Beer | 285 |
| 12.3.1 | Evacuation | 285 |
| 12.3.2 | Flushing with Ring-Bowl or Pure Gas | 287 |
| 12.3.2.1 | Flushing with Ring-Bowl Gas | 288 |
| 12.3.2.2 | Flushing with Pure Gas | 288 |
| 12.3.3 | Pressurization | 288 |

| | | |
|----------|--|-----|
| 12.3.4 | Filling | 288 |
| 12.3.5 | Settling and Snifting | 290 |
| 12.4 | Filling Systems for Beer | 290 |
| 12.4.1 | Mechanical Level-Controlled Filling Systems | 290 |
| 12.4.1.1 | Mecafill VKPV – The Mechanical System for Bottling Beer | 292 |
| 12.4.2 | Electronic Level-Controlled Filling Systems | 292 |
| 12.4.2.1 | Sensometric VPVI – Filling With an Electronic Probe | 294 |
| 12.4.2.2 | Sensometric VPL-PET – Probe-Controlled Long-Tube Filler for Single-Chamber and Multi-Chamber Operation | 295 |
| 12.4.3 | Electronic Volumetric Filling Systems | 296 |
| 12.4.3.1 | Volumetric VOC – The Can Filler | 297 |
| 12.4.3.2 | Volumetric VODM-PET – Filling With Flow-Metered Quantitative Measurement | 300 |
| 12.4.4 | Associated System Modules | 301 |
| 12.4.4.1 | Fobbing | 301 |
| 12.4.4.2 | Crowners | 303 |
| 12.4.4.3 | Screw-Cappers for Plastic Screw Caps | 304 |
| 12.5 | Constituent Parts of a Bottling Line | 305 |
| 12.5.1 | Bottle Washer | 305 |
| 12.5.1.1 | Treatment zones | 306 |
| 12.5.1.2 | Components of a Bottle Washer | 307 |
| 12.5.1.3 | Typical Bottle Treatment Sequence | 311 |
| 12.5.2 | Inspection and Monitoring Units | 313 |
| 12.5.2.1 | Machine Types | 313 |
| 12.5.2.2 | Inspection Tasks | 316 |
| 12.5.2.3 | Inspection Technology | 318 |
| 12.5.2.4 | Reliability of the Inspectors | 319 |
| | References | 320 |

13 Labeling 321

Jörg Bückle

| | | |
|--------|--|-----|
| 13.1 | Some Basic Remarks on Machine Construction | 321 |
| 13.2 | Wet-Glue Labeling | 324 |
| 13.2.1 | Foiling | 326 |
| 13.3 | Hotmelt Labeling | 327 |
| 13.3.1 | Hotmelt Labeling with Pre-cut Labels | 328 |
| 13.3.2 | Reel-Fed Hotmelt Labeling | 330 |
| 13.3.3 | Roll on/Shrink on | 331 |
| 13.3.4 | Tamper-Evident Seals | 332 |
| 13.4 | Pressure-Sensitive Labeling | 332 |
| 13.5 | Sleeving | 334 |
| 13.5.1 | Stretch-Sleeve Process | 335 |
| 13.5.2 | Shrink-Sleeve Process | 336 |
| 13.6 | Date Coding and Identification | 337 |

