FUNDAMENTALS OF

STEAM GENERATION CHEMISTRY

BRAD BUECKER

PennWell

Contents

FIGURES

TABLES

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

$$F = G \bullet \frac{m_1 \bullet m_2}{r^2} \qquad \textit{[Eq. 1–1]}$$

Force of Electrical Charge

$$F = C \bullet \frac{q_1 \bullet q_2}{r^2} \qquad \textit{[Eq. 1–2]}$$

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 CO_2 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*

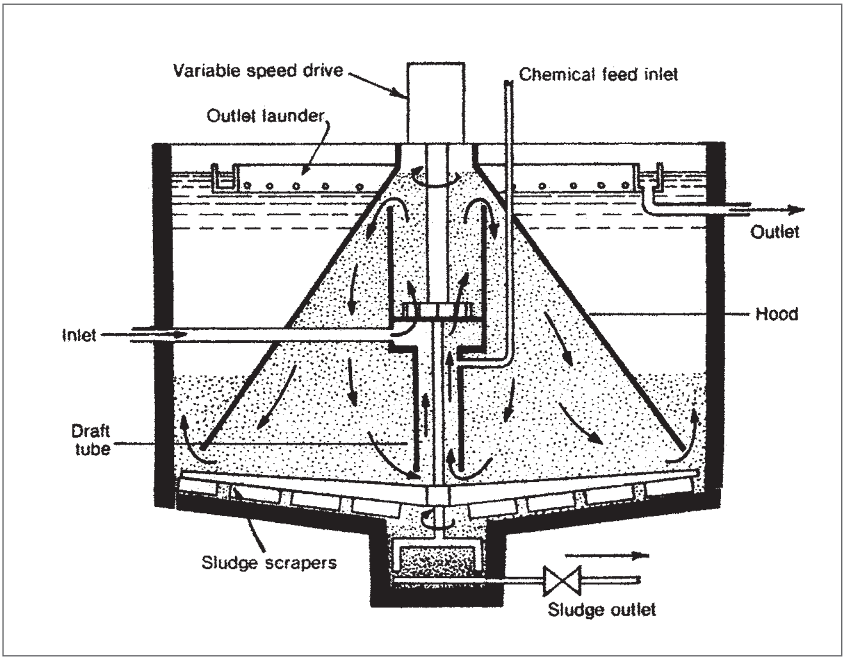

Fig. 3–6 *Clarifier Arrangement I*
Source: Drew Principles of Industrial Water Treatment. Drew Industrial is a subdivision of Ashland Chemical Company.

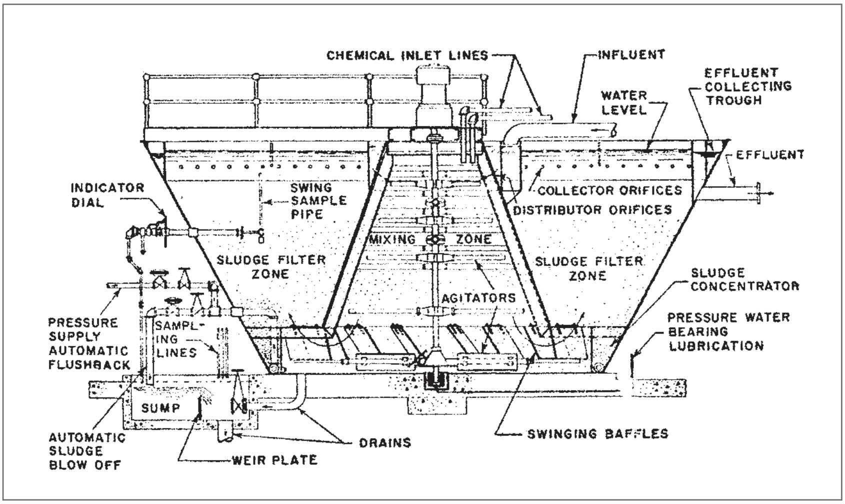

Fig. 3–7 *Clarifier Arrangement II*
Source: Drew Principles of Industrial Water Treatment. Drew Industrial is a subdivision of Ashland Chemical Company.

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 collecter 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.

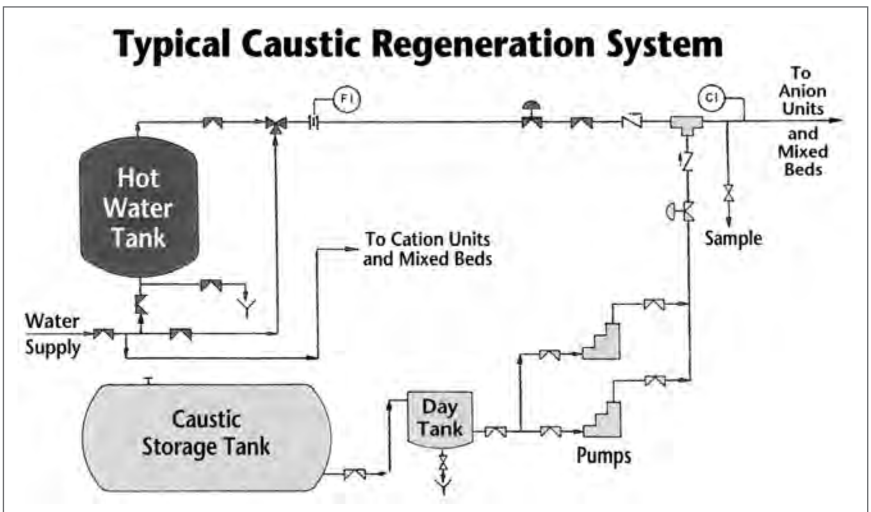

Fig. 3–20 *Typical Caustic Regeneration System*
Source: BetzDearborn, Inc., a division of Hercules, Inc.

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-