

FUNDAMENTALS OF
STEAM
GENERATION
CHEMISTRY

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CONTENTS

Introduction	xiii
1 General Chemistry	1
2 The Chemistry of Natural Water Supplies	35
3 Makeup Treatment	.....	59
4 Fundamentals of Steam Generation and Sources of Contamination	.....	133
5 Chemical Treatment Programs for Steam Generating Systems	.....	185
6 Monitoring Techniques & Control Guidelines	.....	225
7 Cooling Water Chemistry	.....	265
Bibliography	.....	315
Index	.....	319

FIGURES

1-1	Periodic Table	7
1-2	Electronegativities	18
1-3	An Electrochemical Reaction	28
2-1	Carbon Dioxide Molecule	36
2-2	Water Molecule	37
2-3	Relationship of CO_2 , HCO_3^- , and CO_3^{2-} in water	43
2-4	Solubility of Gypsum and Calcium Carbonate vs. Temperature	54
3-1	Outline of a Common Surface Water Pretreatment Scheme	60
3-2	Outline of Mixing and Settling Zones in a Clarifier	63
3-3	Amine General Structure	64
3-4	Non-ionic Functional Group	65
3-5	An-ionic Functional Group	65
3-6	Clarifier Arrangement I	66
3-7	Clarifier Arrangement II	66
3-8	Clarifier Arrangement III	67
3-9	Calcium Removal vs. Carbonate Alkalinity	74
3-10	Magnesium Removal vs. pH Source	75
3-11	Silica Reduction Possible in the Softening Process	76
3-12	Example of a Groundwater Pretreatment System	78
3-13	Organic Backbone of Common Ion Exchange Resins	81

FUNDAMENTALS OF STEAM GENERATION CHEMISTRY

3-14	Selectivity of a Strong Acid Cation Resin	82
3-15	Selectivity of a Strong Base Anion Resin.	86
3-16	Forced Draft Aerator	90
3-17	Cocurrent Demineralization	91
3-18	Cocurrent Demineralization after Regeneration . . .	93
3-19	Countercurrent Demineralization	93
3-20	Typical Caustic Regeneration System	94
3-21	Typical Acid Regeneration System	95
3-22	Ion Exchange Vessel Internals	96
3-23	SAC Exchanger Water Quality during a Normal Service Run	97
3-24	SBA Exchanger Water Quality during Normal Operation	97
3-25	Common Distributor Arrangement I	99
3-26	Common Distributor Arrangement II	101
3-27	Twin-bed Ion Exchange System Piping Outline . . .	102
3-28	Conventional Filtration	102
3-29	Filtration Spectrum	103
3-30	Spiral-wound Membrane Structure	105
3-31	Generic Outline of a RO Pressure Vessel	106
3-32	Two-Stage RO Schematic	110
3-33	Two-pass RO Schematic	112
3-34	Skid-mounted Reverse Osmosis Unit	113
3-35	EDR with Power Off	121
3-36	EDR with Power On.	121
3-37	The EDI Process	123
3-38	Flow Diagram of a Makeup Water System	126
4-1	Possible Steam Generating Network for a Co-generating Facility	140
4-2	Condenser Tube Map Showing Air Removal Compartment	145