| | | |
|-------------------------|---|------------|
| 14 | Beer Dispensing | 339 |
| <i>Reinhold Mertens</i> | | |
| 14.1 | Beer Quality in the Draft Beer System | 339 |
| 14.1.1 | Temperature | 339 |
| 14.1.2 | Time on Tap | 339 |
| 14.1.3 | CO ₂ Content | 339 |
| 14.1.4 | Foamhead | 341 |
| 14.1.5 | Pouring the Beer | 341 |
| 14.2 | Design of Draft Beer Systems | 341 |
| 14.2.1 | Requirements for Rooms | 341 |
| 14.2.2 | Requirements for Refrigeration | 342 |
| 14.2.2.1 | Storage/Cabinet Cooling | 342 |
| 14.2.2.2 | Ancillary Cooling | 342 |
| 14.2.2.3 | Bar Cooling | 342 |
| 14.2.3 | Requirements for Beer Lines | 342 |
| 14.2.4 | Requirements for CO ₂ Lines | 343 |
| 14.2.5 | Requirements for Beer Bars/Bar Counter | 343 |
| 14.2.6 | Requirements for Glass-Washing Equipment | 343 |
| 14.2.6.1 | Two-Sink Installation | 343 |
| 14.2.6.2 | Glass Cleaning System | 343 |
| 14.2.6.3 | Glass Washing Machines | 344 |
| 14.2.7 | Calculation of Applied Gauge Pressure | 344 |
| 14.3 | Dispensing | 346 |
| 14.3.1 | Types of Dispensing | 346 |
| 14.3.1.1 | Dispensing from Underneath the Beer Bar | 346 |
| 14.3.1.2 | Dispensing from above the Beer Bar | 346 |
| 14.3.1.3 | Dispensing Direct from the Beer Bar | 346 |
| 14.3.2 | Dispensing with Beer Pumps | 346 |
| 14.3.3 | Dispensing Beer with Pre-mixed Gas (CO ₂ /N ₂) | 348 |
| 14.3.4 | Use of Gas Blenders | 349 |
| 14.3.5 | Computerized Beer Dispensing | 349 |
| 14.3.6 | Beer-Dispensing Tanks | 350 |
| 14.4 | Parts of Draft Beer Systems | 350 |
| 14.4.1 | Requirements for Gas-Pressurized Parts | 350 |
| 14.4.2 | Requirements for Beverage Parts | 351 |
| 14.4.3 | Keg-Tapping Equipment | 351 |
| 14.5 | Hygiene Requirements in Draft Beer Systems | 352 |
| 14.5.1 | Hygiene Target | 352 |
| 14.5.2 | Cleaning and Disinfecting Procedures | 353 |
| 14.5.3 | Hygiene Problem Areas | 354 |
| 14.6 | Testing | 355 |
| 14.6.1 | Hygiene Testing | 355 |
| 14.6.2 | Leak Tests | 355 |
| 14.6.3 | Temperature Tests | 355 |
| 14.7 | Safety Precautions | 356 |

| | | |
|-----------|---|------------|
| 14.7.1 | CO ₂ Gas Alert Units | 356 |
| 14.8 | Final Remarks | 356 |
| | Reference | 357 |
| 15 | Properties and Quality | 359 |
| | <i>August Gresser</i> | |
| 15.1 | Composition of Finished, Bottom-Fermented Beer | 359 |
| 15.2 | Overall Qualities of Bottom-Fermented Beer | 360 |
| 15.3 | Redox Potential | 360 |
| 15.4 | Beer Color | 360 |
| 15.5 | Taste of Beer | 361 |
| 15.6 | Beer Foam | 361 |
| 15.6.1 | Basis of Beer Foam | 362 |
| 15.6.2 | Influence of Gas | 362 |
| 15.6.3 | Influence of Foam Stability | 362 |
| 15.6.4 | Influence of Brewing Liquor | 362 |
| 15.6.5 | Influence of Hop Products | 363 |
| 15.6.6 | Influence of Malt | 363 |
| 15.6.7 | Influence of Mash Filtration | 363 |
| 15.6.8 | Wort Boiling | 363 |
| 15.6.9 | Cold Break Removal | 364 |
| 15.6.10 | Main Fermentation | 364 |
| 15.6.11 | Storage Conditions | 364 |
| 15.6.12 | Beer Filtration | 365 |
| 15.6.13 | Precocious Indicators for the Foam Appearance | 365 |
| 15.6.14 | Conclusion | 365 |
| 15.7 | Bitter Substances in Hops | 366 |
| 15.7.1 | Influence of Cohumulone on the Bittering Quality | 368 |
| 15.7.2 | Influence of Cohumulone on Foam Stability | 369 |
| 15.7.3 | The Influence of Cohumulones on Beer Aging | 369 |
| 15.8 | Aroma Substances in Hops | 371 |
| 15.9 | Polyphenols in Beer Production | 371 |
| 15.9.1 | Definition of Polyphenols | 373 |
| 15.9.2 | Origin of Polyphenols | 373 |
| 15.9.2.1 | Malt Polyphenols | 373 |
| 15.9.2.2 | Hop Polyphenols | 374 |
| 15.9.4 | Polphenolic-Related Reactions during Brewing | 379 |
| 15.9.4.1 | Reaction with Proteins | 379 |
| 15.9.4.2 | Influence of Hops | 379 |
| 15.9.4.3 | Advantages and Disadvantages | 379 |
| 15.9.5 | Value of Anthocyanogens and Other Beer Characteristics | 380 |
| 15.9.6 | Reaction Path of Polyphenolic Components during the Brewing Process | 380 |
| 15.9.7 | Conclusions | 381 |
| 15.10 | N-Heterocycles | 381 |

