precipitation is induced, the Langelier Index is a more reliable indication of scaling tendency.

Prevention of scale in once-through systems is based primarily on the adjustment of *pH*, the application of surface-active agents, or a combination of the two. Normally the addition of a few parts per million of a surface-active agent such as a polyphosphate[28] fed proportionately to a water with a scaling tendency is all that is required to control scale.

Where a given water does not respond satisfactorily to surface-active agents, reduction of *pH* with sulfuric acid or carbon dioxide is often employed. The *pH* is reduced only sufficiently to have it fall within the effective range of the surface-active agent. The use of acid or carbon dioxide is sometimes permitted without polyphosphates when corrosion will not be severe. In this case the *pH* is reduced so that the Langelier Index is less than +0.5. The acid or carbon dioxide must be added with care. Use of automatic *pH* controllers is required if corrosion is to be prevented.

A special case of scale from ferrous bicarbonate decomposition was mentioned previously. Ferrous bicarbonate is considerably less stable than calcium bicarbonate. The prevention of this decomposition can be accomplished by the addition of polyphosphate in low concentrations.[21] The use of polyphosphate in the ratio of two parts by weight to one part by weight of iron is usually most effective. The polyphosphate must be added to the water before exposure of the water to air or chlorine if effective stabilization of the iron is to occur.

Closed Recirculating Systems

The closed recirculating system is one in which water circulates through one heat exchanger where it absorbs heat, has its temperature elevated, and circulates through another heat exchanger in which its temperature is lowered. In cold water or chilled water systems scaling is seldom a problem. In hot water systems scaling is seldom a problem unless there is a large amount of make-up water.[28] In this case surface-active agents such as polyphosphate are used.

Open Recirculating Systems

Where water from condensers and similar equipment is passed through a spray pond or cooling tower and then returned to the equipment, there is an increase in the concentration of solids because of the evaporation of some of the water into the cooling air, and, moreover, the aeration removes carbon dioxide. Both factors promote the tendency to deposit scale.

The corrosive properties of the water can also be increased through the absorption of acid gases such as sulfur dioxide (SO_2), from the air.[28] The absorption of gases from the air 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:

	Percent 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

$$\text{(Make-Up)[Ca(HCO}_3\text{)}_2\text{ conc.]} = \text{(Evap.)[Ca(HCO}_3\text{)}_2\text{ conc.]} + \text{(Drift)[Ca(HCO}_3\text{)}_2\text{ conc.]}$$

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

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

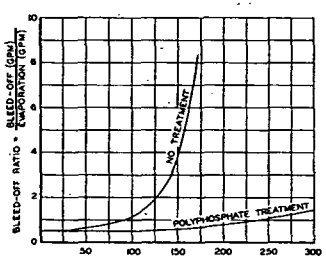

Fig. 5 . . . . Relation of Bleed-Off Requirement to $CaCO_3$ in Make-Up Water

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.

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.

Heating Systems

In hot water heating systems or in steam heating boilers where all condensate is returned, troubles from scaling should not be severe. If necessary, sodium phosphate or sodium carbonate may be added to the water to prevent the formation of adherent calcium sulfate scale.

Boilers and High Temperature Equipment

Where temperature exceeds 250 F, complete softening of the water is the only practical method for minimizing sludge formation. This is usually accomplished by artificial or natural zeolites (called also ion-exchange materials) or by hot-process precipitation softeners.

In boilers operating at pressures above 100 psig virtually all the calcium, magnesium, silica, iron, and manganese salts entering with the feed water are potential scale or sludge formers.

In boilers operating at 100 to 250 psig, the formation of adherent calcium sulfate (anhydrite) scales is most to be feared. Such deposits form on the *hottest* evaporative surfaces. The scale has a low heat conductivity. Even a layer of egg shell thickness may so impede the rate of heat transfer as to bring about over-heating of the metal.

The orthophosphates of sodium are most frequently used to prevent sulfate scales. The concentration of phosphate required is such as to cause the precipitation of calcium phosphate as sludge, thus keeping the boiling water undersaturated with respect to calcium sulfate. To a lesser extent, sodium carbonate (called also soda ash and sal soda) is also used. Most of the effective boiler compounds contain either phosphates or soda ash, or both. Certain organic materials and colloids are sometimes found to minimize scale formation. Where chemicals are introduced directly into the boiler in amounts adequate to prevent scale, sludge is formed in amounts proportionate to the calcium and magnesium salts entering with the feed water. To prevent troublesome accumulation of this sludge, as well as soluble salts, as evaporation occurs, some *blowdown* of boiler water is necessary.

CAUSES AND PREVENTION OF SLIMES

A water containing slime-producing organisms will produce prohibitive amounts of slime *only* when the conditions of use are such as to propagate their life processes. Whenever sufficient food material from normal water or from airborne dust combines with optimum temperature conditions, such as exist on cooling surfaces and air washers, serious quantities of slime will be produced.

Some natural well waters do not contain sufficient foods to support luxuriant slime growths. Algae, which require light for carrying on their life processes, are likely to cause difficulty in cooling towers and other areas where sunlight is abundant. The ordinary slime-forming bacteria are capable of using a wide variety of nitrogenous and cellulose material as food sources. These bacteria thrive best under dark conditions such as exist in condensers and other heat transfer surfaces. Other organisms capable of causing similar difficulties use such a wide variety of food material as algae,[14] iron compounds,[28] and inorganic sulfates.[28]

At present, the use of toxic chemicals and irradiation are the two general means employed in slime control. The value of ultra-violet light, used so broadly in the beverage industry, is somewhat in dispute.

Anti-fouling paints have been developed and are fairly satisfactory for the prevention of the growth of macro-organisms such as *barnacles* and *mussels*, but these paints must be renewed at frequent intervals, and are not applicable to inaccessible areas such as the inside of pipe lines and cooling towers. Satisfactory *anti-sliming* paints have *not* been found.

Table 5 . . . . Common Chemicals Used for Slime Control

Chemical	Trade Name	Physical State*
Chlorine	Chlorine	Gas
Hypochlorites	Calcium Hypochlorites	Crystalline
	Sodium Hypochlorites	
Chlorinated Phenols Sodium—	Chlorophenylphenate	Briquettes
	Tetrachlorophenate	Briquettes
	Pentachlorophenate	Briquettes
Potassium Permanganate	Permanganate of Potash	Crystalline
Copper Sulfate	Blue Vitriol	Crystalline

* As Shipped.

Names and other pertinent data relating to some of the more common chemicals used in slime control are shown in Table 5.

Chlorine is the only chemical to which is attributed the ability to destroy slime-forming organisms. The others are presumed to poison marine organisms, most of which *recover* when the chemical is not used regularly.

While chlorine is the most generally used chemical, the use of others may occasionally prove to be more practicable. Choice of the chemical is conditioned largely by the design and operation of the system.

Open Recirculating Systems

In spray ponds and cooling towers of the open type, light-loving algae growths are likely to cause blocking of the distribution piping and troughs. These organisms are most troublesome in areas accessible to sunlight. Algae slimes are usually stringy in character.

In open recirculating systems, continuous use of small quantities of chlorine is generally most satisfactory. In once-