PART 5

Water Conditioning

Carrier

CONTENTS PART 5 WATER CONDITIONING

SYSTEM DESIGN MANUAL

SUMMARY OF PART FIVE

This part of the system Design Manual presents background material to guide the engineer to a better understanding of the cause, effect and prevention of water problems in various water circulating systems. Some of the more common practices for lessening the effect of scale and corrosion are also included.

The text of this Manual is offered as a general guide for the use of industry and of consulting engineers in designing systems. Judgment is required for application to specific installation, and Carrier is not responsible for any uses made of this text.

CHAPTER 1. WATER CONDITIONING_GENERAL

This chapter will help engineers and owners to recognize the value of conditioned water and its effect on the economics of an air conditioning plant. Included are discussions of chemical and physical characteristics of water, properties of water sources in the United States, and characteristics of water circulating systems.

Since there are many companies specializing in the field of water conditioning, it is important to retain an experienced company on a continuous consulting basis to recommend and to administer conditioning for each system. This practice is recommended because the water conditioning program can vary, depending on the season of the year, geographical location of the structure to be air conditioned, and on the changing chemical characteristics of the make-up water source.

Water used in air conditioning systems may create problems with equipment such as scale formation, corrosion, and organic growths. As a universal solvent, water dissolves gases from the air and mineral matter from the soil and rock with which it comes in contact. Environmental conditions at the air conditioning equipment may promote slime and algae. To provide effective control for all components of a system, an appraisal of the system and water source is recommended. A water conditioning program should be considered for all systems, though in the final analysis it may be found unnecessary.

The techniques and equipment required to solve water problems vary with the character of the water, the kind and size of system, and the facilities available. An effective water treatment system can be selected for a particular job, or the program can be designed to treat only some of the water problems.

BENEFITS OF WATER CONDITIONING

A water conditioning program influences the economic aspects of a system; it helps to insure a satisfactory and more continuous operation of the air conditioning system. Water conditioning lowers power and maintenance costs, and increases the equipment life. The following discussion presents some of the reasons why these economic factors are affected.

A good water conditioning program produces high equipment efficiencies.

Hard water in a natural state is scale forming and, when heated, tends to deposit a lime scale. This deposit and other impurities accumulate on tubes, valves, pumps and pipe lines, restricting flow and affecting heat transfer. *Figure 1* shows scale deposit in a brass tube. The finned copper tubes show the effect of corrosion. A very thin film of scale is enough to affect seriously the efficiency of a heat transfer surface.

Chart 1 illustrates the effect of various thicknesses of scale (expressed as fouling factors) on the suction temperature of a typical flooded cooler.

Chart 2 illustrates the effect of scale on the condensing temperature of a typical water-cooled condenser. Since the amount of work accomplished by the refrigeration compressor is a function of the lift (condensing temperature minus suction temperature), minimum fouling factors result in minimum energy requirements.

Chart 3 shows how the compressor horsepower per ton varies with the scale factor, and how only a small amount of scale in the condenser can greatly increase the compressor horsepower.

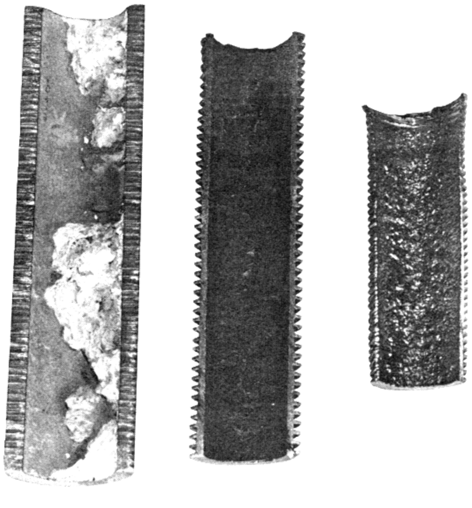
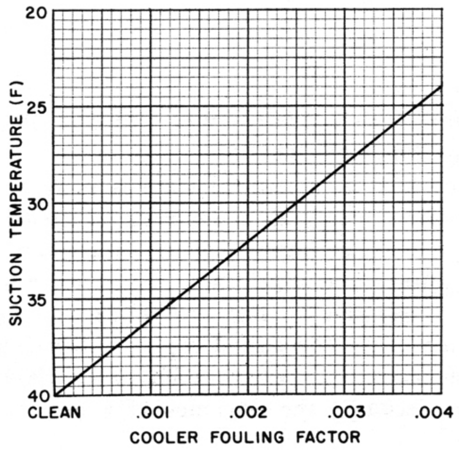


