



संशोधनेन संवृद्धिः

**VASANTDADA SUGAR INSTITUTE**

**MANJARI (B), 412 307**

**Tal. Haveli, Dist. Pune**

Phone 020-26902100 (15 lines) Fax No. : 020-26902244

E-mail: [librarian@vsisugar.com](mailto:librarian@vsisugar.com), [vsilib@vsnl.com](mailto:vsilib@vsnl.com)

Website: [www.vsisugar.com](http://www.vsisugar.com)

---

**Surplus Power Cogeneration in Sugar Industry – K.R.Patil**

**CONTENTS**

<b>Preface</b> .....	xv
<b>Acknowledgments</b> .....	xvii
<b>About Author</b> .....	xix

**SECTION I MECHANICAL**

**Chapter 1**

<b>Cogeneration Principle</b> .....	<b>1</b>
1.1 The cases for cogeneration.....	1
1.2 Basic cogeneration cycles.....	2
1.3 Topping cycle.....	2
1.4 Bottoming cycle.....	3
1.5 Steam generator/back-pressure steam turbine.....	5
1.6 Steam generator/condensing steam turbine.....	6

**Chapter 2**

<b>Surplus Power Cogeneration in India</b> .....	<b>9</b>
2.1 Potential for cogeneration in sugar industry in India.....	10
2.2 Encouraging policies from central government.....	11
2.3 Subsidy by ministry of new and renewable energy (MNRE).....	12
2.4 Important aspects in selection of plant and machinery.....	13
2.5 Regenerative feed heating.....	15
2.6 Power generation through back pressure (B.P) extraction and double extraction cum condensing (DEC) route.....	20
2.7 Topping cycle ratio's.....	22
2.8 Topping cycle ratio calculations.....	23
2.9 Condensing and cooling system.....	32
2.10 Electrical distribution and evacuation system.....	34
2.11 Automation.....	35
2.12 Modernization of sugar mill.....	36
2.13 Conclusions.....	37

**Chapter 3**

<b>Basic Thermodynamic Terminologies</b> .....	<b>39</b>
3.1 Basic parameter.....	39
3.2 Latent heat of vaporization.....	41



3.3 Entropy.....	42
3.4 Mollier diagram.....	42
3.5 Efficiencies.....	44
3.6 Heat rate.....	45
<b>Chapter 4</b>	
<b>Steam and Its Properties.....</b>	<b>47</b>
4.1 Definition and introduction.....	47
4.2 Formation of steam.....	47
4.3 Constant pressure thermodynamic process of steam.....	52
4.4 Steam tables.....	52
<b>Chapter 5</b>	
<b>Boiler.....</b>	<b>70</b>
5.1 Basics of boiler and fuel used.....	72
5.2 Steam generation fundamentals.....	73
5.3 Circulation.....	74
5.4 Boiler output or steam flow.....	75
5.5 Maximum continuous rating (MCR).....	76
5.6 Peak rating.....	76
5.7 Boiler rated and design pressure.....	77
5.8 Boiler temperature.....	77
5.9 Biomass fuels.....	77
5.10 Properties of bagasse as a fuel.....	80
5.11 Bagasse drying by boiler flue gas.....	82
5.12 Sugarcane trash and tops availability.....	93
5.13 Repercussions of trash and tops used for cogeneration as a fuel.....	95
5.14 Fuels other than biomass.....	96
5.15 Effects of ash on boiler performance.....	98
5.16 Furnace.....	99
5.17 Super Heater.....	100
5.18 Boiler bank.....	101
5.19 Steam drum.....	101
5.20 Water drum.....	101
5.21 Pressure parts and drum internals.....	102
5.22 Steam separator.....	102
5.23 Heat recovery units.....	103
5.24 Economizer.....	103



