being processed and the concentration of solids due to evaporation are factors in air washer operation when the air is humidified.

The concentration of scale-forming minerals in open recirculated cooling water is limited by natural drift or windage loss. This is the loss of water droplets from the system. Windage losses from typical systems may be classified as follows, based on recirculating rates:

Type of System	% of Recirculating Rate
Evaporative Condensers and Air Washers	0 to 0.1
Mechanical Draft Cooling Towers	0.1 to 0.3
Atmospheric Cooling Towers	0.3 to 1.0
Spray Ponds	1.0 to 5.0

To show the effect of concentration in a typical mechanical draft system assume:

1. Recirculating rate = 100 gpm.
2. Drift loss = 0.2 percent of recirculating rate = 0.2 gpm.
3. Evaporation rate = 1 percent of recirculating rate = 1.0 gpm.
4. Calcium bicarbonate in make-up water = 100 ppm.
5. Calcium bicarbonate in evaporated water = 0 ppm.

Let K = concentration of calcium bicarbonate in recirculating water = concentration of calcium bicarbonate in drift loss.

The process of concentration in the system may be represented diagrammatically as follows:

Evap. = 1 gpm
$Ca(HCO_3)_2$ = 0 ppm
↑
Recirculating Water System
$K = Ca(HCO_3)_2$ conc.
→ Drift 0.2 gpm, $Ca(HCO_3)_2 = K$ ppm
↑
Make-up = 1.2 gpm
$Ca(HCO_3)_2$ = 100 ppm

The concentration may be obtained from the equation

$$(\text{Make-Up})[Ca(HCO_3)_2 \text{ conc.}] = (\text{Evap.})[Ca(HCO_3)_2 \text{ conc.}] + (\text{Drift})[Ca(HCO_3)_2 \text{ conc.}]$$

$$(1.2)\ (100) = (1)(0) + (0.2)(K)$$

substituting,

$$120 = 0 + 0.2\,K$$

whence,

$$K = 600 \text{ ppm}$$

Therefore the concentration of calcium bicarbonate in the recirculating water equals 600 ppm. This far exceeds the allowable concentration of 170 ppm at which scaling will occur.

To correct this situation, it is imperative to provide a continuous bleed-off or blowdown from the recirculating water circuit. Typical bleed-off requirements are shown in Fig. 5. Reference to the No Treatment curve shows that a bleed-off rate of 1.2 times the evaporation rate is required when a make-up water contains 100 ppm calcium bicarbonate (or alkalinity) if scale is to be prevented. Calculation by a material balance will show that the bleed-off plus drift loss will limit the calcium bicarbonate to 171 ppm.

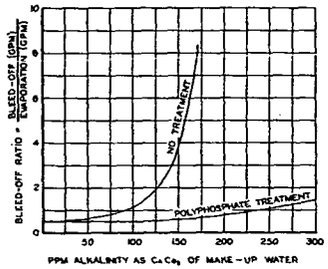

Fig. 5 . . . . Relation of Bleed-Off Requirement to $CaCO_3$ in Make-Up Water

It can be seen from Fig. 5 that very large amounts of bleed-off are required as a make-up water approaches or exceeds 150 ppm of alkalinity. When alkalinity exceeds 175 ppm, bleed-off alone is no longer effective. The use of 5 ppm or less of polyphosphate is extremely effective in reducing the required bleed-off and making possible the use of make-up waters which will not respond to bleed-off alone.

Occasionally, waters are encountered which have exceptionally high alkalinities or which develop high *pH* values when recirculated. The use of sulfuric acid is common in these cases to maintain *pH* values between 7 and 8. Polyphosphates are most always used when acid is required.

It is very important to control acid feeding carefully to avoid serious corrosion. Automatic *pH* controllers are often employed for such a purpose.

Closed Hot Water Heating Systems

This section excludes residential and also other systems in which leakage or loss of water by use or drainage is insignificant and in which consequently, corrosion and formation of scale are not encountered.

Corrosion in a closed system is due to the dissolved gases, primarily oxygen, in the make-up water and to electrolytic attack arising from contact of dissimilar metals in the same water circuit. The higher the water temperature the more severe will be the corrosion. Corrosion control methods may be either mechanical or chemical.

The *mechanical method* usually deaerates the recirculating water to remove corrosive gases but it removes only dissolved gases and hence does not prevent electrolytic action. Since deaerating equipment can be expensive it usually is not warranted for hot water systems.

The *chemical methods* are of two types: (1) the use of sodium sulfite, tannins, or both and (2) the use of corrosion inhibitors. Oxygen removal by chemical means will not prevent electrolytic attack which must usually be prevented by additional chemical treatment. Furthermore, the use of chemical methods for oxygen removal usually will result in a buildup of total solids in the system and may cause sludges to form and reduce the rate of heat transfer.

The most common method for the control of corrosion in closed hot water systems is to use corrosion inhibitors, such as chromates or nitrites. Corrosion inhibitors, when used at proper concentrations, not only prevent attack by dissolved gases such as oxygen, but also prevent electrolytic attack between dissimilar metals. Normally, *pH* adjustment of the recirculated water is not necessary. However, if the *pH* is below 7.0, an alkaline material should be added to obtain a *pH* value between 7.0 and 8.5. If a *pH* higher than 8.5 is found, it should be reduced to fall within the 7.0 to 8.5 range by the careful addition of small amounts of mineral acid. The required concentration of corrosion inhibitors depends upon the temperature to which the water in the system is heated and must be increased as the water temperature becomes higher.