FIG. 1-TUBES SHOWING SCALE DEPOSIT AND CORROSION

CHART 1-EFFECT OF SCALE ON SUCTION TEMPERATURE



Cleaning may be necessary more frequently if too low a fouling factor is specified without a water conditioning program.

The fouling factor specified for selecting a refrigeration system should be chosen with judgment based on experience. *Table 11* in *Chapter 5* lists suggested fouling factors.

CHART 2-EFFECT OF SCALE ON CONDENSING TEMPERATURE

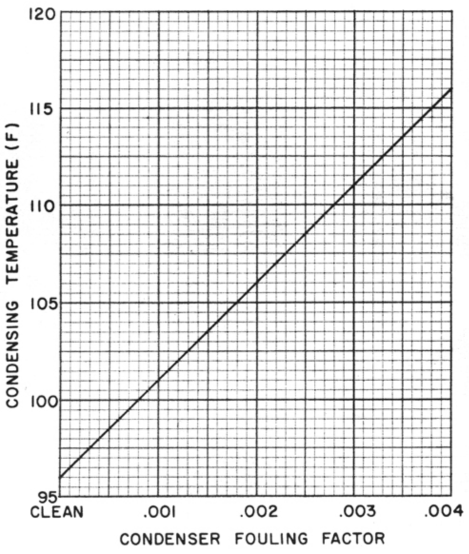
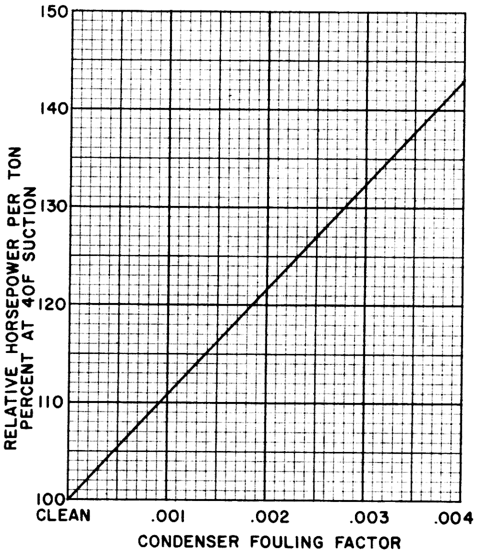


CHART 3-EFFECT OF SCALE ON COMPRESSOR HORSEPOWER



Lower equipment first cost is realized by a proper water conditioning program which allows the selection of a reasonable fouling factor.

Equipment first cost is often affected by the fouling factor which is specified by the engineer. Assume a drive horsepower is specified along with a particular fouling factor. The larger the fouling factor, the more heat exchanger surface is required to accomplish the work load. This increase is illustrated in *Table 1*.

WATER PROBLEMS

Problems produced by water fall into three categories which are discussed in detail in *Chapters 2, 3 and 4* respectively.

1. Scale formation caused by hard water reduces The heat transfer rate and increases the water pressure drop thru the heat exchanger.
2. Corrosion can be caused partly by absorption of gases from the air so that an aggressive condition is created and water attacks the exposed metal. In industrial areas this is frequently a major problem because of heavy pollution of the air by flue gases. Corrosion is prevalent in soft water areas.
3. Organic growths of slime and algae which Form under certain environmental conditions can reduce the heat transfer rate by forming an insulating coating or can promote corrosion by pitting.

TABLE 1—HEAT TRANSFER SURFACE REQUIRED TO OFFSET FOULING

FOULING THERMAL RESISTANCE (hr) (sq ft) (deg F temp diff)/Btu‡	OVER-ALL HEAT TRANSFER COEFFICIENT† Btu/(hr) (sq ft) (deg F temp diff)‡		THICKNESS OF SCALE* APPROX. (in.)	INCREASE OF REQUIRED HEAT TRANSFER AREA† (approximate %)	
	Cooler	Condenser		Cooler	Condenser
clean tubes	400	850	.000	0	0
0.0005	333	595	.006	20	45
0.001	286	460	.012	40	85
0.002	222	315	.024	80	170
0.003	182	240	.036	120	250

*Assume a mean value for the thermal conductivity of the scale of 1.0 Btu/(hr) (sq ft) (deg F per ft).