5.25 Air heater.....	105
5.26 Spreader and stoker for boiler.....	106
5.27 Fundamentals of boiler performance calculations.....	107
5.28 Case study of boiler performance calculations.....	110
5.29 Selection of material for boiler pressure parts.....	126
5.30 Tube metal temperatures.....	127
5.31 Erosion in air heater.....	128
5.32 Steel for boilers.....	129
5.33 High temperature properties.....	130
5.34 Bricks, refractory, insulation and lagging.....	131
5.35 Steam temperature control.....	133
5.36 Boiler auxiliary equipment selection.....	136
5.37 Flue gas dust collecting system.....	140
5.38 Selection of chimney height & diameter.....	144
5.39 Soot blowers.....	145
5.40 Selection of valves and fittings for boiler.....	148
5.41 Types of valves.....	152
<b>Chapter 6</b>	
<b>Deaeration.....</b>	<b>161</b>
6.1 Dearators.....	162
6.2 Dissolubility of O <sub>2</sub> .....	163
6.3 Effect of presence of O <sub>2</sub> in feed water.....	163
6.4 Alkalinity.....	164
6.5 Phosphate treatment of boiler water.....	164
<b>Chapter 7</b>	
<b>Water and its Treatment for Boiler Feed.....</b>	<b>167</b>
7.1 Boiler feed water.....	167
7.2 Impurities of water.....	167
7.3 Effect of various impurities in boiler water.....	169
7.4 Allowable limits of impurities.....	172
7.5 Treatment of the water.....	176
7.6 Hardness removal by softening.....	176
7.7 De-alkalization.....	177
7.8 Demineralization.....	179
7.9 Dosing.....	180
7.10 Phosphates.....	180
7.11 Caustic soda.....	180



7.12 Sodium Sulphite.....	180
7.13 The proprietary feed water conditioning chemicals.....	181
7.14 Blowdown.....	182
7.15 Water treatment for high pressure boilers makeup water treatment.....	183
7.16 Controlling corrosion.....	184
7.17 Basic principles of water treatment for boiler.....	189
7.18 Types of treatment.....	190
7.19 Corrosion.....	194
7.20 Oxygen removal.....	195
7.21 Priming and foaming.....	196
7.22 Antifoams.....	198
7.23 Silica carryover.....	198
7.24 Boiler treatment control.....	198
<b>Chapter 8</b>	
<b>Regenerative Feed Water Heating.....</b>	<b>199</b>
8.1 Dearation of boiler feed water.....	199
8.2 Feed water heating.....	200
8.3 Types of feed heaters.....	201
8.4 Number of feed heating stages.....	203
8.5 Energy cycle.....	204
8.6 Feed water temperature & efficiency.....	206
<b>Chapter 9</b>	
<b>Fans and Blowers.....</b>	<b>213</b>
9.1 Difference between fans, blowers and compressors.....	213
9.2 Fan types.....	213
9.3 Centrifugal fan.....	214
9.4 Axial flow fan.....	216
9.5 Common blower types.....	217
9.6 Fan performance evaluation and efficient system operation.....	219
9.7 Fan laws.....	223
9.8 Fan design and selection criteria .....	223
9.9 Fan performance and efficiency.....	224
9.10 Safety margin.....	227
9.11 Some pointers on fan specification.....	227
9.12 Installation of fan.....	228
9.13 Changes in system resistance.....	229



9.14 Flow control strategies.....	229
9.15 Fan performance assessment.....	235
9.16 Measurements and calculations.....	237
9.17 Energy saving opportunities.....	240
9.18 FRP fans in cooling towers / humidification plants.....	241

