Optimum filter operation will occur when the top layer of sand is slightly more coarse than the rest of the sand. During backwashing, however, the finest sand rises to the top. Various designs using coal and garnet layers in conjunction with sand layers (i.e., *dual-* and *triple-media* filters) overcome this difficulty due to the differences in specific gravity.

Historically, the flow rate has been 2 gpm/ft^2 in rapid sand filter design, although some current filters operate at 8 gpm/ft^2. 4 gpm/ft^2 is a reasonable rate for modern designs.

A water treatment plant should have at least three filters so that two can be in operation when one is being cleaned. Typical total through-puts per filter range from 350 gpm for small plants to 3500 gpm for large plants.

Optimum design of a filtering system includes discharge into a *clearwell.* Clearwells are storage reservoirs with capacities of 30% to 60% of the daily output with a minimum of 12 hours of maximum daily consumption. Demand can be satisfied by the clearwell if one or more of the filters is serviced.

The most common type of service needed by filters is *backwashing.* Filters require backwashing when the pores between sand particles clog up. Typically, this occurs after 1 to 3 days of operation. Backwashing is done when the head loss through the filter bed reaches approximately 8 feet. Backwashing with filtered water expands the sand layer up to 50%, which dislodges the trapped material. Backwashing for 3 to 5 minutes at 8–15 gpm/ft^2 is a reasonable design standard. The head loss is reduced to 1 foot after washing.

Water is pumped through the filter from the bottom during backwashing. The rate at which the water rises in the filter housing varies between 12 and 36 inches per minute. This rise rate should not exceed the settling velocity of the smallest particle which is to be retained in the filter. Backwashing usually takes between 3 and 5 minutes. Water which is collected in troughs for disposal and used for backwashing, constitutes between 1% and 5% of the total processed water (approximately 75–100 gal/ft^2 total).

The actual amount of backwash water can be found from equation 7.52. Be sure to use consistent units.

$$\text{water volume} = \left(\frac{\text{backwash}}{\text{time}}\right)\left(\frac{\text{filter}}{\text{area}}\right)\left(\frac{\text{rise}}{\text{rate}}\right) \qquad 7.52$$

Slow sand filters are similar in design to rapid sand filters, except that the sand layer is thicker (24″ to 48″), the gravel layer is thinner (6″ to 12″), and the flow rate is much lower (0.05 to 0.1 gpm/ft^2). Slow sand filters are limited to low-turbidity applications not requiring chemical treatment. Cleaning is usually accomplished by removing a few inches of sand. Slow sand filters operate with a 0.2 to 4.0 foot head loss.

Other types of filters are seeing limited use.

- **Pressure filters**: Similar to rapid sand filters except incoming water is pressurized up to 25 feet (hydraulic). Filter rates of 2 to 4 gpm/ft^2. Not used in large installations.
- **Diatomaceous earth filters**: 1 to 3 gpm/ft^2; short (20-hour) cycle life.
- **Microstrainers**: Woven stainless steel fabric, usually mounted on a rotating drum.

F. DISINFECTION

Chlorination is used for disinfection and oxidation. As a disinfectant, chlorine destroys bacteria and microorganisms. As an oxidant, it removes iron, manganese, and ammonia nitrogen.

Chlorine can be added as a gas or a solid. (If it is added to the water as a gas, it is stored as a liquid which vaporizes around −35°C.) Liquid chlorine is the predominant form since it is cheaper than hypochlorite solid ($Ca(OCl)_2$). If chlorine liquid or gas is added to water, the following reaction occurs to form hypochlorous acid, which itself ionizes to hypochlorite and hydrogen ions.

$$Cl_2 + H_2O \rightarrow HCl + HOCl \underset{pH<7}{\overset{pH>8}{\rightleftharpoons}} H^+ + OCL^- + HCL \qquad 7.53$$

If calcium hypochlorite solid is added to water, the ionization follows immediately.

$$Ca(OCl)_2 + H_2O \longrightarrow Ca^{++} + 2OCl^- + H_2O \qquad 7.54$$

Chlorine existing in water as hypochlorous acid and hypochlorite ions is known as *free available chlorine* (*free residuals*). Chlorine in combination with ammonia is known as *combined available chlorine* (*combined residuals*).

The average chlorine dose is in the 1 to 2 mg/l range. Minimum chlorine residuals for 70°F water are given in table 7.21. Reliable chlorination requires a pH of water below 9.0. However, inactivated viruses (such as might be present in surface water) require a heavier chlorine concentration. Since treatment of water is by both free and combined residuals, ammonia can be added to the water to produce chloramines.

Excess chlorine can be removed with a reducing agent, usually called a *dechlor.* Sulfur dioxide and sodium bisulfate (sodium metabisulfate) are used in this manner. Aeration also reduces chlorine content, as does passing the water through an activated charcoal filter.