4-3	“A” Boiler Design	159
4-4	“D” Boiler Design	159
4-5	“O” Boiler Design	159
4-6	Water Circulation in a Drum Boiler	160
4-7	Chimney Boiling in a Deposit	161
4-8	Common Steam Separating Scheme	167
4-9	Relative Solubility of Compounds in Steam	170
4-10	Deposition Pattern in Low Pressure End of a Turbine.	171
5-1	A Common Iron Corrosion mechanism.	186
5-2	Hydroquinone	189
5-3	Carbohydrazide	189
5-4	Methyl Ethyl Ketoxime	190
5-5	Amine Distribution Ratios vs. Temperature.	195
5-6	Normal Injection Points of H ₂ O ₂ into OT Systems	196
5-7	Solubility of Magnetite in Ammonia	197
5-8	Surface Films in Deoxygenated vs. Oxygenated Treatments.	198
5-9	Corrosion Characteristics of Carbon Steel vs. pH	205
5-10	Coordinated Phosphate Control Diagram	207
5-11	Control Curves for Coordinated Phosphate Treatments	208
5-12	Structure of EDTA	212
5-13	Change in Silica Volatility vs. Pressure	219
5-14	Allowable Drum Silica Concentrations vs. Pressure	220
5-15	Chemical Feed System.	223
6-1	Recommended Sampling Points in a Steam Generation System	226
6-2	Recommended Liquid Sample Nozzle.	242
6-3	Multiport Steam Sample Tap	243
6-4	Nozzle for Isokinetic Steam Sampling	244

FUNDAMENTALS OF STEAM GENERATION CHEMISTRY

6-5	Converting Steam to Condensate	246
6-6	Conditioning Rack (front)	248
6-7	Conditioning Rack (back)	249
6-8	Conditioning Configuration	250
6-9	Conditioning System with Controller	251
7-1	Cooling Tower	267
7-2	Fill Material in Cooling Towers – 1	268
7-3	Fill Material in Cooling Towers – 2	268
7-4	Corrosion Reaction of Iron by Oxygen	272
7-5	Corrosion Rates of Steel by Season	286
7-6	Tolyltriazole	290
7-7	Butylbenzotriazole	291
7-8	Nomograph to Calculate LSI	293
7-9	Hydroxyethylidene Diphosphonic Acid	290
7-10	Polyacrylate	291
7-11	Dichlorohydantoin	299
7-12	Chlorinated Isocyanuarate	299
7-13	Dissociation of HOBr to OBr ⁻ and H ⁺	300
7-14	Bromo-chloro Hydantoin	301
7-15	Isothiozalone Structures	305
7-16	Quaternary Amines	305
7-17	Bromonitropropanediol (BNPD)	305

TABLES

1-1	Weights of Atomic Particles	3
1-2	The 92 Natural Elements	4
1-3	Oxidation Reduction Potentials	29
2-1	Relationships: pH to Hydrogen	40
2-2	Major Components of the Earth's Atmosphere	44
2-3	Most Common Elements in the Earth's Crust	46
2-4	Chemistry of Selected Water Supplies	48
2-5	Chemistry of the Missouri River at Kansas City	49
2-6	CaCO ₃ Equivalency Table for Common Ions	51
2-7	Water Analysis: Ions as Calcium Carbonate	52
2-8	Solubilities of Mineral Salts	53
2-9	Solubility Product Constants for Common Minerals	55
3-1	Filter Media Sizes	71
3-2	Strong Acid Cation Exchanger Specifications	83
3-3	Ion Exchanger Hydraulic Performance Guidelines	85
3-4	Strong Base Anion Exchanger Specifications	86
3-5	Common Demineralizer Configurations	87
3-6	Pre-treatment Filter Media Specifications	127
4-1	Major Dissolved Ions	146
4-2	Solubility vs. Temperature	156

