lead alloys in sea water, etc., are more widely used in impressed current systems. The distribution of protective current on the cathode, power costs, and stray current effects on neighboring structures must be considered when selecting the number, form, and arrangement of the anodes.

A recent development in impressed current cathodic protection is automatic potential control.[14] In this system, the potential of the structure is continuously measured against a reference electrode by a monitoring system which regulates the protective current applied to maintain the structure at a preselected protective potential value. Since the protective current requirements vary from place to place and from time to time, the automatic potential control system assures full protection at all times and prevents excessive cathodic protection, which would accelerate coating damage by electro-endosmotic effect;[15] and cathodic attack on amphoteric metals such as aluminum and power wastage.

*Limitations.* Full cathodic protection is dependent upon adequate current flow reaching all surfaces to be protected. On bare surfaces, the relation between an anode and cathode configuration determines, in large part, the distribution of protective current. For example, relatively simple anode systems will adequately distribute protective current on the outside of storage tanks, well coated pipelines, tank interiors, and water boxes of heat exchangers. However, the protective current received on the interior of a condenser tube from anodes in the water box diminishes rapidly, within approximately two diameters of the tube entrance.

Rapid attenuation of the protective effect occurs on the exterior of bare pipelines in conductive media. Therefore, protective current sources must be applied at more frequent intervals.

Harmful effects of stray currents from a cathodic protection system upon neighboring utilities or other isolated metallic systems must be considered. All underground cathodic protection installations should be reported to, and examined in cooperation with, local electrolysis committees.

*Economics.* Since the cathodic protection principle must be adapted to meet the specific needs of each corrosion problem, the costs vary widely. Although the annual costs for protecting large coated structures may range from $.002 to $.02 per sq ft per year, the annual cost for protecting similar bare surfaces may vary from $.02 to $.20 per sq ft per year.

## Environmental Change

Another approach in the battle against corrosion is to change the environment so that it is less aggressive to the equipment. One of the more familiar examples of this approach in the refrigeration industry is the use of solid desiccants, such as silica gel, for maintaining a low moisture level in refrigerant lines. Another application of desiccants is for minimizing atmospheric corrosion by maintaining a low relative humidity. The familiar *moth-balling* technique for preserving decommissioned ships and other heavy equipment is an example of this.

Vapor phase corrosion inhibitors can be employed to minimize atmospheric corrosion in certain cases. Dicyclohexylammonium nitrite, for example, is sometimes used for the protection of steel parts within sealed containers. A related compound, cyclohexylamine dicarbonate, has been used in Great Britain for the protection of idle boilers.

Adding alkali to water to raise the *pH*, and using corrosion inhibitors, such as chromates, are other examples of reducing corrosive attack by changing the environment. Corrosion inhibition in water systems is discussed more fully in the next section. Inhibitors for corrosion control are added to glycol antifreeze solutions, lubricants, lithium bromide absorption refrigeration brines, and other liquids.

The local environment at a metal surface can sometimes be made less corrosive. This is the principle involved in the addition of filming amines to steam in order to protect condensate lines and in the addition of certain additives to fuel oil in order to reduce fireside corrosion in boilers.

Finally, some modifications of equipment design to reduce the likelihood of corrosion are also essentially environmental changes, e.g., the elimination of crevices and the provision of weep holes to prevent water accumulation.

## WATERSIDE CORROSION AND DEPOSITS

The occurrence and correction of corrosion in water systems is so closely interwoven with the occurrence and correction of other water-caused troubles that it is virtually impossible to consider them separately. The most common of these water problems in heating and cooling systems are one or more of the following: (1) Corrosion, (2) Scale formation, (3) Biological growths, and (4) Suspended solid matter.

The importance of having some knowledge of these problems can be appreciated from the fact that each of them can, to a varying degree, cause serious reductions in the cooling or heating capacity of a system and can cause premature equipment failure, in some cases with widespread damage and danger to persons in the vicinity.

