growths. Similarly, periodic mechanical removal of slimes from readily accessible areas reduces the chemical biocide requirements and make them more effective.

Chlorine and chlorine-yielding compounds, such as sodium hypochlorite and calcium hypochlorite, are among the most effective biocidal chemicals. However, they are not always applicable to the control of organic materials in cooling systems. In air washers, for instance, their odor may become offensive; in wood cooling towers, excessive concentrations of chlorine can cause rapid deterioration of wood construction, and in metal equipment, higher concentrations of chlorine can accelerate corrosion. In systems large enough to justify equipment for the controlled feeding of chlorine, its use may be both safe and economical.

The use of chlorinated phenols is much safer and usually provides satisfactory control of most slime and algae conditions. Certain quaternary ammonium compounds are also used as biocides from time to time. They must be used carefully, however, because some of them are foam-generating compounds, and their concentration must be carefully controlled, or they must be used in conjunction with foam suppressors. A recent effective addition to the biocidal chemicals is tributyl tin oxide, which can be used alone or in conjunction with quaternary ammonium compounds.

Copper sulfate, which is used widely for the control of algae in lakes and reservoirs, should not be used in cooling systems because the copper can *plate out* on ferrous surfaces, causing accelerated pitting. In alkaline waters, it precipitates out and is ineffective. Proprietary compounds are available in which copper is chemically combined in complexes of much greater stability which may be used safely in such equipment and in all waters.

The manner of feeding slime control chemicals to a system is of great importance. Often, the continuous feeding of low dosages is neither effective nor economical. Better results may be obtained by shock feeding larger concentrations to the system in order to achieve a toxic level of the chemical in the water for a sufficiently long time to kill the organisms present. At times, organisms tend to appear to build up an immunity to the particular chemical being used so that it may be necessary to change the biocidal chemical occasionally, in order to keep the organic growths under control.

Suspended Solids. Suspended solids are undesirable in heating and cooling water systems. Settling out on heat exchange surfaces, they can be as effective as scale or slime in reducing heat transfer. They may accumulate to an extent sufficient to interfere with water flow, and localized corrosive attack can occur beneath such accumulations. Abrasive dirt particles can cause excessively rapid wear of such moving parts as pump shafts and mechanical seals.

Although no chemical treatment procedures are available for removal of suspended solids particles, corrective measures can be taken in some cases when the potential problem is sufficiently serious. In larger cooling towers, the suspended solids content can be kept to an acceptably low level by the use of *side stream filters*. These are ordinary sand filters or other filters through which 1 to 5 percent of the circulating water is continuously passed.

Before any new system is put into operation, it is important to flush it thoroughly, to remove as much suspended material as possible. A chemical detergent cleaning is also desirable in such cases.

The protection of localized areas can frequently be carried out by special methods. Thus, pump-packing glands or mechanical shaft seals can be protected by fresh water makeup, or by circulating water from the pump casing, through a cyclone separator or filter, into the lubricating chamber.

Gross solid contaminants are kept out of large once-through cooling systems by means of trash screens. Recirculating systems utilize strainers. In closed recirculating systems particles of mill scale and of some iron oxide corrosion products are magnet-responsive and can be removed by utilizing magnetic separators or strainers in which the screens are made of a magnetic alloy or in which permanent magnets have been fastened to the screens.

In smaller equipment, a good dirt control measure is the installation of backflush connections and shut-off valves on all condensers and heat exchangers, so that they can be readily backflushed with makeup water or detergent solutions to remove accumulated settled dirt.

Selection of Water Treatment

From the preceding section it is apparent that there are a number of methods available for the correction of almost any water-caused difficulty. If there is any single statement in the field of water treatment which approaches a universal truth, it is that no one treatment method is applicable to all cases. In any one system, the selection of the proper water treatment method and the details of the chemicals and equipment necessary to apply that method will depend upon a considerable number of factors. Most people quickly recognize that the chemical characteristics of the water are important and they may even recognize that these characteristics change with the operation of the equipment. The influence of economics upon the choice of water treatment method is also fairly clear. Less often is there recognition of the other nonchemical influences upon the selection of the proper water treatment.[27,28]

Among these nonchemical factors are the design of individual major components of the system, such as the cooling tower or boiler, the operation of the equipment, and human factors, such as the quantity and quality of operating personnel available.

