through systems, where large quantities of water are used, intermittent treatment a few times each day will usually result in satisfactory slime removal and chemical economies.

Neither the phenols nor copper sulfate may be used for the removal of slime already formed. For this purpose, chlorine gas or suitable chlorine liberating compounds may be used. After being cleaned, the other chemicals may be used to prevent the reestablishment of slime in the system. The removal of green algae from a cooling tower should never be used as an indication that the true slime-forming organisms on heat exchanger surfaces have been removed. The more resistant slime formers, which so materially reduce heat transfer efficiency, will often be unaffected by treatment which completely eliminates algae.

Copper sulfate must be used with care because it can cause serious corrosion of steel in a system. It is also ineffective in alkaline water because the copper is precipitated from the water.

Closed Once-Through Systems

In equipment where light is excluded, slime formations are due to fungi. Usually, they predominate on the heat exchange surfaces. Bacteria form thick, soft slime. Yeast and molds form tough rubbery slimes. Chlorine and hypochlorite solutions, fed intermittently, are usual preventatives.

UNDERWATER CORROSION

When deleterious substances are present in water, the corrosivity of the solution is increased in proportion to the amount of deleterious substances present, the temperature, and usually the rate of flow of the solution over the metal surfaces. There are other relevant factors, but their influence in general is subordinate to those mentioned. Dissolved oxygen, acid gases, and chloride salts are the *corrosion accelerators most frequently encountered.*

Neutral and slightly alkaline waters saturated with air, corrode iron at a rate about triple that for the same water free of air. Hot water containing oxygen will corrode iron at a rate three to four times that for the same water when cold.

Corrosion of iron decreases as the *pH* of water solutions increases, and practically ceases at a *pH* of 11. Film-forming agents such as chromium, nickel, and silicon, can be added in the manufacturing of metals to provide increased corrosion resistance. In some processes, inhibitors, such as chromates, can be added to the water to minimize corrosion.

Soft water, as for example the effluent from zeolite softeners, is likely to be several times more corrosive to iron than hard waters. In small installations, the use of copper or brass pipe usually is a practical expedient. Cement-lined pipe and tanks suitably resist attack.

Where the water contains slime-forming organisms, especially those bacteria that thrive on iron, chlorination of the water is imperative to inhibit tuberculation and subsequent pitting.

Bituminastic paints, applied at *regular* intervals upon *well cleaned* surfaces, will measurably prolong the life of equipment handling cold waters.

It is generally agreed that the rate at which oxygen reaches the surface determines the rate of corrosion of ferrous metals. Underwater, the oxygen diffusion to a surface is often restricted by films and scale that form on the surface, and consequently the rate of corrosion differs from that of surfaces exposed to the atmosphere or to alternately wet and dry conditions.

All ferrous metals will not corrode at the same rate. A thorough knowledge of the conditions to be encountered and experience gained from tests of the materials in service are required when attempting to predict performance or life in a given service.

Copper, aluminum, and other non-ferrous metals and their alloys have been found effective in resisting many types of underwater corrosion. Corrosion of ferrous metals with which these metals are in contact, may be accelerated *in water of good conductivity.*

The environmental conditions are responsible for length of service of any metal. No single material is suitable for all types of service.

Once-Through Systems

Where corrosion can be expected in once-through systems, it may be minimized through the use of one of the following methods:[32]

1. Forming a protective film of calcium carbonate on the metal surfaces.
2. Providing mechanical or chemical deaeration, or both, of the water.
3. Using organic or inorganic corrosion inhibitors, or both, in low concentrations.

Formation of a thin protective calcium carbonate film is accomplished by adjustment of the water until the Langelier Index has a value greater than +0.5. This is rather difficult in systems which have a wide variation in temperature. Since the Langelier Index is dependent on temperature, when a water is adjusted to form a protective film on those surfaces of higher temperature, no film will form on colder surfaces. Therefore, this method of corrosion control *is more applicable to large municipal distribution systems.* Where heat transfer is involved, the method is usually impractical except under unusual circumstances. When this method is used, *pH* is increased by using an inexpensive alkali such as lime, caustic soda, or soda ash. Lime is usually used for waters of low calcium content. Caustic soda or soda ash are used for waters of high calcium content.

Mechanical[33] and chemical deaeration are not often used in once-through systems because of relatively high operating costs. Mechanical deaeration also requires the use of costly equipment. Chemical deaeration is usually accomplished by raising *pH* with caustic soda and by continuously feeding catalyzed sodium sulfite in proportion to water flow. The use of catalyzed sulfite is not permitted in water to be used for potable purposes.

There are several corrosion inhibitors such as chromate, polyphosphates, and silicates which are effective in once-through systems.[34] Polyphosphate at a concentration of 2 to 5 ppm has been found useful in controlling tuberculation of iron pipe and in reducing overall corrosion. Usually, more effective treatment is to use chromate polyphosphate at concentrations of less than 60 ppm.

Sodium silicate is often used in relatively soft waters by increasing the silica content about 8 ppm. It is used primarily to reduce corrosion in potable water supply systems.