It is rare that adequate recognition is given to the complexity of the control of waterside operating problems, particularly in heating and cooling systems. The proper handling of such problems involves water chemistry, engineering, economics, and personnel administration during each stage of the system development, design, construction, installation and operation. The information presented in this chapter is intended to provide the reader with a background for better understanding of the causes and handling of water problems in heating and cooling systems. However, it is necessarily far from sufficient to qualify the reader as an expert and omits many water problems and treatment methods not usually encountered in these systems. Additional information is available in References 1, 3, 4, 5, and 16.

Table 5 .... Analyses of Typical Public Water Supplies

| Substance | Unit | Location or Area[a,b] (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|---|
| Silica | $SiO_2$ | 2 | 6 | 12 | 37 | 10 | 9 | 22 | 14 | ..... |
| Iron | Fe | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | ..... |
| Calcium | Ca | 6 | 5 | 36 | 62 | 92 | 96 | 3 | 155 | 400 |
| Magnesium | Mg | 1 | 2 | 8 | 18 | 34 | 27 | 2 | 46 | 1,300 |
| Sodium | Na | 2 | 6 | 7 | 44 | 8 | 183 | 215 | 78 | 11,000 |
| Potassium | K | 1 | 1 | 1 | .... | 1 | 18 | 10 | 3 | 400 |
| Bicarbonate | $HCO_3$ | 14 | 13 | 119 | 202 | 339 | 334 | 549 | 210 | 150 |
| Sulfate | $SO_4$ | 10 | 2 | 22 | 135 | 84 | 121 | 11 | 389 | 2,700 |
| Chloride | Cl | 2 | 10 | 13 | 13 | 10 | 280 | 22 | 117 | 19,000 |
| Nitrate | $NO_3$ | 1 | .... | 0 | 2 | 13 | 0 | 1 | 3 | ..... |
| Dissolved Solids | ..... | 31 | 66 | 165 | 426 | 434 | 983 | 564 | 948 | 35,000 |
| Carbonate Hardness | $CaCO_3$ | 12 | 11 | 98 | 165 | 287 | 274 | 8 | 172 | 125 |
| Non-Carbonate Hardness | $CaSO_4$ | 5 | 7 | 18 | 40 | 58 | 54 | 0 | 295 | 5,900 |

[a] All values are parts per million of the unit cited to nearest whole number (see References 17).

[b] Numbers indicate location or area as follows:
(1) Catskill supply—New York City
(2) Swamp Water (Colored) Black Creek, Middleburg, Florida
(3) Niagara River (Filtered) Niagara Falls, New York
(4) Missouri River (Untreated) Average
(5) Well Waters—Public Supply—Dayton, Ohio—30–60 ft
(6) Well Water—Maywood, Illinois—2090 ft
(7) Well Water—Smithfield, Va.—320 ft
(8) Well Water—Roswell, N. Mexico
(9) Ocean Water—Average



Table 6 .... Variations in Composition of Schuylkill River Water at Belmont Filter Plant, Philadelphia, Pa.

| Sample Date[a] | pH | Total Hardness (Parts Per Million) | Total Alkalinity (Parts Per Million) | Chloride (Parts Per Million) | Sulfate (Parts Per Million) | Total Dissolved Solids (Parts Per Million) |
|---|---|---|---|---|---|---|
| January | 7.0 | 73 | 32 | 5 | 48 | 123 |
| February | 6.7 | 93 | 38 | 6 | 59 | 155 |
| March | 7.2 | 105 | 42 | 6 | 52 | 145 |
| April | 7.3 | 106 | 43 | 7 | 60 | 169 |
| May | 6.9 | 102 | 39 | 7 | 66 | 187 |
| June | 6.9 | 137 | 49 | 10 | 89 | 218 |
| July | 6.9 | 176 | 65 | 15 | 114 | 282 |
| August | 7.3 | 166 | 67 | 14 | 87 | 235 |
| September | 7.2 | 175 | 63 | 16 | 109 | 268 |
| October | 6.9 | 205 | 70 | 21 | 135 | 341 |
| November | 7.6 | 181 | 61 | 8 | 121 | 289 |
| December | 6.7 | 184 | 58 | 18 | 121 | 286 |
| Minimum | 6.7 | 73 | 32 | 5 | 48 | 123 |
| Maximum | 7.6 | 205 | 70 | 21 | 135 | 341 |

[a] 1949. Samples were composites for the 1st ten days of each month.