FUNDAMENTALS OF STEAM GENERATION CHEMISTRY

4-3	Most Common Boiler Deposits	163
4-4	Effects of Boiler Deposits on Heat Transfer	164
4-5	Common Silicate Deposits in Turbines	174
4-6	Heat Tolerance of common Boiler Materials	178
4-7	Composition of Iron- and Nickel-based Used in Power Plant Applications	179
5-1	Most Popular pH-Conditioning Compounds	194
5-2	Feedwater Guidelines	199
5-3	Water Chemistry Guidelines from ASME – 1	200
5-4	Water Chemistry Guidelines from ASME – 2	202
5-5	Water Chemistry Guidelines from ASME – 3	203
5-6	Recommended Steam Purity Guidelines – 1	217
5-7	Recommended Steam Purity Guidelines – 2	217
5-8	General Guidelines for Turbine Contaminants	218
6-1	Steam Turbine Guidelines — 1	238
6-2	Steam Turbine Guidelines — 2	239
6-3	Steam Purity Requirements for Conventional Turbines and Combustion Turbines	240
6-4	Condenser Performance Data	253
6-5	Condenser Tube Correction Factors	262
6-6	Cooling Water Correction Factors	263
7-1	Recommended Dosage Ranges for Corrosion Inhibitor Programs	289
7-2	Comparison of Water Cooling Scale Indices	295
7-3	Relationships of HCO ₃ , CO ₃ , and OH to P and M Analyses	298
7-4	Guidelines for Scale Inhibitor Residuals	301
7-5	Typical Dosages for Foulant Treatments	304

GENERAL CHEMISTRY

1

Important Physical Concepts: Electric Charge and Gravity

Forces govern our physical world. Some of the most common, readily-observable forces include gravity, magnetism, and friction. Two forces that are of importance to this discussion are gravity and especially electrical charge. The equations for both are similar.

Force of gravity

$$F = G \cdot \frac{m_1 \cdot m_2}{r^2} \quad [\text{Eq. 1-1}]$$

Force of Electrical Charge

$$F = C \cdot \frac{q_1 \cdot q_2}{r^2} \quad [\text{Eq. 1-2}]$$

In the first equation, G is a value known as the gravitational constant, m_1 and m_2 are the masses of two bodies, and r is the distance between them. In the second equation, C is also a constant

One Other Concept

Before proceeding to reaction mechanisms, I want to introduce one other simple concept. Later sections and chapters will outline reactions first performed by scientists as experiments or to establish base-line data. Many of these were conducted under conditions known as “standard temperature and pressure,” or STP for short. STP is defined as one atmosphere of pressure at 25°C (77°F).

Acid-Base Reactions

Acids and bases are among the most common chemicals on the planet and are manufactured and used by industry in enormous quantities. Even the power industry uses a reasonable share. The definition of an acid has evolved over the years along with the knowledge of chemistry. Very early descriptions of an acid included the following:

- Tastes sour
- Turns blue litmus dye red
- Reacts with carbonate minerals to produce carbon dioxide
- Neutralizes a base
- Reacts with metals and causes the evolution of hydrogen gas

All of these are true, and as we shall see elsewhere, the latter statement describes a corrosion reaction, but none are exceptionally scientific. The descriptions of a base were not any better.

- Tastes bitter
- Feels slippery
- Turns blue litmus red
- Absorbs carbon dioxide
- Neutralizes an acid

As chemistry became more precise, several better descriptions of acids and bases evolved. They include the following:

The Chemistry of Natural Waters

As we started to learn in the preceding section, natural waters contain many impurities. We will examine in more detail the processes by which water absorbs impurities.

Effects of the Atmosphere on Water Chemistry

Table 2–2 lists the major components of the earth’s atmosphere. While nitrogen and oxygen by far make up the bulk of atmospheric compounds, other chemicals exist in significant quantities. Most important is carbon dioxide. As we have seen, moisture picks up CO₂ from the atmosphere and from the soil. Carbon dioxide reacts with water to produce carbonic acid, which by itself lowers pH.

Major Constituents of the Lower Atmosphere	
Component	Percent by Weight
Nitrogen	75.53%
Oxygen	23.14
Argon	1.28
Carbon Dioxide	0.05
Neon	1.25×10^{-3}
Krypton	2.89×10^{-4}
Ozone	1×10^{-4}
Helium	7.2×10^{-5}
Xenon	3.6×10^{-5}
Hydrogen	3.48×10^{-6}

* Dry atmosphere.