## **Chapter 10**

<b>Bagasse and Ash Handling System.....</b>	<b>243</b>
10.1 Bagasse handling system.....	243
10.2 System design principles.....	244
10.3 Standards for belt conveying system.....	245
10.4 Major equipments used for the system.....	247
10.5 Brief description of components used for the system.....	247
10.6 Belt conveyor.....	248
10.7 Idler details.....	249
10.8 Conveyor pulleys details.....	250
10.9 Take up & tensioning devices details.....	251
10.10 Skirt board details.....	252
10.11 Belt scrapper details.....	252
10.12 Deck & seal plate.....	253
10.13 Hood & guards.....	253
10.14 Main bagasse carrier & bagasse elevator.....	254
10.15 Discharge hood & chutes.....	255
10.16 Supporting structure.....	256
10.17 Design norms and minimum requirements for conveyor supporting structures.....	257
10.18 Safety switches and hooters.....	259
10.19 Ash handling system.....	261

## **Chapter 11**

<b>Fundamentals of Steam Turbines.....</b>	<b>265</b>
11.1 Fundamental difference between reciprocating and turbine engines.....	265
11.2 Impulse turbine.....	269
11.3 Reaction turbine.....	271
11.4 Turbine staging.....	273
11.5 Combination turbine.....	277
11.6 Heat rate.....	278
11.7 Steam turbine thermodynamic design.....	278



11.8 Velocity ratio.....	285
11.9 Stage performance.....	285
11.10 Steam turbines factors which can and do affect turbine efficiency.....	289
11.11 Windage loss.....	290
11.12 Steam quality and blade deposits.....	291

## Chapter 12

<b>Constructional Details of Steam Turbines.....</b>	<b>295</b>
12.1 Turbine rotor.....	295
12.2 Turbine main bearings.....	297
12.3 Lubrication.....	298
12.4 Turbine blades and blade fixtures.....	301
12.5 Glands.....	303
12.6 Turbine casing.....	304
12.7 Housings of thrust bearings and journal bearings.....	305
12.8 Nozzles.....	305
12.9 Diaphragms.....	307
12.10 Lubricating oil system.....	308
12.11 Centrifuge.....	309
12.12 Speed reduction gear box.....	309
12.13 Materials of construction of various parts in steam turbine.....	310
12.14 Loss of power.....	311
12.15 Recommended steam purity – limits.....	312
12.16 Rotor balancing.....	313
12.17 Preparation for running.....	315
12.18 Constructional details of steam turbine.....	317
12.19 Recommended bearing cooling water analysis.....	320

## Chapter 13

<b>Salts and Silica Deposits in Steam Turbine.....</b>	<b>321</b>
13.1 Kinds of deposits.....	321
13.2 Sodium Chloride (NaCl) .....	325
13.3 Silica (SiO <sub>2</sub> ) .....	325
13.4 Sodium Sulphate (Na <sub>2</sub> SO <sub>4</sub> ).....	326
13.5 Sodium Hydroxide (NaOH).....	326
13.6 Sodium Phosphate (NaPO <sub>4</sub> ).....	326
13.7 Summary.....	327



## Chapter 14

<b>Surface Condenser in Cogeneration Plant.....</b>	<b>329</b>
14.1 Constructional features of surface condenser.....	330
14.2 Cooling water circulation.....	331
14.3 Quantity of air and its pressure.....	334
14.4 Dalton's law of partial pressures.....	335
14.5 General construction.....	340
14.6 Testing for leaky tubes.....	341
14.7 Allowing for contraction and expansion.....	341
14.8 Operation.....	342
14.9 Temperature difference.....	342
14.10 Maintaining mean temperature difference.....	344
14.11 Reduction of surface.....	344
14.12 Resistance to heat flow.....	344
14.13 Arrangement of tubes.....	346
14.14 Effects of circulating-water velocity through the tubes.....	347
14.15 Turbine condenser.....	348
14.16 Vacuum augmentation system (or steam jet ejectors).....	349
14.17 Condensate extraction pumps.....	350

