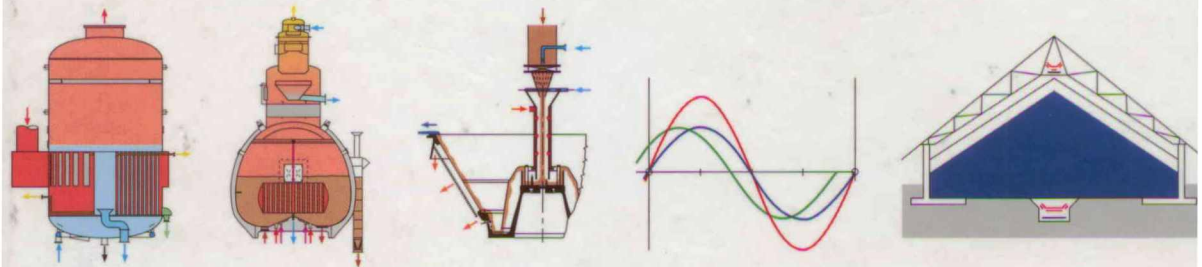


Peter Rein

Cane Sugar Engineering



▼ Bartens

Contents

About the author	5	2.1.2	Effect on recoverable sugar	43
Preface	7	2.1.3	Effect on mill capacity	45
Contributors	9	2.1.4	Field soil and dirt	46
List of symbols	23	2.1.5	Dextran	46
List of subscripts	25	2.1.6	Effect on mill costs	46
Abbreviations	26	2.2	Cane payment systems	47
Terminology	27	2.2.1	Options for payment	47
1 SUGARCANE	31	2.2.2	Cane payment recoverable sugar formulae	47
1.1 Structure of cane	32	2.2.3	Distribution of proceeds between growers and millers	48
1.1.1 Anatomy of the cane stalk	32	2.3	Cane sampling	49
1.1.2 Location of sucrose and impurities	34	2.3.1	Core sampling of cane	49
1.1.3 Definitions of components	34	2.3.2	Hatch sampling	50
1.2 Composition of cane	35	2.3.3	Grab sampling	51
1.2.1 Clean stalk	35	2.3.4	First expressed juice sampling	51
1.2.2 Tops and leaves	35	2.3.5	Cane tracking	52
1.2.3 Typical composition of delivered cane	36	2.4	Methods of analysis	52
1.2.4 Composition of fiber	37	2.4.1	Press method	52
1.2.5 Nonsucrose in cane	38	2.4.2	Wet disintegration method	53
1.2.6 Extraneous matter	39	2.4.3	First expressed juice	53
1.2.7 Effect of cane delays	39	2.4.4	Accurate measurement of sucrose by chromatography	54
1.2.8 Effect of cane variety	41	2.4.5	NIR Measurements	54
1.2.9 Changes due to climatic conditions and time of season	41		References	56
References	42	3	✓ SUPPLY AND HANDLING OF SUGARCANE	59
2 CANE EVALUATION AND PAYMENT	43	3.1	Harvesting, transport and storage of cane	59
2.1 Evaluation of cane quality	43	3.1.1	Harvesting methods	59
2.1.1 Quality parameters	43	3.1.2	Transport systems	62
		3.1.3	Bundle handling	63
		3.1.4	Container systems	63
		3.1.5	Cane weighing	63
		3.1.6	Storage systems	63

3.1.7	Damage and deterioration of cane	63	5	MILLING	99
3.2	Unloading cane	64	5.1	Extraction by mills	99
3.2.1	Tippers	64	5.1.1	Extraction	99
3.2.2	Spillers	65	5.1.2	Other measures of mill performance	100
3.2.3	End-tipping trucks	65	5.2	Theory of milling	101
3.2.4	Gantry cranes	66	5.2.1	Basic volumetric model	101
3.3	Cane tables and cross carriers	66	5.2.2	Assumptions for simple model	101
3.3.1	Feeder tables	66	5.2.3	Cane throughput formulae	102
3.3.2	Spiller tables	66	5.2.4	Feed ratio for maximum throughput	102
3.4	Cane cleaning	67	5.2.5	Compaction ratio, compression ratio and fiber fills	102
3.4.1	Dry cleaning	67	5.2.6	Fiber with extracted juice ("cush cush")	103
3.4.2	Cane washing	69	5.2.7	Non-cylindrical rolls	103
3.4.3	Wash water handling and waste disposal	70	5.2.8	Floating rolls	103
3.5	Cane conveying	71	5.2.9	Friction and feed opening	104
3.5.1	Apron carriers	71	5.2.10	Influence of roll diameter on mill feeding	104
3.5.2	Belt conveyors	72	5.2.11	Reabsorption, shearing in the cane and slip	105
3.5.3	Chain and slat conveyors	73	5.2.12	Mill load and torque	106
3.5.4	Magnets	74	5.3	Mills and mill components	107
3.5.5	Conveyor drives and automatic control	74	5.3.1	Conventional mills	107
	References	76	5.3.2	Headstocks	108
4	CANE PREPARATION	79	5.3.3	Mill rolls	109
4.1	Objectives and measurement of cane preparation	79	5.3.4	Roll grooving	112
4.1.1	Objectives	79	5.3.5	<i>Messchaert</i> grooves	113
4.1.2	Effect of cane preparation on extraction	80	5.3.6	Lotus rolls	114
4.1.3	Measurement of cane preparation	81	5.3.7	Mill hydraulics and loadings	114
4.2	Cane knives	83	5.3.8	Mill bearings	115
4.2.1	Leveler knives	83	5.3.9	Mill pinions	116
4.2.2	Cane knifing arrangements	83	5.3.10	Trash plates and scrapers	116
4.2.3	Knife speeds and power requirements	84	5.4	Two-roll mills	117
4.2.4	Details of knives and rotors	85	5.4.1	Stork-Werkspoor development	117
4.3	Shredders	86	5.4.2	STG-FCB	117
4.3.1	Types of shredder	86	5.4.3	Bundaberg's high extraction mill	117
4.3.2	Shredder feeding	87	5.4.4	Fives Cail extraction unit	118
4.3.3	Factors affecting the preparation achieved	89	5.5	Mill drives	119
4.3.4	Shredder size and throughput	90	5.5.1	Mill drive power requirements	119
4.3.5	Hybrid shredders	90	5.5.2	Prime movers for mills	119
4.3.6	Technical details of heavy duty shredder design	92	5.5.3	Mill gearing	122
4.3.7	Power requirements for cane preparation	94	5.5.4	Mill couplings and tail bars	123
4.3.8	Prime mover requirements	96	5.6	Cane preparation	124
4.4	Operation and maintenance	97	5.7	Mill settings	125
	References	98	5.7.1	Mill roll settings	125
			5.7.2	Adjustment for top roll float	127
			5.7.3	Pressure feeder settings	127
			5.7.4	Underfeed roll settings	127
			5.7.5	Chute openings	127
			5.7.6	Trash plate settings	128