Once-through Systems. Economics is the overriding consideration in the treatment of water in once-through systems. The quantities of water to be treated are usually so large that any treatment other than simple filtration or the addition of a few ppm of a polyphosphate, silicate, or other inexpensive chemical would not be feasible. In such systems it is generally less expensive to invest more in corrosion resistant materials of construction rather than to attempt to treat the water.

Open Recirculating Systems. The selection of water treatment for open recirculating systems is affected to a considerable extent by the size of the system. At one extreme, large industrial cooling tower systems use such huge quantities of water that it is necessary to minimize the concentration of any treatment chemical used. In these systems, sizeable expenditures for chemical treatment and control equipment can be justified, as can the use of competent operating personnel. At the other extreme, in small air-conditioning and refrigeration cooling towers, the total amount of water used is so small that multiplying chemical concentrations by a factor of ten can mean the expenditure of only a few more dollars per month, whereas the cost of the entire system is such that little or nothing can be justified by way of chemical feeding or automatic control equipment, and only part-time, unskilled operating personnel can be employed.

Thus, a typical water treatment scheme for a large industrial cooling tower system operating at upwards of 10,000 gpm circulation rate might include scale control by means of a controlled bleed and alkalinity reduction by automatically *pH*-controlled sulfuric acid feed combined with corrosion control. The latter is obtained by feeding a mixed inhibitor with a concentration on the order of 50 ppm, with efficacy that would depend both upon the maintenance of a *pH* within a very narrow range (between 6 and 7) and on periodic controlled chlorination with chlorine gas for slime control.

On the other hand, in a small air-conditioning or refrigeration cooling tower circulating at 100 gpm, treatment might consist of a controlled bleed to minimize scale formation, and the maintenance of 200 to 500 ppm of sodium chromate for corrosion control; plus the occasional application of a shock dose of sodium pentachlorophenate for the control of organic growths.

A comprehensive discussion of water conditioning for air-conditioning systems has appeared recently.[29]

Closed Recirculating Systems. In theory, no treatment should be needed for the water in closed recirculating systems (hot water heat, chilled water, combined cooling and heating) because the total amount of scale that could be deposited from the water initially filling the system would be insufficient to interfere significantly with heat transfer. In the case of corrosive water, the total amount of corrosion damage resulting from the initial fill would not be serious. However, operating experience in a great many of these systems has shown that appreciable water losses are the rule rather than the exception[19] and, therefore, sound engineering practice dictates that they be treated.

With makeup waters which are scale-forming at the operating temperatures, the use of a softened makeup is desirable. Treatment for corrosion control should be used with all waters. The selection of such treatment is often determined by other considerations. Although chromates are the most effective corrosion inhibitors for these systems, the yellow color of the chromate may rule out its use in locations where a leak or an inadvertently opened valve may cause staining of rugs or other furnishings. In such cases, recourse may be had to buffered nitrites with mercaptobenzthiazole, or to sulfites in hot systems.

The use of phosphates or polyphosphates should be avoided in closed systems because of the ultimate precipitation of calcium phosphates which may result in the clogging of orifices and vents.

High temperature hot water systems are a special class of closed systems. The typical treatment for such systems is softening and deaeration of the makeup combined with internal treatment to adjust the *pH* to the alkaline side and to maintain a small sulfite residual.

In hot water heating systems, the concentration of chromate or nitrite inhibitor is normally higher than that carried for chilled water systems.

Brine systems require still higher inhibitor concentrations because of the high conductivity of the solutions. Minimum chromate concentrations, for example, are 1800 ppm sodium chromate in calcium chloride brine and 3600 ppm sodium chromate in sodium chloride brine.