## Chapter 15

<b>Cooling Towers.....</b>	<b>353</b>
15.1 Psychrometer.....	353
15.2 Dry-cooling.....	356
15.3 Wet cooling tower or evaporative type.....	358
15.4 Condensing and cooling system.....	363
15.5 Dry cooling tower or non evaporative type cooling.....	364
15.6 Precautions for installation of cooling tower.....	367
15.7 Condenser chocking.....	367
15.8 Cooling water piping.....	367
15.9 Water treatment & blow down in wet cooling tower.....	368
15.10 Hot water distribution.....	369
15.11 Chemical treatment.....	369
15.12 Foaming.....	370

## SECTION II AUTOMATION AND ELECTRICALS

## Chapter 16

<b>Automation for Cogeneration Plant.....</b>	<b>373</b>
16.1 Distributed Control System (DCS).....	380



16.2 Elements.....	381
16.3 Applications.....	381
16.4 Advantages expected from automation.....	383
16.5 General arrangement of automation system installed in the plant.....	383
16.6 Various parameters to be measured.....	384
16.7 Field instruments.....	386
16.8 Major controls of the boiler and its auxiliaries.....	394
16.9 Typical input output allocation of DCS.....	409
16.10 Typical scada screens of boiler overview.....	433
<b>Chapter 17</b>	
<b>Power House -TG Set Electricals.....</b>	<b>437</b>
17.1 Alternator.....	438
17.2 Constructional details of alternator.....	439
17.3 Incoming vacuum circuit breakers panel.....	441
17.4 LA, SC, PT (Lightning arrestor, surge capacitor, potential transformer) panel.....	442
17.5 Metering and relay panel.....	444
17.6 Tripping system.....	445
17.7 NGR (Neutral Ground Resister Panel) .....	445
17.8 Synchronising panel.....	446
17.9 AVR panel (Automatic Voltage Regulator).....	449
17.10 Brushless excitation system.....	450
17.11 Turbine supervisory panel (TSP).....	451
17.12 Power control centre (PCC) panel.....	453
17.13 Motor Control Centre (MCC) panel.....	453
17.14 Basic components of the control panel.....	455
17.15 Functions of MCC.....	458
<b>Chapter 18</b>	
<b>Generator Protections.....</b>	<b>459</b>
18.1 Under / over voltage.....	459
18.2 Under / over frequency.....	459
18.3 Over fluxing (over voltage & under frequency).....	459
18.4 Differential protection.....	460
18.5 Thermal protection-resistive temperature device.....	461
18.6 Phase over current protection.....	462
18.7 Voltage restrained over current protection.....	463
18.8 Reverse power.....	463





18.9 Low power forward.....	463
18.10 Over power.....	463
18.11 Reverse reactive power.....	464
18.12 Field failure/Loss of excitation.....	464
18.13 Current unbalance/Negative phase sequence.....	464
18.14 Unintentional energization or dead machine protection.....	465
18.15 Restricted earth fault.....	465
18.16 Non-directional earth fault.....	466
18.17 100% stator earth fault.....	466
18.18 Residual over voltage protection.....	467
18.19 Sensitive earth fault.....	468
18.20 Rotor earth fault.....	468
18.21 Breaker failure protection.....	469
18.22 Power swing and pole slipping.....	469
18.23 PT fuse failure protection.....	470
18.24 CT supervision.....	470
18.25 Diode failure protection.....	470

## **Chapter19**

<b>Electrical System for Cogeneration Plant.....</b>	<b>473</b>
19.1 Synchronizing & Interfacing Scheme.....	473
19.2 Design Criteria.....	473
19.3 11 KV VCB panel.....	474
19.4 11 KV XLPE cables & cable termination.....	484
19.5 Battery, battery charger cum DCDB.....	486
19.6 11KV (Export /Distribution / Converter transformer/ Fibrizer/spare) feeder.....	489
19.7 Cogeneration plant lighting.....	490
19.8 Earthing.....	490
19.9 Safety equipment's.....	490
19.10 Erection material.....	490
19.11 Statutory approvals.....	491
19.12 132KV Switchyard equipments.....	491
19.13 Earthing.....	504
19.14 Power line carrier communication.....	505
19.15 Renewable Energy Certificates (REC).....	512