5.7.7	Practical optimization of mill settings	129	6.2.7	Interstage juice application	159
5.8	Imbibition and related issues	129	6.2.8	Instrumentation and control	160
5.8.1	Imbibition	129	6.3	Recycle of clarifier mud	160
5.8.2	Implications of cush with extracted juice	133	6.4	Factors affecting diffuser work	161
5.8.3	Maceration and maceration carriers	133	6.4.1	Cane preparation	161
5.8.4	Juice recycling	134	6.4.2	Cane residence time	162
5.8.5	Low-pressure extraction	134	6.4.3	Imbibition rate	162
5.8.6	Mill drainage	134	6.4.4	Number of stages	163
5.9	Mill feeding	134	6.4.5	Percolation rate and flooding	163
5.9.1	Roll surface preparation	135	6.4.6	Temperature	163
5.9.2	Chevrons	135	6.5	Dewatering of bagasse	163
5.9.3	Pusher feeders	135	6.6	Control and operation of diffusers	165
5.9.4	<i>Donnelly</i> chutes	135	6.6.1	Monitoring of efficiency of extraction	165
5.9.5	Pressure feeders	137	6.6.2	Control of feed of cane and bed speed	166
5.9.6	Toothed pressure feeders	138	6.6.3	Control of percolation in diffusers	166
5.10	Mill capacity	138	6.6.4	pH control	167
5.10.1	Individual mill size and capacity	139	6.6.5	Corrosion control in diffusers	167
5.10.2	Milling tandem capacity	139	6.6.6	Maintenance of diffusers	168
5.10.3	Number of mills	140	6.6.7	Microbiology of extraction	168
5.10.4	Mill speed	141	6.7	Comparison with milling	169
5.11	Mill control	141	6.7.1	Capital costs	169
5.11.1	Throughput and other mill controls	141	6.7.2	Maintenance and operating costs	169
5.11.2	Routine mill tests	142	6.7.3	Effect on steam balance and power requirements	169
5.11.3	Mill lift and hydraulic pressures	144	6.7.4	Effect on raw juice quality	170
5.11.4	Mill operation	144	6.7.5	Juice screening and filtration	171
5.12	Sucrose losses along the milling train	144	6.7.6	Effect on overall sucrose recovery	171
5.12.1	Physical losses	144	6.7.7	Effect on operations	172
5.12.2	Sucrose destruction losses	144	6.7.8	Expansion of mill and diffuser capacity	172
5.12.3	Measurement and control of sucrose destruction	145	6.7.9	Maximum capacity of a single extraction line	173
5.12.4	Cane payment implications	145		References	173
	References	146			
✓ 6	CANE DIFFUSION	149	✓ 7	MILL AND BAGASSE CONVEYORS	175
6.1	Theory	149	7.1	Mill intercarriers	175
6.1.1	Mechanism of extraction	149	7.1.1	Apron intercarriers	175
6.1.2	Variables affecting extraction	150	7.1.2	Belt-type intercarriers, low incline	176
6.1.3	Fiber packing density	150	7.1.3	Chain-and-slat scraper intercarriers	176
6.1.4	Juice holdup	151	7.1.4	Belt-type intercarriers	181
6.1.5	Juice percolation rates	151	7.1.5	<i>Meineke</i> chute conveyors	182
6.1.6	Mass and energy balances	153	7.2	Bagasse conveyors	183
6.1.7	Sizing of diffusers	154	7.2.1	Bagasse belt conveyors	183
6.2	Plant and equipment	154	7.2.2	Bagasse chain conveyors	186
6.2.1	Types of diffuser	154	7.2.3	Bagasse feeding to boilers	186
6.2.2	Moving bed diffusers	155	7.2.4	Bagasse sampling	187
6.2.3	Cane feed arrangements	156	7.3	Magnets	187
6.2.4	Diffuser drive requirements	157		References	188
6.2.5	Mechanical details	158			
6.2.6	Juice heating	159			