| | | |
|-----------|--|-----|
| 15.10.1 | Presence of Heterocycles | 381 |
| 15.10.2 | N-Heterocycles in the Malting Process | 383 |
| 15.10.3 | Mashing Conditions | 383 |
| 15.10.4 | Wort Boiling | 386 |
| 15.11 | DMS | 386 |
| 15.11.1 | Formation of DMS | 386 |
| 15.11.2 | Barley and Malt | 387 |
| 15.11.3 | Temperature | 387 |
| 15.11.4 | Withering and Kilning | 387 |
| 15.11.5 | Malt Cleaner | 388 |
| 15.11.6 | Brewhouse | 388 |
| 15.12 | Gushing (Uncontrolled Overflow or Overfoaming of Beer) | 389 |
| 15.12.1 | General | 389 |
| 15.12.2 | Determination of the Gushing Behavior of Beer Induced by Raw Materials | 389 |
| 15.12.3 | Metal Ions in Bottled Beer | 389 |
| 15.12.4 | Precipitation of Calcium Oxalate Crystals | 390 |
| 15.12.5 | Filter Media | 392 |
| 15.12.6 | Malt-Induced Gushing | 392 |
| 15.12.7 | Chemical Components Causing Gushing | 394 |
| | References | 395 |
| 16 | Stability of Beer | 399 |
| | <i>August Gresser</i> | |
| 16.1 | Flavor Stability | 399 |
| 16.1.1 | Introduction | 399 |
| 16.1.2 | Reasons for Beer Aging | 401 |
| 16.1.3 | Changes of Aromatic Compounds | 402 |
| 16.1.4 | Definition of Indicator Substances | 403 |
| 16.1.5 | Technological Measurements to Preserve Organoleptic Stability | 404 |
| 16.1.5.1 | Barley Variety | 404 |
| 16.1.5.2 | Germination | 405 |
| 16.1.5.3 | Wort Preparation | 409 |
| 16.1.5.4 | Mash Filtration | 413 |
| 16.1.5.5 | Wort Boiling | 413 |
| 16.1.5.6 | Hot Break Removal | 414 |
| 16.1.5.7 | Flotation (Removal of Cold Break) | 414 |
| 16.1.5.8 | Yeast Handling | 414 |
| 16.1.5.9 | Fermentation and Maturation | 417 |
| 16.1.5.10 | Filtration | 418 |
| 16.1.5.11 | Filling | 420 |
| 16.1.5.12 | Analytical Control of Flavor Stability and Stale Flavor Compounds | 422 |
| 16.2 | Lightstruck Flavor | 423 |
| 16.3 | Colloidal Stability of Beer | 428 |

| | | |
|----------|--|-----|
| 16.3.1 | Introduction | 428 |
| 16.3.1.1 | Composition of Turbidity in Beer | 430 |
| 16.3.2 | Mechanism of Turbidity Formation | 430 |
| 16.3.3 | Influence of Raw Materials and Auxiliary Materials | 431 |
| 16.3.4 | Brewhouse | 431 |
| 16.3.4.1 | Malt Milling | 431 |
| 16.3.4.2 | Mashing Procedure | 431 |
| 16.3.4.3 | Mash Filtration | 431 |
| 16.3.4.4 | Wort Boiling | 431 |
| 16.3.4.5 | Hot Break | 431 |
| 16.3.5 | Fermentation and Storage | 432 |
| 16.3.6 | Filtration | 432 |
| 16.4 | Stabilization Systems | 432 |
| | References | 434 |