## Chapter 20

<b>Transformers.....</b>	<b>515</b>
20.1 Types of transformers.....	515
20.2 Important parameters to specify the transformers.....	516
20.3 Sizing of transformers.....	518
20.4 Explosion vent/PRV.....	520
20.5 Testing of transformers.....	522
20.6 Installation & commissioning.....	522
20.7 Maintenance of transformers.....	522

## Chapter 21

<b>Generator Transformer Protection.....</b>	<b>523</b>
21.1 Protection philosophy.....	523
21.2 Electromechanical.....	523
21.3 Solid State.....	524
21.4 Numeric.....	524
21.5 Instantaneous overcurrent relay.....	524
21.6 Overload relay.....	524
21.7 Back up overcurrent and earth fault relay.....	525
21.8 Inverse definite minimum time (IDMT) (51).....	525
21.9 Earth fault relay (50N/51N or 50G/51G).....	526
21.10 Restricted earth fault protection (64).....	526
21.11 Thermal overload relay (49).....	526
21.12 Current unbalance protection (46).....	526
21.13 I <sup>2</sup> T Protection.....	527
21.14 Voltage protection.....	527
21.15 Over fluxing (24).....	528
21.16 Negative sequence overvoltage (47).....	528
21.17 Directional power protection (32P).....	529
21.18 Sudden pressure (63).....	529
21.19 Directional phase overcurrent protection.....	529
21.20 Directional earth fault protection (67N/67NC).....	529
21.21 Differential relay (87).....	530
21.22 Breaker failure relay (50BF).....	531
21.23 Frequency protection relays.....	532
21.24 Neutral displacement relay (59D).....	532
21.25 Vector surge relay (78).....	533
21.26 Trip circuit supervision relay (95).....	533
21.27 Generator transformer protection SLD.....	534



## Chapter 22

<b>DG Set.....</b>	<b>535</b>
22.1 DG Set as a system.....	536
22.2 Selection considerations.....	537
22.3 Sizing of a Genset.....	538
22.4 Safety features.....	538
22.5 Maximum single load on DG set.....	539
22.6 Unbalanced load effects.....	539
22.7 Operational factors.....	539
22.8 Energy saving measures for DG sets.....	542
22.9 Starting of a DG set.....	542
22.10 Selection scheme.....	543
22.11 Manual mode.....	543
22.12 Three-attempts start.....	543
22.13 Switching off.....	544
22.14 Lubricating oil.....	544
22.15 Fuel oil solenoid valve (SV).....	544
22.16 Speed and voltage control.....	544
22.17 Protection of a DG set.....	545

## Chapter 23

<b>Power Quality Pollution Due To Harmonics And Its Mitigation.....</b>	<b>547</b>
23.1 How Harmonics are generated.....	548
23.2 Damages caused due to harmonics.....	548
23.3 Sources of harmonics.....	549
23.4 Typical ill-effects due to harmonics.....	550
23.5 Harmonics.....	550
23.6 Measurement of harmonics.....	551
23.7 Transformers.....	552
23.8 Motors.....	553
23.9 Capacitor banks.....	554
23.10 Cables.....	555
23.11 Drives/Power supplies.....	555
23.12 Requirement of measurement.....	556
23.13 Elimination of harmonics.....	556
23.14 Filter components.....	557
23.15 Measurement and analysis: Case study.....	557
23.16 Technical details related to D.C. load.....	558
23.17 Measurement and graphs.....	561



<b>Chapter 24</b>	
<b>Electrical Energy Performance Assessment.....</b>	<b>571</b>
<b>Appendix I</b>	
Abbreviation and Acronyms.....	587
<b>Appendix II</b>	
Conversion of Units.....	593
<b>Appendix III</b>	
Subject Index.....	603