8	RAW JUICE HANDLING	189	9.8	Clarified juice heaters	216
8.1	Juice screening	189	9.8.1	Objectives	216
8.1.1	Types of screen	189	9.8.2	Sizing heaters	217
8.1.2	Cush cush return	192		References	218
8.1.3	Screen cleaning	192			
8.1.4	Screening clarified juice	192	✓ 10	CLARIFICATION	219
8.2	Juice mass flow measurement	193	10.1	Chemical and physical processes	219
8.2.1	Batch scales	193	10.1.1	Objectives of juice clarification	219
8.2.2	Other metering systems	194	10.1.2	Analysis of raw juice	220
8.3	Juice sampling and analysis	194	10.1.3	Effects of heating and lime addition to juice	220
8.3.1	Sampling systems	194	10.1.4	Chemical reactions occurring in simple juice clarification	220
8.3.2	Suspended solids sampling	195	10.1.5	Variants of defecation clarification procedures	221
8.3.3	Pol vs. sucrose analysis	195	10.1.6	Practical procedures for defecation clarification	223
8.4	Juice pumping	195	10.1.7	Optimal pH of clarified juice	224
8.4.1	Pump duties	195	10.1.8	Role of phosphoric acid in juice and additions of phosphate	224
8.4.2	Materials of construction	198	10.2	Lime supply and handling	225
8.4.3	Raw juice tank sizing	198	10.2.1	The quality of lime	225
8.4.4	Juice flow control	199	10.2.2	Lime slaking and handling	225
	References	200	10.2.3	Milk of lime and lime saccharate	226
9	JUICE HEATING	201	10.3	pH control	227
9.1	Theoretical considerations	201	10.4	Types of clarifier	228
9.1.1	Heat balance	201	10.4.1	Description of clarifiers	228
9.1.2	Heat transfer rate	202	10.4.2	Residence times	232
9.1.3	Heat transfer coefficient in tubular juice heaters	203	10.4.3	Flash tanks	233
9.1.4	Use of evaporator vapors	204	10.4.4	Batch settling tests	233
9.2	Tubular heater design	204	10.4.5	Capacities of clarifiers	235
9.2.1	Heat transfer coefficients	205	10.5	Operation of the clarifier station	236
9.2.2	Liquid velocities	206	10.5.1	Clarifier operation	236
9.2.3	Heater area calculations	206	10.5.2	Mud level control, mud consistency	236
9.2.4	Tubular heater details	207	10.5.3	Phosphoric acid and other additives	237
9.2.5	Pressure drop calculations	209	10.5.4	Liquidation	237
9.3	Plate heaters	210	10.6	Flocculants and dosing systems	238
9.4	Direct contact heaters	211	10.6.1	Types of flocculants	238
9.4.1	Sizing of direct contact heaters	212	10.6.2	Physical reactions of flocculation	238
9.4.2	Heater details	212	10.6.3	Flocculant preparation and addition	239
9.4.3	Effect on thermal economy	212	10.6.4	Flocculant testing	239
9.5	Scaling and cleaning	212	10.6.5	Cationic flocculants	239
9.5.1	Scale characterization	212	10.7	Sulfitation	240
9.5.2	Formation of scale	213	10.7.1	Preparation of sulfur dioxide	240
9.5.3	Tube cleaning	213	10.7.2	Sulfur furnaces	240
9.5.4	Vapor side fouling	213	10.7.3	Use of anhydrous liquid sulfur dioxide	241
9.6	Juice flash tanks	213	10.7.4	Sulfur and lime consumption	241
9.6.1	Requirements of flashing	213	10.7.5	Sulfitation apparatus	242
9.6.2	Types of flash tank	214	10.7.6	Sulfitation procedures	242
9.6.3	Sizing of tanks and nozzles	214			
9.6.4	Flow splitting to clarifiers	215			
9.6.5	Temperature control	215			
9.7	Liquid-liquid heaters	216			