17 Analysis and Quality Control 437

Heinz-Michael Anger, Stefan Schildbach, Diedrich Harms, and Katrin Pankoke

| | | |
|----------|--|-----|
| 17.1 | Introduction | 437 |
| 17.2 | Analyses | 439 |
| 17.2.1 | Density, Extract, Alcohol Content, Original Gravity and Degree of Fermentation | 440 |
| 17.2.2 | Photometric Measurements | 444 |
| 17.2.2.1 | Color | 445 |
| 17.2.2.2 | Free Amino Nitrogen (FAN) | 446 |
| 17.2.2.3 | Bitter Units | 446 |
| 17.2.2.4 | Photometric Iodine Reaction | 446 |
| 17.2.2.5 | Thiobarbituric Acid Index (TBI) | 446 |
| 17.2.2.6 | Total Polyphenols and Anthocyanogens | 447 |
| 17.2.2.7 | Ions | 447 |
| 17.2.2.8 | α -Amylases According to EBC/ASBC: Dextrinizing Units | 447 |
| 17.2.2.9 | Other Photometric Measurements | 447 |
| 17.2.3 | pH Measurement | 448 |
| 17.2.4 | Conductivity | 449 |
| 17.2.5 | Titration Methods | 449 |
| 17.2.5.1 | Acid–Base Titration | 449 |
| 17.2.5.2 | Complexometric Titration | 450 |
| 17.2.5.3 | Manganometric Titration | 450 |
| 17.2.5.4 | Diastatic Power: Iodometric Titration | 450 |
| 17.2.6 | Determination of Nitrogenous Compounds | 451 |
| 17.2.6.1 | Determination According to Kjeldahl | 451 |
| 17.2.6.2 | Determination According to Dumas (Combustion Method) | 451 |
| 17.2.6.3 | Near-IR Transmission Spectroscopy | 451 |
| 17.2.6.4 | Fractions of Nitrogenous Compounds | 452 |
| 17.2.7 | Carbon Dioxide | 453 |

| | | |
|-----------|---|-----|
| 17.2.8 | Measurement of Oxygen | 454 |
| 17.2.9 | Measurement of Chlorine Dioxide by a Sensor | 455 |
| 17.2.10 | Head Retention (Foam) | 455 |
| 17.2.11 | Turbidity and Non-Biological Stability | 456 |
| 17.2.12 | Viscosity | 457 |
| 17.2.13 | Congress Mash | 458 |
| 17.2.14 | Spent Grain Analysis | 459 |
| 17.2.15 | Friabilimeter | 459 |
| 17.2.16 | Grading | 460 |
| 17.2.17 | Hand Assessment | 460 |
| 17.2.18 | Homogeneity and Modification | 460 |
| 17.2.19 | Protein Electrophoreses | 460 |
| 17.2.20 | Gushing | 461 |
| 17.2.21 | Hop Bitter Substances | 461 |
| 17.2.22 | Continuous Flow Analysis (CFA) | 461 |
| 17.2.23 | Chromatographic Analyses | 461 |
| 17.2.23.1 | High Performance Liquid Chromatography (HPLC) | 462 |
| 17.2.23.2 | Gas Chromatography (GC) | 463 |
| 17.2.24 | Enzymatic Analyses | 464 |
| 17.2.25 | Determination of the Calorific Value of Beer | 466 |
| 17.2.26 | Atomic Absorption Spectroscopy (AAS) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) | 466 |
| 17.2.27 | Sulfur Dioxide: Distillation Method | 467 |
| 17.2.28 | Emzyme Linked Immuno Sorbent Assay (ELISA) | 468 |
| 17.2.29 | Electron Spin Resonance Spectroscopy (ESR) | 469 |
| 17.3 | Analyses in Daily Quality Control | 469 |
| | References | 473 |
| 18 | Microbiology | 477 |
| | <i>Werner Back</i> | |
| 18.1 | Microflora in the Brewery | 477 |
| 18.2 | Manufacturing Cultures | 479 |
| 18.3 | Foreign Yeasts | 480 |
| 18.4 | Beer-Spoilage Bacteria | 481 |
| 18.5 | Detection of Beer Pests | 484 |
| | References | 490 |
| 19 | Certification | 491 |
| | <i>Bernd Lindemann</i> | |
| 19.1 | Management Systems and Business Management | 491 |
| 19.2 | Management Systems Standards | 491 |
| 19.2.1 | DIN EN ISO 9000, 9001 and 9004 | 492 |
| 19.2.2 | DIN EN ISO 14001 | 492 |
| 19.2.3 | DIN EN ISO 22000 | 492 |
| 19.2.4 | Global Food Safety Initiative | 493 |