Open Recirculating Systems

Corrosion in open recirculating systems, such as air washers and cooling towers, is usually controlled by use of

corrosion inhibitors such as chromates, polyphosphates, a combination of chromate and polyphosphate, and nitrites.[35, 36] Mechanical or chemical deaeration is not practicable in open systems because of the high rate of aeration. It is not practicable to use high *pH* values of 11 or more in systems containing wood. High *pH* will cause serious delignification of wood. High *pH* values also prevent control of scale. Corrosion control is usually carried out in the *pH* range of 6.5–8.

Chromates are by far the most effective corrosion inhibitors. It is extremely important, however, to maintain an adequate concentration of 300–500 ppm, which is effective for most systems. If for economic reasons substantially lower concentrations are used, serious pitting corrosion may occur.

Polyphosphates are most effective in reducing tuberculation. It is not usually possible to reduce overall corrosion to anywhere near the degree possible with chromate.

Where economy of treatment is of primary importance, a substantial reduction of pitting and overall corrosion can be obtained by using as little as 60 ppm of a mixture of polyphosphate and chromate. Close control over *pH* is a requirement for good corrosion control by this process.

Sodium nitrite has not had widespread use as a corrosion inhibitor in open recirculating systems. It has been reported that difficulty may be encountered in maintaining effective concentrations. Considerable *field experience is needed to* further qualify this inhibitor.

Closed Recirculating Systems

The term Closed Recirculating System is in reality a misnomer. Except for relatively small systems, most closed systems are open because they most usually require make-up water. Recently, tests conducted on 84 closed systems indicated that more than 50 percent of the systems had one or more water changes per month because of leakage. Weekly water changes were found in more than 10 percent of the systems.[37] Continuous make-up, of course, replenishes oxygen in the system, thus promoting corrosion. It is imperative, therefore, that corrosion control be provided for most closed systems. The age old assumption that closed systems are closed is no longer valid.

Corrosion control is usually accomplished by (1) mechanical or chemical deaeration or (2) use of corrosion inhibitors such as chromates and nitrites.

The use of polyphosphates is not generally recommended for closed systems because they will revert to ineffective orthophosphates unless there is a large replacement of water containing polyphosphate.

Higher concentrations of chromate are usually maintained *in closed systems as compared with open systems. This is* primarily due to the fact that, since water losses are usually small, the cost of maintaining excess chromate as a safety factor is small.

Treating Chemicals

Whenever chemicals are used to control scale, corrosion, algae, and slime, competent advice from a water chemist is desirable. Often factors considered irrelevant to the layman, will be of much importance in securing effective treatment. Very often troubles are created through improper use of chemicals and are more serious than if they were not used.[38]

Refrigerating Systems

Corrosion in refrigerating systems is confined to surfaces in contact with brines or those in contact with refrigerant.

Brines. Refrigerating brines usually are comprised of sodium chloride, calcium chloride, or calcium and magnesium chlorides. The corrosivity of dilute brines is higher than their more concentrated solutions. The corrosivity of sodium brines, other conditions being fixed, is about 1.5 times greater than brines of the alkaline earth metals.

Brines are excellent electrolytes. Contact of dissimilar metals of wide potential differences, when in contact with brines, results in rapid corrosion by galvanic action.

The leakage of air, acid refrigerants, or both, accelerates the corrosivity of brines. Ammonia precipitates calcium and magnesium salts, thus clogging the system at restricted points.

The addition of caustic soda and sodium dichromate to brine solutions to inhibit corrosion of iron, is a more or less general practice. Sodium silicate and sodium phosphate are also used at times, but tests indicate they are not as effective as is sodium dichromate. It has been suggested[39] that 125 lb of sodium bichromate per 1000 cubic feet of calcium chloride brine, and 200 lb per 1000 cubic feet of sodium chloride brine, be added to inhibit brines; that when salt or calcium chloride is added to "strengthen" brine, sodium dichromate also be added in the amounts shown in Table 6.

Table 6 .... Quantities of Sodium Dichromate to be Added to Maintain Initial Concentration

Specific Gravity of Brine to be Strengthened	Lb Sodium Dichromate per 100 Lb $CaCl_2$ Added
1.16	0.695
1.18	0.621
1.20	0.556
1.22	0.502
1.24	0.455
	Lb of Sodium Dichromate per 100 Lb NaCl Added
1.12	1.79
1.14	1.47
1.16	1.32
1.175	1.18

Refrigerants.[40] The common refrigerants, except those of the hydrocarbon type, will attack the common metals and alloys if *moisture is present.* Even a very small amount of *water may cause severe corrosion with certain refrigerants.* The amount required need only be sufficient to produce a water film on the metal surface.

With the halogenated hydrocarbons, complete elimination of water is much to be desired. Where ammonia is used, copper and its alloys, aluminum and zinc, are attacked especially at elevated temperatures. When sulfur dioxide is used, more than 50 ppm (0.005 percent) of water will cause appreciable corrosion of virtually all the common materials.

Minimizing Steam Condensate Corrosion

There are four expedients that may be utilized to minimize corrosion in steam condensate systems: (1) treatment of the boiler feed water so as to eliminate deleterious gases entrained with the steam, (2) design of the condensing equip-