10.7.7	Advantages and disadvantages of sulfitation	243	12.2.1	<i>Rillieux's</i> principles	273
10.7.8	Sulfitation of syrup	243	12.2.2	Vapor bleeding	273
	References	244	12.2.3	Cocurrent vs. countercurrent vs. mixed flow systems	274
✓ 11	FILTRATION	245	12.2.4	Heat transfer rates	275
11.1	Mud handling and bagacillo addition	245	12.2.5	Heat losses	277
11.1.1	Mud quantities	245	12.2.6	Quantity of incondensable gases	278
11.1.2	Handling of muds	248	12.3	Multiple effect calculations – shortcut calculations	278
11.1.3	Mud mixers	249	12.4	Multiple effect calculations – rigorous evaporator calculations	280
11.1.4	Bagacillo quantities	250	12.4.1	Derivation of equations	280
11.2	Filter equipment details	251	12.4.2	Calculation by the rigorous method	281
11.2.1	Plate and frame filter press technologies	251	12.4.3	Comparison of the shortcut and rigorous calculation methods	283
11.2.2	Rotary drum vacuum filters	252	12.5	Factors affecting steam economy and capacity	283
11.2.3	Equipment details	252	12.5.1	Influence of number of effects	283
11.2.4	Conditioning of filter feed	255	12.5.2	Effect of vapor bleeds	285
11.2.5	Screens and scrapers	255	12.5.3	Effect of exhaust steam and last vessel absolute pressures	285
11.2.6	Capacity and sizing	256	12.5.4	Effect of clarified juice temperature	286
11.2.7	Level control and filter boot agitation	257	12.5.5	Use of condensate flash	287
11.2.8	Filter cake washing	258	12.5.6	Heating surface distribution	288
11.2.9	Operational control	260	12.6	Evaporator equipment	288
11.2.10	Filter cake analyses and mud solids retention	260	12.6.1	Types of evaporator	288
11.2.11	Cake handling	262	12.6.2	Comparison of types of evaporator	291
11.3	Filtrate handling	262	12.6.3	Pre-evaporators	293
11.3.1	Filtrate quantities	262	12.6.4	Vapor line sizing	294
11.3.2	Filtrate collection and pumping	263	12.7	Design of tubular evaporator vessels	294
11.3.3	Entrainment separation	263	12.7.1	Calandria design	294
11.3.4	Filter condensers	264	12.7.2	Tube and tube plate dimensions and specifications	296
11.3.5	Filtrate clarification	264	12.7.3	Downtakes	297
11.4	Microbiological losses	265	12.7.4	Removal of condensate and incondensable gases	297
11.4.1	Effect of temperature	265	12.7.5	Liquid feed and offtake systems	298
11.4.2	Purity changes and lactic acid monitoring	265	12.7.6	Plate evaporator details	299
	References	266	12.8	Operation of evaporators	299
✓ 12	EVAPORATION	269	12.8.1	Optimum operating conditions	299
12.1	Boiling heat transfer	269	12.8.2	Automatic control of evaporators	300
12.1.1	Range of temperatures and pressures	269	12.8.3	Effect of steam superheat	300
12.1.2	Boiling point elevation	271	12.8.4	Testing for leaks	302
12.1.3	Hydrostatic head	271	12.8.5	Arrangement of vessels in series and parallel	302
12.1.4	Single vessel equations	271	12.8.6	Syrup pumping	302
12.1.5	Definition of the heat transfer coefficient	272	12.8.7	Causes of under-performance	302
12.2	Principles of multiple effect evaporation	273	12.8.8	Sucrose losses in evaporators	303
			12.8.9	pH Change	303
			12.9	Entrainment separation	304

12.9.1	Types of separator	304	13.6	Ejector systems	337
12.9.2	Sizing and design	307	13.6.1	Steam jet ejectors	337
12.10	Condensate removal and flashing	309	13.6.2	Water jet ejectors	338
12.10.1	Piping systems	309	13.7	After coolers	338
12.10.2	Traps and U-legs	309		References	338
12.10.3	Flash pots	310			
12.11	Scaling and cleaning of evaporators	310	✓14	SYRUP CLARIFICATION	339
12.11.1	Occurrence of scaling	310	14.1	Introduction	339
12.11.2	Characterization of scale	312	14.2	Principles involved	340
12.11.3	Anti-scalants	312	14.2.1	Effect of operating parameters	340
12.11.4	Chemical cleaning	312	14.2.2	Effect of added chemicals	341
12.11.5	Mechanical cleaning	314	14.2.3	Aeration of syrup	342
12.11.6	Steam side cleaning	314	14.2.4	Clarification of B and C molasses	342
12.12	Starch and dextran removal	315	14.2.5	Application of syrup clarification in the raw sugar mill	343
12.12.1	Enzyme properties	315	14.3	Benefits of syrup clarification	345
12.12.2	Optimal use of enzyme	315	14.3.1	Sugar quality	345
	References	316	14.3.2	Massecurite viscosity	346
✓13	CONDENSERS AND VACUUM EQUIPMENT	319	14.4	Equipment	346
13.1	Basics	319	14.4.1	Clarifier vessels	346
13.1.1	Absolute pressures required	319	14.4.2	Systems of aeration	347
13.1.2	Water and vapor quantities	320	14.4.3	Scum handling	348
13.1.3	Effect of condenser water temperature	321	14.4.4	In-line mixer	348
13.1.4	Incondensable gas quantity	322	14.5	Operation	349
13.1.5	Total quantity of cooling water used in a factory	323	14.5.1	Control of addition of chemicals	349
13.1.6	Heat recovery	323	14.5.2	Laboratory testing and evaluation	349
13.2	Condensers	324	14.5.3	Scum layer control	350
13.2.1	Condenser arrangements and requirements	324	14.6	Enhancement of color removal	350
13.2.2	Types of condenser	324		References	351
13.2.3	Design of countercurrent condensers	325	15	CRYSTALLIZATION	353
13.2.4	Materials of construction	329	15.1	Fundamentals of crystallization	353
13.2.5	Barometric seal	329	15.1.1	Solubility and supersaturation	353
13.2.6	Absolute pressure control	330	15.1.2	Crystal growth and nucleation	354
13.2.7	Identifying air leaks	330	15.1.3	Effect of nonsucrose	356
13.3	Injection water pumps	331	15.1.4	Crystallization rates	356
13.4	Spray ponds and cooling towers	331	15.1.5	Boiling point elevation	357
13.4.1	Design and specification of cooling systems	331	15.1.6	Crystal size and shape	359
13.4.2	Cooling towers	332	15.1.7	Massecurite crystal content	360
13.4.3	Sprays ponds	333	15.1.8	The crystallization process	361
13.4.4	Entrainment and drift losses	334	15.1.9	Objectives of the pan house	361
13.4.5	Water quality and treatment	334	15.2	Sugar boiling schemes	362
13.5	Vacuum pumps	334	15.2.1	Description of boiling schemes used	362
13.5.1	Liquid ring pumps	335	15.2.2	Comparison of boiling schemes	365
13.5.2	Sizing of pumps	335	15.2.3	Pan floor calculations and mass balances	365
13.5.3	Service water system	336	15.2.4	Effect of the relationship between pol and sucrose and between Brix and dissolved solids	368
13.5.4	Pump efficiency and testing	336	15.2.5	Effect on sugar color	368