| | | |
|-----------|--|-----|
| 19.2.5 | IFS | 493 |
| 19.2.6 | BCR | 494 |
| 19.2.7 | DIN EN ISO 17025 | 494 |
| 19.3 | Principles and Similarities | 494 |
| 19.4 | Legal Requirements | 495 |
| 19.4.1 | Regulation (EU) 178 | 495 |
| 19.4.2 | Regulation (EU) 852 | 495 |
| 19.5 | Certification According to ISO Standards | 495 |
| 19.6 | Certification through IFS and BCR | 496 |
| 19.7 | Certification through HACCP | 496 |
| 20 | World Beer Market | 497 |
| | <i>Jens Christoph Riese and Hans Michael Eßlinger</i> | |
| 20.1 | Introduction | 497 |
| 20.2 | Statistics | 498 |
| 20.2.1 | Raw Materials for Brewing | 498 |
| 20.2.1.1 | Barley and Malt Market | 498 |
| 20.2.1.2 | Global Malt Production | 501 |
| 20.2.2 | Beer Consumption | 503 |
| 20.2.3 | Beer Styles | 503 |
| 20.2.4 | Packaging | 505 |
| 20.3 | Beer Markets and Their Key Players in 2004 | 505 |
| 20.3.1 | Beer Markets | 507 |
| 20.3.1.1 | Europe | 507 |
| 20.3.1.2 | America | 508 |
| 20.3.1.3 | Asia | 509 |
| 20.3.1.4 | Africa | 509 |
| 20.3.1.5 | Australia and Pacific Beer Markets | 509 |
| 20.3.1.6 | Profitability | 510 |
| 20.3.2 | World's Top Brewers | 510 |
| 20.3.3 | Branding in the Global Brewing Industry | 511 |
| | References | 513 |
| 21 | Physiology and Toxicology | 515 |
| | <i>Manfred Walzl</i> | |
| 21.1 | Astounding Health Benefits of Beer | 515 |
| 21.2 | Beer and Alcohol | 521 |
| 21.3 | Beer and Cancer | 521 |
| 21.4 | Beer Helps to Protect the Stomach and the Arteries | 522 |
| 21.5 | Lower Risk of Developing Kidney Stones | 522 |
| 21.6 | Ideal Sports Drink | 523 |
| 21.7 | Improved Concentration, Better Performance and Quicker Reactions | 523 |
| 21.8 | Against Bacteria | 524 |
| 21.9 | Beer Removes Metals from the Organism | 524 |

| | | |
|-----------|--|------------|
| 21.10 | Beer is ‘Clean’ | 525 |
| 21.11 | Beer Makes Beautiful | 525 |
| 21.12 | Beneficial Minerals | 526 |
| 21.13 | Legend of the Beer Belly | 527 |
| 21.14 | ‘Beer Prescription’ | 527 |
| | References | 528 |
| 22 | Automation | 531 |
| | <i>Georg Breithauer, Jens Uwe Müller, and Markus Ruchter</i> | |
| 22.1 | Introduction | 531 |
| 22.2 | Measurement Technology | 533 |
| 22.2.1 | Level | 534 |
| 22.2.2 | Temperature | 534 |
| 22.2.3 | pH Value | 536 |
| 22.2.4 | Pressure | 536 |
| 22.2.5 | Flow | 536 |
| 22.2.6 | Conductivity | 537 |
| 22.2.7 | Oxygen | 538 |
| 22.2.8 | Turbidity | 539 |
| 22.2.9 | Dosing | 541 |
| 22.2.10 | Limit Monitors | 541 |
| 22.2.11 | ‘In-Line’ Measurement | 541 |
| 22.3 | Control Strategies | 542 |
| 22.3.1 | Classic Algorithms | 542 |
| 22.3.2 | Advanced Algorithms | 543 |
| 22.3.3 | Advanced Control of the Lauter Tun | 545 |
| 22.3.3.1 | Description of the Lauter Tun | 545 |
| 22.3.3.2 | Process Characteristics | 547 |
| 22.3.3.3 | Structure of the Controller | 548 |
| 22.3.3.4 | Results | 548 |
| 22.4 | Process Control System (PCS) | 550 |
| 22.5 | Information Technologies | 551 |
| 22.6 | Conclusions | 552 |
| | References | 554 |
| 23 | Malthouse and Brewery Planning | 555 |
| | <i>Walter Flad</i> | |
| 23.1 | Malthouse Planning | 555 |
| 23.1.1 | Introduction | 555 |
| 23.1.2 | Storage of Barley and Malt | 555 |
| 23.1.3 | Steeping | 556 |
| 23.1.4 | Germination | 556 |
| 23.1.5 | Kilning | 557 |
| 23.1.6 | Show Case Malting Plant | 557 |
| 23.1.6.1 | Design of the Steeping, Germination and Kilning Tower | 557 |