Table 2–2 Major Components of the Earth’s Atmosphere

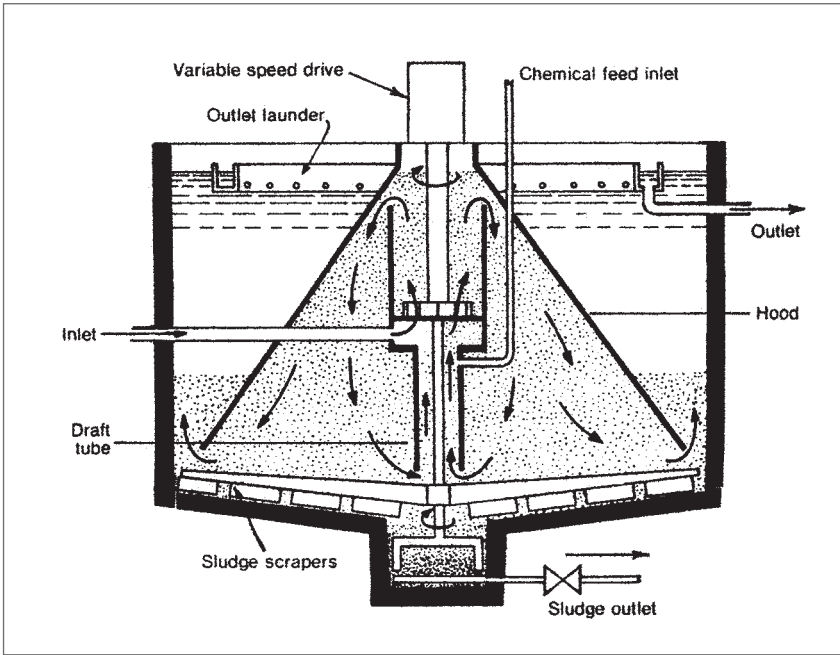


Fig. 3-6 Clarifier Arrangement I
 Source: Drew Principles of Industrial Water Treatment. Drew Industrial is a subdivision of Ashland Chemical Company.

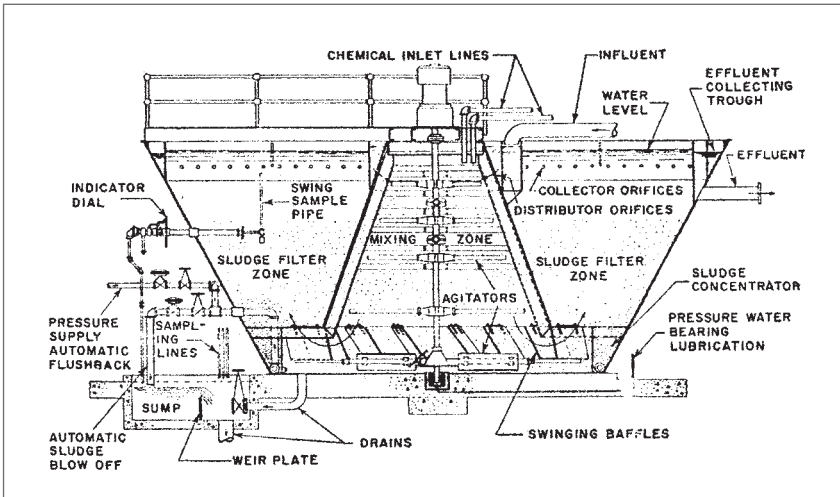


Fig. 3-7 Clarifier Arrangement II
 Source: Drew Principles of Industrial Water Treatment. Drew Industrial is a subdivision of Ashland Chemical Company.

resins may require regenerant with three times the hydrogen or hydroxide capacity of the ionic loading, weak beds can often be restored with near stoichiometric amounts of regenerant. In fact, in most systems utilizing weak acid or weak base exchangers, the waste regenerant from the SAC or SBA exchanger is used as the regenerant solution for the weak bed. This reduces chemical consumption over that which would be used to regenerate the beds separately.