15.2.6	Effect of massecuite exhaustion and crystal yield	368	16.1.5	Pumping and handling massecuites	408
15.2.7	Factors affecting C massecuite quantity	369	16.2	Equipment	409
15.2.8	Capacity and steam requirements	369	16.2.1	Batch and continuous crystallizers	409
15.3	Batch vacuum pans	370	16.2.2	Horizontal vs. vertical crystallizers	410
15.3.1	Types of pan	370	16.2.3	Horizontal crystallizers	410
15.3.2	Pan circulation	371	16.2.4	Vertical crystallizers	411
15.3.3	Batch pan design	371	16.2.5	Heat transfer coefficients	414
15.3.4	Pan capacity	375	16.2.6	Cooling system design	414
15.3.5	Evaporation rates	376	16.2.7	Crystallizer drives	415
15.3.6	Stirrers and circulation steam	376	16.2.8	Vacuum crystallizers	416
15.3.7	Entrainment separation	378	16.2.9	Massecuite pumps	416
15.4	Continuous vacuum pans	379	16.3	Operation and control	417
15.4.1	Types of continuous pan	379	16.3.1	Operation of continuous crystallizers	417
15.4.2	Design of continuous pans	384	16.3.2	Massecuite flow characteristics	418
15.4.3	Comparison of batch and continuous pan systems	387	16.3.3	<i>Maillard</i> reaction	420
15.5	Pan control and operation	389	16.3.4	Cooling water circuits	420
15.5.1	Conduct of a batch boiling	389		References	421
15.5.2	Seeding	390	17	CENTRIFUGAL SEPARATION	423
15.5.3	Meeting crystal size	390	17.1	Theory	423
15.5.4	Vacuum testing	390	17.1.1	Batch and continuous centrifugals	423
15.5.5	Assessing the quality of pan boiling	391	17.1.2	Centrifugal forces	424
15.5.6	Boiling temperatures and pressures	392	17.1.3	Solid-liquid separation theory	426
15.5.7	Effect of pan conditions and operation on sugar quality	393	17.1.4	Washing efficiency	426
15.5.8	Continuous pan operation	393	17.1.5	Crystal breakage	427
15.6	Pan instrumentation and control	394	17.2	Batch centrifugals	427
15.6.1	Measurement transducers	394	17.2.1	General description	427
15.6.2	Control valve sizing	395	17.2.2	Batch cycle	428
15.6.3	Batch pan control	396	17.2.3	Comparison of different designs	428
15.6.4	Automatic control of continuous pans	397	17.2.4	Centrifugal capacities	430
15.7	Pan floor peripheral equipment	399	17.2.5	Centrifugal drives	431
15.7.1	Molasses conditioning	399	17.2.6	Operation of batch centrifugals	431
15.7.2	Feed tanks	399	17.2.7	Basket inspection	434
15.7.3	Storage tanks	399	17.2.8	Feed mixers	434
15.7.4	Vacuum seed receivers	399	17.3	Continuous centrifugals	434
15.7.5	Cutover systems	399	17.3.1	General description	434
15.7.6	Strike receivers	400	17.3.2	Comparison of different designs	435
	References	400	17.3.3	Centrifugal capacities	437
16	COOLING CRYSTALLIZERS	403	17.3.4	Screens	438
16.1	Theoretical considerations	403	17.3.5	Operation of continuous centrifugals	440
16.1.1	Objectives and requirements of cooling crystallization	403	17.3.6	Continuous high grade centrifuges	441
16.1.2	Residence times and temperatures	404	17.3.7	Comparison of batch and continuous high grade centrifugals	443
16.1.3	Mixing/stirring	404	17.3.8	Melter and mingling centrifugals	443
16.1.4	Rheological properties of massecuites	405	17.4	Massecuite reheating	444
			17.4.1	Mother liquor supersaturation	444
			17.4.2	Reheater area requirements	445
			17.4.3	Types of reheater	446
			17.4.4	Pressure drop in tubular reheaters	448
			17.5	Remelters and minglers	448