New systems normally are contaminated with dirt, grease, oil and other matter which, unless removed from the system, could interfere with heat transfer. They should be cleaned with an alkaline, detergent-type cleaner before being put in operation. After cleaning, the system should be thoroughly drained and flushed.

Low-Pressure Steam Heating Systems

A low-pressure steam heating system is one operating at a pressure not exceeding 15 psig. The amount of condensate returned to the boiler may be the equivalent of 90 to 100 percent of the water evaporated. Since air moves in and out of steam systems through the air vents, the condensate is freely exposed to oxygen, some of which is dissolved and returned to the boiler together with free carbon dioxide and other gases that may also be in contact with the condensate. Make-up water for the system will also introduce the same gases and in some cases may have a high free carbon dioxide content with consequent low *pH* value.

Corrosion in low-pressure boilers is due mainly to dissolved oxygen in the water entering the boiler. Corrosion is therefore usually prevented by chemical or mechanical removal of oxygen. On some of the larger systems deaerating feed water heaters may be used but since they will not normally remove all of the oxygen enough may remain to cause corrosion.

It is customary even when mechanical deaerating equipment is used, to supplement it with chemical removal of the oxygen. This is usually accomplished by feeding chemical treatment internally to the boiler water. Such chemical treatment will consist of sodium sulfite, in conjunction with tannins and alkalinity-forming chemicals. It is considered good practice to maintain a *pH* value in the range of 10.5 to 11.5 and a sulfite residual of 30 to 40 ppm, at all times. Before proceeding with chemical treatment, enough water should be drained from the bottom of the boiler to remove any sludge or precipitates that have collected.

High-Pressure Steam Heating Systems

This section deals with proper treatment of water for use in high-pressure systems. The treatment and other considerations also apply to those low-pressure systems in which large amounts of untreated water are added to the condensate returned to the boiler.

The problems encountered are due to (1) scale formation, (2) corrosion, (3) pitting, and (4) foaming and priming.

Scale is caused primarily by calcium and magnesium salts which precipitate as carbonates and sulfates. In waters having a high silica content, silicate scales may also be encountered.

In order to prevent the formation of scale in a system, it is necessary to feed a proper phosphate and organic sludge conditioner, maintain the correct *pH*, and provide an adequate blowdown. Where extremely hard waters are encountered, or where very large amounts of untreated make-up water are employed, it is sometimes desirable to soften the untreated make-up water in order to reduce chemical treatment costs. When there is little return of condensate to such systems, the method of feed is of utmost importance if adequate control of scale formation is to be obtained.

Accepted practice indicates that *pH* values should be maintained between 10.5 and 11.5. In addition, sufficient phosphate should be fed to the boiler water to maintain a phosphate residual of 30 to 50 ppm at all times. There are a number of different types of phosphates which can be used, the selection of which depends upon operating conditions. In addition, a sufficient blowdown must be provided (preferably a bottom blowdown) to maintain total dissolved solids in the boiler water at a satisfactory low level. The permissible concentration of total solids is dependent upon the make-up water characteristics and the method of operating the system.

Corrosion and *pitting* are due primarily to dissolved gases present in the boiler water, but also can be caused by an acid condition of the untreated feed water. Pitting and corrosion caused by dissolved oxygen can be prevented by the use of a feed water deserating heater and chemical deaeration by means of sodium sulfite, hydrazine, or tannin. A sulfite residual of 30 to 40 ppm should be maintained at all times.

For *pH* control, an alkaline material should be used when necessary. The use of soda ash should be avoided, because when soda ash is heated by the boiler water, carbon dioxide is liberated. The free carbon dioxide will be carried over with the steam and cause serious corrosion of steam condensate lines. An alkaline material which does not have a carbonate content should be used whenever possible.

For best results in treatment of boiler water, a separate chemical should be used for controlling each of the following: phosphate, *pH*, and sulfite. In many cases, attempts to control all three by means of a single compound may not produce the required results.

Other problems encountered in heating systems include foaming and priming which will invariably lead to the undesirable carryover of boiler water into the steam system. Foaming and priming may be due to the poor quality of untreated boiler feed water which, for example, may contain much organic and suspended matter or a large amount of total dissolved solids. Even when feed waters are of relatively good quality, foaming and priming can occur if there is inadequate blowdown or inadequate control of internal chemical treatment. Anti-foaming chemicals are available for reduction of foaming.

Minimizing Steam Condensate Corrosion

Corrosion in steam condensate lines is due to the presence of deleterious gases, such as oxygen and carbon dioxide. There are three methods which may be used to minimize this type of corrosion:

1. Treatment of the boiler feed water so as to eliminate undesirable gases, such as oxygen, which otherwise would be entrained with the steam.
2. Chemical treatment of the condensate so as to neutralize dissolved gases, such as carbon dioxide.
3. Use of film-forming types of chemicals, which will protect or isolate the metallic surfaces from the condensate.

Elimination of oxygen in the boiler water, and therefore from the steam itself, can be accomplished either mechanically or chemically, as described in the section on High-Pres-