Mixed-Beds

Although regeneration of mixed-beds is an infrequent process, it is very important and must be handled with care, since two resins are involved. Regeneration is usually performed in the exchange vessel. Anion resin is lighter than cation resin, and when the MB resin is backwashed, the process causes the two resins to settle into distinct layers. Figure 3–20 illustrates the generic outline of a mixed-bed exchanger. It also shows common demineralizer internals, including the central collection header found in mixed-bed vessels. The central collector sits at the cation/anion resin interface. During regeneration, acid is introduced below the cation resin and flows upwards. Caustic is introduced above the anion resin and flows downwards. The waste regenerant from each is collected at the interface.

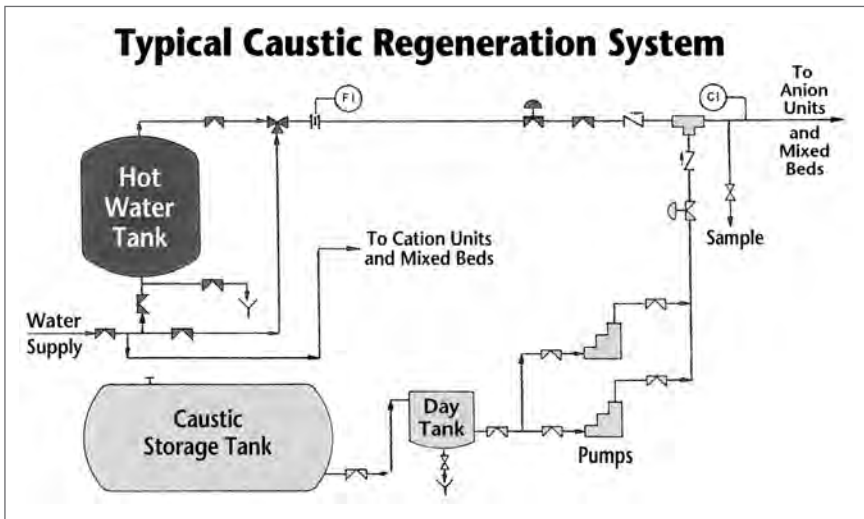


Fig. 3–20 *Typical Caustic Regeneration System*
 Source: BetzDearborn, Inc., a division of Hercules, Inc.

lines. This has changed, and now fiberglass vessels are being constructed with side-entry ports. The vessels are designed with close tolerances, especially at the end caps so that the permeate and concentrate flow along the required paths and do not intermingle. Failure of O-rings or improper alignment of end-caps can lead to poor performance from a vessel.

Piping. For high-pressure RO piping, stainless steel is the popular choice. Often, however, one will see high-pressure flexible hose connecting one pressure vessel to another.

RO Flow Control and Monitoring.

The three most important measurements for monitoring RO operation are flow, pressure, and conductivity. Other important measurements include temperature, pH (especially for CA membranes) and oxidation-reduction potential (ORP, especially for TFC membranes). Flow is extremely important because it will change if membranes foul, tear, or degrade due to chemical or microbiological attack. Monitoring of flow rate, or perhaps more accurately, flow performance, is not a mindless task, as temperature directly affects the amount of water that will pass through the membranes. When water cools it becomes more dense, and its passage is restricted through the membranes. At the same pump pressure, flow may decrease by almost 50 percent when the influent temperature drops from 77°F to 50°F. Conversely, the flow may increase by 10 percent with a 10-degree rise in temperature above 77°F. A conversion calculation must be included in any flow measurements at temperatures other than 77°. This is called “normalizing” the flow rate. Without this correction, it would be difficult to accurately determine whether a change in flow rate was related to temperature or a system or membrane upset. Membrane manufacturers supply normalizing calculations that allow the operator to accurately normalize flow rates.

The change in flow due to temperature brings up an interesting problem when designing a reverse osmosis system. How should the feed pump and membrane quantity be determined? Several methods are possible. The system could be sized to produce the required capacity at the coldest inlet water temperature. The system might then be cycled more fre-