17.5.1	Design of remelters	448	20.3.3	Juice heating	485
17.5.2	Details of magma mixers	449	20.3.4	Clarification	485
	References	452	20.3.5	Evaporation	486
✓ 18	MOLASSES EXHAUSTION	455	20.3.6	Pan boiling	486
18.1	Molasses exhaustibility	455	20.3.7	Centrifugal operations	486
18.1.1	Solubility of sugar in molasses	455	20.4	Specifications and standards	486
18.1.2	Laboratory exhaustion trials	457	20.4.1	Non-centrifugal sugars	487
18.1.3	Target purity equations for molasses exhaustion	457	20.4.2	Centrifugal sugars	487
18.1.4	Simplified methods for estimation of dry substance and ash	459	20.4.3	Standards for direct consumption centrifugal sugars	487
18.1.5	Effect of high dextran and starch contents	460	20.5	Payment systems	488
18.1.6	<i>Maillard</i> reaction	460	20.5.1	Pol-based payment	488
18.2	Quantity of C massecuite and final molasses	461	20.5.2	Quality-based payment systems	489
18.3	Optimum operation of C stations	461	20.6	Refining qualities	491
18.3.1	Effect of factory operating conditions on molasses exhaustion	461	20.6.1	Polarization	491
18.3.2	Recommended practice for achieving good molasses exhaustion	462	20.6.2	Color	491
18.4	Molasses desugarization	463	20.6.3	Filterability	491
18.4.1	Chromatographic separations	463	20.6.4	Dextrans	492
18.4.2	Ethanol precipitation	464	20.6.5	Starch	493
18.4.3	Other chemical methods	464	20.6.6	Moisture	494
	References	465	20.6.7	Ash	494
			20.6.8	Reducing sugars	495
			20.6.9	Other parameters	495
				References	496
✓ 19	DRYING AND STORAGE OF RAW SUGAR	467	✓ 21	MOLASSES HANDLING AND STORAGE	499
19.1	Theory of drying	467	21.1	Molasses quantity, quality and composition	499
19.1.1	Context and objective	467	21.1.1	Calculation of quantities of molasses	499
19.1.2	Drying mechanisms	467	21.1.2	Typical analyses	500
19.1.3	Modeling	468	21.1.3	Physical properties	503
19.1.4	Practical interpretation	470	21.2	Molasses cooling	504
19.2	Sugar driers	471	21.2.1	Requirements	504
19.2.1	Types of equipment	471	21.2.2	Types of cooling system	504
19.2.2	Design and sizing	476	21.2.3	Heat transfer coefficients	505
19.2.3	Instrumentation and automation	479	21.2.4	Temperature control	506
19.3	Handling and storage	479	21.3	Pumping and piping systems	506
19.3.1	Conveyors and hoppers	479	21.3.1	Piping design for molasses handling	506
19.3.2	Raw sugar warehousing	479	21.3.2	Choice of molasses pump	507
	References	481	21.3.3	Mass flow measurement	508
✓ 20	RAW SUGAR QUALITY	483	21.4	Storage of molasses	509
20.1	Introduction	483	21.4.1	Degradation in storage	509
20.2	Grades of raw sugar	483	21.4.2	Prevention of <i>Maillard</i> reaction	509
20.3	Effect of raw house operations on sugar quality	484		References	510
20.3.1	Cane transport and harvesting	485	✓ 22	SUGAR REFINING	511
20.3.2	Sucrose extraction	485	22.1	White sugar yield	512
			22.2	Affination and melting	512
			22.2.1	Raw sugar handling	513
			22.2.2	Mingling	513

22.2.3	Affination of sugar	513	23.2.1	Comparison of decolorization systems	541
22.2.4	Design of melters	514	23.2.2	Combinations of clarification and decolorization	542
22.3	Clarification processes	515	23.3	Ion exchange decolorization	542
22.3.1	Carbonatation	515	23.3.1	Type of resin used	542
22.3.2	Phosphatation	518	23.3.2	Resin usage	542
22.3.3	Comparison of carbonatation and phosphatation	520	23.3.3	Ion exchange systems	543
22.4	Sulfitation	521	23.3.4	Color removal	544
22.5	Filtration	521	23.3.5	Regeneration of resin	544
22.5.1	Equations for filtration	521	23.3.6	Treatment of effluent	545
22.5.2	Laboratory filtration measurements	522	23.4	Bone char	545
22.5.3	Types of filters	522	23.4.1	Advantages and disadvantages	545
22.5.4	Filter area required	523	23.4.2	Char systems used	545
22.5.5	Filter operation	523	23.4.3	Regeneration	546
22.5.6	Cake handling and desweetening	524	23.4.4	Sweet water handling	546
22.5.7	Deep bed filtration	525	23.5	Activated carbons	546
22.6	Evaporation and crystallization	526	23.5.1	Activated carbon systems	546
22.6.1	Evaporator systems	526	23.5.2	Color removal	547
22.6.2	Crystallization schemes and yields for white sugar	526	23.5.3	Regeneration	547
22.6.3	White pan house operation	528	23.5.4	Energy consumption	547
22.6.4	Recovery house operations	529	23.6	Use of additives	547
22.7	White sugar standards	530	23.6.1	Oxidants	547
22.8	Steam requirements	530	23.6.2	Color precipitants	548
22.8.1	Steam/melt ratios	531	23.7	Decolorization of cane juice	548
22.8.2	Reducing steam consumption by operational and plant changes	531	23.7.1	Chemical treatments	548
22.8.3	Pinch technology studies	532	23.7.2	Membranes	548
22.9	White-end refineries	532	23.7.3	Ion exchange	549
22.9.1	Advantages of back-end refineries	532		References	549
22.9.2	Operation in season	532	✓ 24	WHITE SUGAR HANDLING AND CONDITIONING	551
22.9.3	Off-crop refining	533	24.1	Drying, cooling and conditioning	551
22.10	Direct production of white sugar	533	24.1.1	Conditioning	551
22.10.1	Plantation white sugar	533	24.1.2	Refined sugar drying and cooling	556
22.10.2	Options for white sugar production in a raw mill	533	24.2	Refined sugar storage	557
	References	534	24.2.1	Types of bulk silo	557
✓ 23	COLOR AND DECOLORIZATION SYSTEMS	537	24.2.2	Bulk storage design and operation	560
23.1	Colorants and color formation in processing	537	24.2.3	Ventilation	562
23.1.1	Nature and origin of colorants	537	24.2.4	Packed sugar storage	562
23.1.2	Measurement of color	539	24.2.5	Color formation	563
23.1.3	Identification of colorants	539	24.3	Sugar handling	563
23.1.4	Color formation in the raw sugar mill	539	24.3.1	Conveying	563
23.1.5	Color formation in the refinery	540	24.3.2	Hoppers, chutes and transfer points	565
23.1.6	Color inclusion in sugar crystals	540	24.3.3	Screening or sieving	567
23.2	Choice of optimal refinery decolorization scheme	541	24.3.4	Sugar dust explosions	569
			24.3.5	Dedusting	571
			24.4	Bagging and packaging	572
			24.4.1	Weighers and feeders	572
			24.4.2	Packaging materials	572