| | | |
|-----------|--|-----|
| 23.1.6.2 | Calculations | 560 |
| 23.1.7 | Consumption Data | 561 |
| 23.2 | Brewery Planning | 562 |
| 23.2.1 | Brewhouse | 563 |
| 23.2.2 | Wort Cooling | 564 |
| 23.2.3 | Malt Silos and Malt Treatment | 564 |
| 23.2.4 | Fermenting, Maturation and Storage Tanks | 565 |
| 23.2.5 | Yeast Management | 566 |
| 23.2.6 | Filtration | 566 |
| 23.2.7 | Bright Beer Tanks | 566 |
| 23.2.8 | Bottling Plant | 567 |
| 23.2.9 | Kegging Plant | 567 |
| 23.2.10 | Space Requirement of Full Packs and Returned Empties | 567 |
| 23.2.11 | Utilities and Power Supply | 568 |
| 23.2.11.1 | Supply with Heat | 568 |
| 23.2.11.2 | Supply with Coldness | 568 |
| 23.2.11.3 | CO ₂ Recovery | 569 |
| 23.2.11.4 | Supply with Compressed Air | 569 |
| 23.2.11.5 | Supply with Electrical Power | 569 |
| 23.2.11.6 | Supply with Fresh Water | 569 |
| 23.2.12 | Key Figures for New Breweries | 569 |
| 23.2.12.1 | Required Land Area | 569 |
| 23.2.12.2 | Required Investment Costs | 573 |
| 23.2.13 | Documentation and Specifications | 575 |
| | References | 576 |

24 Packaging 577

Jörg Bückle

| | | |
|--------|--|-----|
| 24.1 | Selecting the Suitable Machine Configuration | 577 |
| 24.2 | Packing into Packs Open at the Top | 578 |
| 24.2.1 | Classical Machine Design | 578 |
| 24.2.2 | Robot Technology | 582 |
| 24.3 | Wrap-around Packaging | 584 |
| 24.4 | Shrink-Wrap Packaging | 587 |
| 24.5 | Multipacks Made of Paperboard | 592 |
| 24.6 | Multipacks with a Plastic Carrier | 593 |

25 Cleaning and Disinfecting 595

Udo Praeckel

| | | |
|----------|--------------------------|-----|
| 25.1 | Cleaning | 596 |
| 25.1.1 | Cleaning Agents | 597 |
| 25.1.1.1 | Alkaline Cleaning Agents | 597 |
| 25.1.1.2 | Acidic Cleaning Agents | 599 |
| 25.2 | Disinfecting | 600 |
| 25.3 | Cleaning Methods | 603 |

| | | |
|-----------|--|------------|
| 25.3.1 | Non-Recovery CIP Cleaning Method | 603 |
| 25.3.2 | Recovery Tank CIP Cleaning Method | 604 |
| 25.3.3 | Combined CIP Cleaning Method | 605 |
| 25.4 | Material Compatibility | 611 |
| 25.5 | Cleaning Glass Bottles | 613 |
| 25.5.1 | Bottle-Cleaning Machine | 614 |
| 25.5.1.1 | Residual Draining | 614 |
| 25.5.1.2 | Pre-soak with Pre-spray | 615 |
| 25.5.1.3 | Main Caustic Soaker Bath and Caustic Spray | 615 |
| 25.5.1.4 | Intermediate Spray, Hot- and Cold-Water Zones | 615 |
| 25.5.2 | Use of Chemicals in the Bottle-Washing Machine | 616 |
| 25.6 | Cleaning PET Bottles | 617 |
| 25.7 | Cleaning Barrels | 617 |
| 25.8 | Foam Cleaning | 619 |
| 25.9 | Work Safety and Environmental Protection | 620 |
| 26 | Waste Water | 621 |
| | <i>Karl Glas</i> | |
| 26.1 | Introduction | 621 |
| 26.2 | Characterization of Brewery Waste Water | 621 |
| 26.2.1 | Types of Waste Water | 621 |
| 26.2.2 | Waste water Constituents | 622 |
| 26.2.3 | Analysis of Waste Water | 623 |
| 26.3 | Preliminary Investigations to Determine Waste Water Pollutant Load and to Plan Waste Water Plants | 625 |
| 26.4 | Practical Example of a Waste Water Measurement | 626 |
| 26.4.1 | Determination of Concentration and Volume | 626 |
| 26.4.2 | Load Values | 626 |
| 26.5 | Specific Characteristic Parameters of Waste Water | 627 |
| 26.5.1 | Total Waste Water | 627 |
| 26.5.2 | Split Streams | 629 |
| 26.6 | In-house Measures | 631 |
| 26.6.1 | Classification of In-house Measures | 631 |
| 26.6.2 | Goal of In-house Measures | 632 |
| 26.6.3 | Practical Check-List of In-house Measures for the Production Steps | 632 |
| 26.7 | Waste Water Treatment | 632 |
| 26.7.1 | Neutralization | 632 |
| 26.7.1.1 | Neutralization of Carbonic Acid (CO ₂) | 632 |
| 26.7.1.2 | Neutralization with Flue Gas | 634 |
| 26.7.2 | Mixing and Equalizing Tanks | 634 |
| 26.7.3 | Aerobic Waste Water Treatment | 635 |
| 26.7.3.1 | Activated-Sludge Plant | 635 |
| 26.7.3.2 | High-Performance Reactors | 636 |
| 26.7.3.3 | SBR | 636 |

