Table 7.21
Minimum Chlorine Residuals (mg/l)

pH Value	Free residuals after 10–20 minutes	Combined residuals after 1–2 hours
6.0	0.2	1.0
7.0	0.2	1.5
8.0	0.4	1.8
9.0	0.8	3.0*
10.0	0.8	3.0*

*not recommended

Alternatives to chlorination have become popular since THM's were traced to the chlorination process. Chlorine dioxide can be used in place of chlorine, but it is expensive. In high dosages, chlorine dioxide is also thought to produce its own toxic byproducts. Ozone is a more powerful disinfectant than chlorine, but it is expensive to generate and requires costly contact chambers. Ozone, which is used extensively in Western Europe, Canada, the USSR, and Japan, is generated onsite by running high voltage electrical currents through dry air or pure oxygen.

G. FLUORIDATION

Fluoridation can occur any time after filtering. Smaller utilities almost always choose liquid solution and a volumetric feeding mechanism, with solutions being manually prepared. Larger utilities use gravimetric dry feeders with sodium silicofluoride or solution feeders with fluorsilic acid. The characteristics and dose rates of common fluorine compounds are given in table 7.22.

Table 7.22
Dose Rates for Fluorine Compounds

Formula	H_2SiF_6	NaF	Na_2SiF_6
Form	liquid	solid	solid
Typical purity	22–30%	90–98%	98–99%
Dose to obtain 1.0 mg/l (in pounds per million gallons)	35.2 (with 30% purity)	18.8 (with 98% purity)	14.0 (with 98.5% purity)

Defluoridation (required if the fluoride exceeds 1.5 mg/l) can be achieved with calcined alumina or bone char (tricalcium phosphate). Softening using lime can also be used when waters contain smaller amounts of fluoride. Each 45 to 65 mg/l reduction in magnesium will result in a 1.0 mg/l reduction in fluoride.

H. IRON AND MANGANESE REMOVAL

Several methods of removing iron exist. (Manganese is not easily removed by aeration alone. However, the remaining methods work.)

- Aeration, followed by sedimentation and filtration

$$Fe^{++} + O_x \rightarrow FeO_x \downarrow \qquad 7.55$$

- Aeration, followed by chemical oxidation, sedimentation, and filtration. Chlorine or potassium permanganate may be used as an oxidizer.
- Manganese zeolite process: Manganese dioxide removes soluble iron ions.
- Lime water softening

Table 7.23 lists the characteristics of iron and manganese removal processes.

I. WATER SOFTENING

- Lime and Soda Ash Softening

Water softening can be accomplished with lime and soda ash to precipitate calcium and magnesium ions from the solution. Lime treatment has added benefits of disinfection, iron removal, and clarification.

Lime (CaO) is available as *granular quicklime* (minimum purity: 90% CaO) or *hydrated lime*, $Ca(OH)_2$. *Quicklime* is slaked prior to use, which means that water is added to form a lime slurry in an exothermic reaction.

$$CaO + H_2O \rightarrow Ca(OH)_2 + \text{heat} \qquad 7.56$$

The hydrated lime is delivered to the water supply as a suspension (i.e., *milk of lime*).

Soda ash is usually available as 98% pure sodium carbonate (Na_2CO_3).

FIRST STAGE TREATMENT: In the first stage treatment, lime added to water reacts with free carbon dioxide to form calcium carbonate precipitate.

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O \qquad 7.57$$

Next, the lime reacts with calcium bicarbonate.

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O \qquad 7.58$$

Any magnesium hardness is also removed at this time.

$$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + 2H_2O + MgCO_3 \qquad 7.59$$

To remove the soluble $MgCO_3$, the pH must be above 10.8. This is accomplished by adding an excess of approximately 35 mg/l of CaO or 50 mg/l of $Ca(OH)_2$ plus lime to satisfy equation 7.60.

$$MgCO_3 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + Mg(OH)_2 \downarrow \qquad 7.60$$