Boilers. Many volumes have been written about boiler water treatment[3,5,16,30] and it would be presumptuous to attempt more than the most superficial coverage of this subject in the space available. Probably the most important observations that can be made here are to call attention to the facts that a wide range of treatment procedures can be used for boiler waters, and that, in any particular case, the method selected must depend upon the composition of the makeup water, the operating pressure of the boiler, and the makeup rate, as well as other considerations.

Probably the greatest number of boilers in use are low pressure boilers for the generation of steam or hot water for space heating. Yet, less has been written about water treatment for these boilers than for the high pressure boilers used for electric power generation.

A low pressure steam heating boiler should have a very limited makeup requirement, and the most common waterside problem with such boilers is corrosion. Treatment with higher chromate concentrations on the order of 500 to 2000 ppm sodium chromate, or with alkaline materials to keep the *pH* of the boiler water above 10.5 with a caustic alkalinity of at least several hundred ppm (as $CaCO_3$), is generally sufficient. Actually, some of the most serious damage can be caused during the summer layup of such boilers, and it is particularly important to have a sufficiently high inhibitor concentration present at such times.[31]

As operating pressures and makeup rates go up, the corrosion problem does not decrease, but the scale problem increases in importance. In very general terms, corrosion is controlled by the use of an open heater or, at higher operating pressures, a deaerating heater to remove oxygen from the boiler feedwater, the maintenance of a sulfite or hydrazine residual as an oxygen scavenger in the boiler water, and the maintenance of a sufficiently high *pH* in the boiler water. Scale is controlled by external softening and by internal treatment to precipitate residual traces of calcium, generally as a phosphate (hydroxy apatite), and magnesium (as magnesium hydroxide or a basic silicate). A rough birds-eye view of boiler water quality requirements is given in Table 10.

Treatment of the boiler water is also often affected by the end use of the steam. This may range from reduction of alkalinity so it can minimize condensate line corrosion by keeping carbon dioxide low in the steam, to silica removal for the protection of steam turbines against siliceous turbine blade deposits. Antifoam agents are also used for improved boiler operation and steam quality.

Return Condensate Systems. Three approaches are used in the minimizing of corrosion in condensate systems: (1) eliminating alkalinity from all water entering the boiler so as to minimize the amount of steam in the condensate lines, (2) the use of volatile amines, such as morpholine and cyclohexylamine, to neutralize carbon dioxide and thus raise the *pH* of the condensate, (3) the introduction of filming amines, such as octadecylamine, into the steam so as to form a thin, hydrophobic film on the condensate line surfaces. The latter is particularly effective in minimizing corrosion by oxygen.

Table 10 .... Typical Boiler Water Quality Requirements for Various Operating Pressures[a]

Operating Pressure psig	to 250	250–500	500–1000	Over 1000
Total Hardness[a]	0	0	0	0
Alkalinity[a,b]	300–700	300–500	200–400	100–200
pH[b]	10.5–11.5	10.5–11.0	10.5–11.0	10.5–10.8
Silica	125	50–90	10–35	0.1–2.5
Dissolved Solids	2500–3000	2000–2500	1000–2000	500–1000
Suspended Solids	300–600	150–300	40–150	5–20
Dissolved Oxygen	0.015	0.007	0.005	0.005
Sodium Sulfite[b]	30–60	30–60	15–30	10–20
Phosphate[b]	40–80	20–50	20–40	10–40
Oil	1.0	0.1	—	—

[a] All values except *pH* in ppm.
[b] Range. Other values are maxima.
[c] This table provides an incomplete guide only. More detailed investigations must be made before setting requirements for any specific boiler.

UNDERGROUND CORROSION

The occurrence of corrosion activity on subsurface structures must always be anticipated. In addition to the economic loss attributable to actual destruction of the underground facilities by corrosion, the loss of valuable fluids and continuity of service, and the creation of hazards to life and property must be considered.