- 26.7.3.4 Aerated Waste Water Ponds 637
- 26.7.4 Anaerobic Waste Water Treatment 637
- 26.7.4.1 Biochemical Basics 637
- 26.7.5 Combination of Aerobic–Anaerobic Techniques 640
- 26.7.6 Comparison of Anaerobic and Aerobic Techniques 640
- References 641

27 Energy 643

Georg Schu

- 27.1 Introduction 643
- 27.2 Heat Requirements of the Brewery 643
- 27.2.1 Heat Consumption in the Brewery 644
 - 27.2.1.1 Brewhouse 644
 - 27.2.1.2 Service Warm Water 645
 - 27.2.1.3 Keg Cleaning 646
 - 27.2.1.4 Bottle-Rinsing Machinery 646
 - 27.2.1.5 Others (Pasteurization, Flash Pasteurization, CIP) 646
 - 27.2.1.6 Room Heating and System Losses 647
- 27.2.2 Boiler House 647
 - 27.2.2.1 Boiler Plant and Combustion 647
 - 27.2.2.2 Heat Carrier Systems 647
 - 27.2.2.3 Fuels 648
 - 27.2.2.3 Optimization Possibilities: Exhaust Emission Heat Exchanger, Degassing, Oxygen Regulation, Water Treatment and Blow-Off 648
 - 27.2.2.4 Possibilities for Heat Recovery 648
 - 27.2.2.4.1 Wort Cooling 648
 - 27.2.2.4.2 Vapor Condenser 650
 - 27.2.2.4.3 Waste Heat from Vapor Condensate 650
 - 27.2.2.4.4 Waste Heat from Compressed Air 650
 - 27.2.2.4.5 Waste Heat from the Refrigeration System 651
- 27.3 Power Supply 652
 - 27.3.1 Requirement Figures 652
 - 27.3.2 External Power Supply 652
 - 27.3.2.1 Supply and Measurement at the Release Point 652
 - 27.3.2.2 Power Factor Correction 653
 - 27.3.2.3 Supply Contracts 653
 - 27.3.3 Electric Power Consumption of the Brewery 653
 - 27.3.3.1 The Brewhouse 653
 - 27.3.3.2 The Filling Area 654
 - 27.3.3.3 Drive System and Components 655
 - 27.3.3.4 Lighting 655
 - 27.3.3.5 Heat Supply 656
 - 27.3.4 Optimization of the Electrical Power Supply: Load Management 656
 - 27.3.5 Combined Heat and Power (CHP) 657