24.4.3	Forming, filling and sealing	573	26.2.2	Bagasse weighing	602
24.4.4	Baling and palletizing	574	26.2.3	Bagasse stores and reclaim systems	603
24.4.5	Speciality products	574	26.2.4	Bulk pile storage of bagasse	605
	References	576	26.2.5	Baling	606
✓ 25	CHEMICAL CONTROL OF FACTORIES	577	26.3	Bagasse drying	606
25.1	Measurements and analyses	577	26.3.1	Effect on boiler efficiency and capacity	607
25.1.1	Overview of commonly used analyses	577	26.3.2	Types of drier	607
25.1.2	Limitations and accuracies	579	26.3.3	Operational issues	609
25.1.3	Determination of mass flow rates	581	26.3.4	Other alternatives for bagasse drying	610
25.1.4	Cane analysis	581	26.4	Bagacillo collection	610
25.2	Factory sucrose balances	582	26.4.1	Bagacillo screens	611
25.2.1	Recovery calculations	582	26.4.2	Pneumatic louver separation	611
25.2.2	Application of true sucrose analytical data	583	26.4.3	Pneumatic extraction	611
25.2.3	Calculation of stock of sugar in process	584	26.4.4	Pneumatic transport	612
25.2.4	Undetermined loss	584	26.4.5	Screw conveyors	613
25.2.5	Mechanisms and causes of undetermined losses	585	26.4.6	Bagacillo cyclones	613
25.3	Evaluation of factory performance	586	26.5	De-pithing of bagasse	614
25.3.1	Overall factory	586	26.5.1	Fiber/pith split	614
25.3.2	Extraction section	586	26.5.2	Pneumatic separation	615
25.3.3	Boiling house	587	26.5.3	De-pithers	615
25.3.4	Other factory performance measurements	589	26.5.4	Fiber quality assessment	616
25.3.5	Time account	589		References	616
25.4	Inversion losses	589	✓ 27	STEAM GENERATION	619
25.4.1	Measurement of inversion losses	589	27.1	Introduction	619
25.4.2	Calculation of inversion losses from <i>Vukov's</i> equations	590	27.2	Combustion calculations	619
25.4.3	Correction for effect of temperature and dilution on pH	590	27.2.1	Fuel characteristics	619
25.4.4	<i>Stadlers</i> data	591	27.2.2	Combustion air requirements	622
25.4.5	Tables for estimation of inversion	591	27.3	Boiler efficiency	625
25.5	Factory reporting	593	27.3.1	Measuring efficiency	625
25.5.1	Purpose	593	27.3.2	Quantifying losses	625
25.5.2	Benchmarking and technical auditing of factory figures	593	27.4	Furnace design	628
25.5.3	Format of factory reports	594	27.4.1	Types of furnaces	628
	Appendix: Checklist for undetermined loss	596	27.4.2	Bagasse feeding and metering	629
	References	600	27.4.3	Grate heat release rates	630
✓ 26	BAGASSE HANDLING, STORAGE AND DRYING	601	27.4.4	Grate design for high efficiency and low emissions	631
26.1	Bagasse characteristics	601	27.4.5	Bagasse distributors and over fire air design	633
26.2	Bagasse storage and reclaim	602	27.4.6	Furnace size	633
26.2.1	Bagasse conveying	602	27.5	Boiler design	634
			27.5.1	Design overview	634
			27.5.2	Heat transfer	635
			27.5.3	Boiler support structure	638
			27.5.4	Convection bank	640
			27.5.5	Superheater	640
			27.5.6	Circulation	641