## Water Characteristics

Between the time that it falls as rain, sleet, or snow and the time that it is pumped into a user's premises, water dissolves at least a little of almost every gas and solid substance with which it comes in contact. It is these dissolved impurities, rather than the water itself, which are the primary causes of the various *water* problems.

The chemistry of water is not simple. Almost infinite variations are found in the compositions of water supplies. Table 5, showing chemical analyses of some typical public water supplies, gives a slight indication of these variations. Furthermore, the water received at a given location may vary widely from time to time, either because supplies from different sources are being used or because the composition of a single supply fluctuates, as in the case of water supplies obtained from rivers (Table 6).

Another, and often neglected, characteristic which affects water-caused problems is that the composition of the water added to a system does not necessarily remain the same after the system starts to operate.[16] Changes in chemical composition take place as the result of evaporation, aeration, corrosion, and scale formation. These chemical changes, temperature changes, formation of biological growths, and the accumulation of suspended matter all tend to produce operating results which may differ from those anticipated on the basis of the chemical analysis of the makeup water.

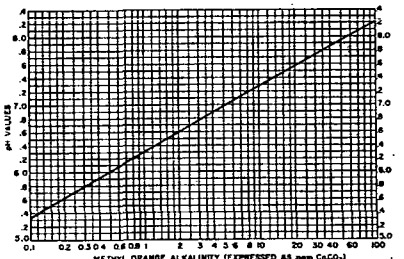


Fig. 1 .... Relationship Between Bicarbonate Alkalinity, Free Carbon Dioxide, and *pH*[4]

*Chemical Characteristics.* The type and amount of dissolved inorganic materials, including gases, define the chemical characteristics of any water. Typical water analyses such as those shown in Table 5 are not complete, but give only the major constituents and those important for municipal and average industrial use of the water. The many minor constituents which are present in most water supplies have little or no importance for the overwhelming majority of water uses.

In water analyses, all values, except *pH*, are usually given as parts per million (ppm), the weight of material dissolved in a million parts by weight of the water or solution. Thus, a 1 percent solution corresponds to 10,000 ppm. It is important to keep in mind that, when water analyses are reported in ppm, the chemical species must also be given. Thus, the same calcium concentration in a single water might be variously expressed as 100 ppm as $CaCO_3$, 56 ppm as $CaO$, or 40 ppm as $Ca$.

Other units are also used in reporting water analyses. Table 7 summarizes a few of the more common of these, together with factors for converting their numerical values into ppm. Most water analyses include only dissolved solids and omit the dissolved gases which are also present. Certain of these, such as nitrogen, have virtually no effect upon any use of water. Others, such as oxygen, carbon dioxide, and hydrogen sulfide, produce important effects in water systems. Carbon dioxide can either be measured directly or can be estimated from the *pH* and total alkalinity by making use of one of the many available variations of Tillmann's curves (Fig. 1). Oxygen and hydrogen sulfide, on the other hand, in order to have any meaning must be measured by special techniques at the time the sample is collected. Because oxygen is so important in the corrosion of metals and because it is so readily dissolved to at least a limited extent as the result of contact with air in many water systems, the water chemist will often simply make the conservative assumption that any water supply which has had an opportunity to come into contact with air will be ssturated with oxygen in accordance with its partial pressure in air and the water temperature.

Of the chemical constituents normally reported in a water analysis, *total hardness* is probably the item most commonly recognized by laymen. Strictly speaking, this is a measure of the dissolved substances which prevent soap from lathering. In most cases it corresponds to the calcium and magnesium

Table 7 .... Conversion Factors for Water Analyses

| To Convert | Into | Multiply by |
|---|---|---|
| Grains per U. S. gallon | ppm | 17 |
| Grains per Imperial gallon | ppm | 14.2 |
| Grams per liter | ppm | 1000 |
| Mg per liter | ppm | 1 |