| | | |
|-----------|--|-----|
| 27.4 | Cold Supply | 657 |
| 27.4.1 | Cooling Requirements | 658 |
| 27.4.1.1 | Design of Fermentation and Storage Cellar | 658 |
| 27.4.1.2 | Location/Climatic Zone | 658 |
| 27.4.2 | Cold Production | 658 |
| 27.4.3 | Goals for an Optimal Cold Supply | 661 |
| 27.5 | Compressed Air Supply | 662 |
| | References | 663 |
| 28 | Environmental Protection | 665 |
| | <i>Jochen Keilbach</i> | |
| 28.1 | Introduction | 665 |
| 28.2 | Environmentally Relevant Subjects in Relation to Brewing | 665 |
| 28.2.1 | Waste Water | 665 |
| 28.2.1.1 | Avoidance of Waste Water by Reduction of Water Usage | 665 |
| 28.2.1.2 | Composition of Brewery Waste Water | 666 |
| 28.2.1.3 | Waste Water Disposal | 667 |
| 28.2.2 | Energy | 668 |
| 28.2.2.1 | Renewable Energy | 669 |
| 28.2.3 | Brewery Emissions | 670 |
| 28.2.3.1 | Gaseous Emissions | 670 |
| 28.2.3.2 | Dust Emissions | 672 |
| 28.2.3.3 | Noise Emission | 672 |
| 28.2.4 | Waste | 673 |
| 28.2.4.1 | Special Brewery-Specific Production Waste | 673 |
| | References | 674 |
| 29 | Sensory Evaluation | 675 |
| | <i>Bill Taylor and Gregory Organ</i> | |
| 29.1 | Introduction to the Five Senses | 675 |
| 29.2 | How to Assess the Flavor of Beer | 676 |
| 29.2.1 | Technique for Flavor Assessment | 677 |
| 29.2.2 | Additional Points | 677 |
| 29.2.3 | Requirements for Attendance | 678 |
| 29.2.4 | Overall Assessment | 678 |
| 29.3 | Description of the Main Flavor Attributes | 679 |
| 29.3.1 | Sulfur Dioxide | 679 |
| 29.3.2 | Hydrogen Sulfide/Mercaptan | 680 |
| 29.3.3 | Dimethylsulfide/Cooked Vegetable | 681 |
| 29.3.4 | Solvent | 682 |
| 29.3.5 | Acetaldehyde | 682 |
| 29.3.6 | Estery/Fruity | 682 |
| 29.3.7 | Hoppy | 683 |

| | | |
|---------|---|-----|
| 29.3.8 | Floral | 684 |
| 29.3.9 | Spicy | 684 |
| 29.3.10 | Fresh Grass | 684 |
| 29.3.11 | Clove/4-VG | 684 |
| 29.3.12 | Grainy/Straw | 685 |
| 29.3.13 | Malty | 685 |
| 29.3.14 | Caramelized | 685 |
| 29.3.15 | Roasted | 685 |
| 29.3.16 | Fatty Acid | 685 |
| 29.3.17 | Butyric | 686 |
| 29.3.18 | Cheesy | 686 |
| 29.3.19 | Diacetyl | 686 |
| 29.3.20 | Yeasty | 686 |
| 29.3.21 | Oxidized | 687 |
| 29.3.22 | Acidic/Sour | 687 |
| 29.3.23 | Alcoholic | 688 |
| 29.3.24 | Body | 688 |
| 29.3.25 | Sweetness | 689 |
| 29.3.26 | Bitterness | 689 |
| 29.3.27 | After-bitterness | 690 |
| 29.3.28 | Astringency | 690 |
| 29.3.29 | Metallic | 690 |
| 29.4 | Sensory Evaluation Environment | 691 |
| 29.4.1 | Panel Leader | 691 |
| 29.4.2 | Sensory Manual | 692 |
| 29.4.3 | Panel Motivation | 692 |
| 29.5 | Types of Sensory Tests | 693 |
| 29.5.1 | Paired Comparison Test | 693 |
| 29.5.2 | Duo-Trio Test | 693 |
| 29.5.3 | Triangle Test | 693 |
| 29.5.4 | Flavor Profile and Rating Test | 693 |
| 29.5.5 | Fresh and Aged Test | 694 |
| 29.6 | Selection, Training and Validation of Panelists | 694 |
| 29.7 | Building a Sensory Capability | 695 |
| 29.7.1 | Training Programme Overview | 695 |
| 29.7.2 | Level 1 – Difference Panelist | 696 |
| 29.7.3 | Level 2 – ‘Beer Quality Acceptance’ Panelist | 696 |
| 29.7.4 | Level 3 – ‘Profile’ Panelist | 698 |
| 29.7.5 | On-going Level 3 Performance Monitoring | 699 |
| 29.8 | Applications for Flavor Assessment | 699 |
| 29.8.1 | In-Process Sample Testing | 699 |
| 29.8.2 | Final Beer Testing | 700 |
| 29.8.3 | Consumer Research | 700 |
| | References | 701 |

| | | |
|-----------|--|-----|
| 30 | Technical Approval of Equipment | 703 |
| | <i>Walter Flad and Hans Michael Eßlinger</i> | |
| 30.1 | Generalities | 703 |
| 30.2 | Technical Approval of Brewhouses | 703 |
| 30.3 | Technical Approval of Filling Lines | 704 |
| 30.3.1 | Efficiency tests according to DIN 8782 | 705 |
| 30.3.2 | Reporting of Efficiency Tests | 706 |
| 30.4 | Other Key Figures | 706 |
| | References | 708 |
| | Index | 709 |