27.5.7	Heat recovery	641	28.3.4	Options for reducing process steam usage	671
27.5.8	Erosion	642	28.4	Overall steam balance	671
27.5.9	Fans	642	28.4.1	High pressure steam	671
27.6	Controls and instrumentation	643	28.4.2	Exhaust steam usage	674
27.6.1	Steam demand profile	643	28.4.3	Other factors affecting the steam balance	675
27.6.2	Control loops	644	28.4.4	Power available for export	675
27.6.3	Instrumentation	646	28.5	Vapor recompression	676
27.6.4	Control technologies	647	28.5.1	Situations conducive to recompression	676
27.7	Stack emissions and discards disposal	648	28.5.2	Thermo-compression	676
27.7.1	Regulations and units of measurement	648	28.5.3	Mechanical vapor recompression	678
27.7.2	Particulate emissions	648		References	678
27.7.3	Dust collectors	650			
27.7.4	Choice of collector and collector location	652	29	WATER AND CONDENSATE SYSTEMS	679
27.7.5	Gaseous emissions	653	29.1	Factory water balance	679
27.7.6	Discards disposal	655	29.1.1	Water inputs and losses	679
27.8	Boiler operation and maintenance	656	29.1.2	Evaporation losses	680
27.8.1	Manufacturer's manuals	656	29.1.3	Water balances	680
27.8.2	Start-up and shutdown	656	29.2	Boiler feed water	682
27.8.3	Control systems	656	29.2.1	Condensate recovery	682
27.8.4	Other operational concerns	656	29.2.2	Condensate quality	682
27.8.5	Upgrading boilers	657	29.2.3	Monitoring sugar contamination in condensate	683
27.9	Boiler feed water systems	659	29.2.4	Softening	684
27.9.1	Source of boiler feed water	659	29.2.5	Pressure-dependent quality parameters	684
27.9.2	Required water quality	659	29.2.6	Feed water storage	684
27.9.3	Feed pump and feed control valve sizing	659	29.3	Factory process water requirements	684
27.9.4	Deaeration	661	29.3.1	Imbibition	684
27.9.5	Feed water treatment	662	29.3.2	Process water usage	684
27.9.6	Boiler blowdown	662	29.4	Service water requirements	685
27.10	Feed water and steam reticulation	663	29.4.1	Raw water	685
27.10.1	Pipework design	663	29.4.2	Treated water	685
27.10.2	Pressure letdown systems	665	29.4.3	Service cooling systems	686
	References	666	29.4.4	Boiler ash and scrubber water	686
28	FACTORY STEAM BALANCE	667	29.4.5	Firewater supply	686
28.1	Steam available from bagasse	667	29.5	Treatment of effluent	686
28.1.1	Quantity of bagasse	667	29.5.1	Surplus water handling systems	686
28.1.2	Steam generated from bagasse	667	29.5.2	Quantity of surplus water to be treated	686
28.2	Sugar mill steam requirements	668	29.5.3	Quality of surplus water stream	688
28.2.1	Prime mover energy requirements	668	29.5.4	Effluent treatment standards	688
28.2.2	Balance between high pressure and exhaust steam requirements	669	29.5.5	Biological treatment	689
28.2.3	Steam losses	669		References	692
28.3	Process steam usage	669			
28.3.1	Evaporator configuration	670			
28.3.2	Pan requirement	670			
28.3.3	Juice heating requirements	670			

30	ELECTRICITY	693	31.2.4	Furfural manufacture	721
30.1	Generation of electricity	693	31.2.5	Integrated biomass processing	721
30.1.1	Factory requirements	693	31.2.6	Charcoal and activated carbon	723
30.1.2	Selection of voltage	694	31.2.7	Boiler ash, smuts and fly ash	724
30.1.3	Steam turbines	694	31.3	Cane leaves and tops	724
30.1.4	Steam usage	698	31.3.1	Collection as additional fuel	724
30.2	Alternators	698	31.3.2	Recovery of value-added products	724
30.2.1	Size	698	31.4	Sugar based by-products	725
30.2.2	Type	698	31.5	Molasses	726
30.2.3	Efficiency	699	31.5.1	Fermentation products	726
30.2.4	Control equipment	699	31.5.2	Animal feed	727
30.2.5	Lubrication and cooling	699	31.5.3	Use as a fertilizer	728
30.2.6	Electrical control	700	31.5.4	Recovery of products of value	728
30.2.7	Protection	700	31.6	Ethanol production	728
30.3	Operation of the power house	700	31.6.1	Ethanol yields	728
30.3.1	Alternator and turbine monitoring	700	31.6.2	Fermentation systems	729
30.3.2	Load control	700	31.6.3	Distillation	731
30.3.3	Vibration monitoring	701	31.6.4	Storage and handling	733
30.3.4	Sale and purchase of power	701	31.6.5	Stillage production and disposal	733
30.4	Electric motors	702	31.6.6	Carbon dioxide recovery	735
30.4.1	Classes	702	31.6.7	Economics of ethanol production	735
30.4.2	Insulation class	702		References	737
30.4.3	Voltage supply	703	32	PHYSICAL PROPERTIES	739
30.4.4	Speed and slip	703	32.1	Steam and water	739
30.4.5	Direct current (DC) motors	705	32.1.1	Equations representing steam and water properties	739
30.4.6	Variable frequency drives	705	32.1.2	Tables for saturated steam	739
30.5	Power distribution and usage	705	32.1.3	Properties of superheated steam	739
30.5.1	Transformers	705	32.2	Juice and syrup	744
30.5.2	Cable sizing	706	32.3	Sugarcane	744
30.5.3	Power factor correction	709	32.4	Sugar	744
30.6	Cogeneration	711	32.4.1	Crystal density	744
30.6.1	Back pressure and condensing turbines	711	32.4.2	Bulk densities	744
30.6.2	Safety systems	711	32.4.3	Specific heat and enthalpy	746
30.6.3	Control	712	32.4.4	Solubility of sucrose	746
30.6.4	Power wheeling	712	32.5	Bagasse	746
30.6.5	Gasification	712	32.5.1	Density of fiber	746
	References	713	32.5.2	Bulk density	746
31	BY-PRODUCT UTILIZATION	714	32.5.3	Dry fiber bulk density	747
31.1	Filter cake	715	32.5.4	Coefficient of friction	747
31.1.1	Quantity and quality of filter cake	715	32.6	Lime	747
31.1.2	Use in fields	716	32.6.1	Milk of lime	747
31.1.3	Composting	716	32.6.2	Lime	747
31.1.4	Extraction of value added products	717		References	747
31.1.5	Animal feed	717		Tables, SI units	748
31.2	Bagasse	717		Conversion factors	750
31.2.1	Use in pulp and paper	717			
31.2.2	Bagasse board	720	Subject index		752
31.2.3	Animal feeds	721			