†The over-all heat transfer coefficients selected for this illustration are typical for a flooded cooler and a water-cooled refrigerant condenser. However, because it is possible to have different over-all heat transfer coefficients depending on the systems, the effect on the over-all heat transfer by the scale will vary.

‡Sq ft of inside surface of tube in heat exchanger.

WATER SOURCE APPRAISAL

An appraisal of the water supply source should include a chemical analysis and a determination of composition fluctuation over a period of time.

A water supply analysis together with the estimated water temperatures of the system makes possible a determination of the problems that may be encountered on a specific installation.

CONSTITUENTS AND CHARACTERISTICS OF WATER

The constituents of impurities in water can be classified as dissolved solids, liquids or gases, and suspended matter.

An example of a dissolved solid is sodium chloride or calcium carbonate in solution. Dissolved materials cannot be removed by filtration. Oxygen and carbon dioxide are dissolved in water, but in water conditioning for air conditioning these gases are not normally determined in the water analysis. An example of suspended matter which can be removed by filtration is mud, clay or silt. *Table 2* illustrates the wide range of constituents in typical water sources. However, *pH* is omitted in *Table 2* because it may have a wide range in a particular water.

Several characteristics of water such as *pH* value, alkalinity, hardness and specific conductance are of particular importance in water conditioning and are explained in detail.

pH Value

The *pH* value is one of the most important control factors in water treatment. It is an arbitrary symbol adopted to express the degree of acidity or alkalinity of a water sample. Neutral water has a *pH* of 7.0. Values below 7.0 and approaching 0 are increasingly acid while values from 7.0 to 14.0 are increasingly alkaline. Most natural waters have a *pH* of 6.0 to 8.0 Water containing free mineral acids may

TABLE 2—MINERAL ANALYSES TYPIFYING COMPOSITION OF WATERS AVAILABLE AND USED INDUSTRIALLY IN THE U.S.A.

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	1300
Sodium	Na	2	6	7	44	8	183	215	78	11000
Potassium	K	1	1	1		1	1	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	2700
Chloride	Cl	2	10	13	13	10	280	22	117	19000
Nitrate	NO_3	1		0	2	13	0	1	3	
Dissolved Solids		31	66	165	426	434	983	564	948	35000
Carbonate Hardness	$CaCO_3$	12	11	98	165	287	274	8	172	125
Noncarbonate Hardness	$CaSO_4$	5	7	18	40	58	54	0	295	5900

[a] All values are parts per million of the unit cited to nearest whole number (Reference 1).

[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., 330 ft
(8) Well Water — Roswell, New Mexico
(9) Ocean Water — Average

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have *pH* values below 4.5. A *pH* below 7.0 gives rise to corrosion of equipment with which water comes in contact. When the *pH* is high (above 7.5 or 8.0), calcium carbonate scale is deposited more readily

The *pH* is usually measured by an electrometric pH meter in the laboratory. It can also be determined by the use of color indicators, comparing the solution with standard shades of colors over the range of a particular indicator. There are several standard indicator slides to cover the range from 0-14.0 *pH*.

The definition of *pH* is the logarithm of the reciprocal of the hydrogen ion concentration (moles per liter).

$$pH = \log_{10} \frac{1}{H+}$$

where H+ is the hydrogen ion concentration.

When pure water, H_2O, ionizes into H+ and OH- ions, 0.0000001 grams of hydrogen ions per liter are liberated. This can be written as 1×10^{-7}, or as a *pH* of 7.0.

Alkalinity

Alkalinity is the most important characteristic of a water when determining the scale forming tendency. It is defined in *Chapter 6.* Generally, alkalinity is a measure of the acid neutralizing power of a water, and is determined by titration indicator.

Alkalinity may be classified in two ways with respect to a *pH* value as follows:

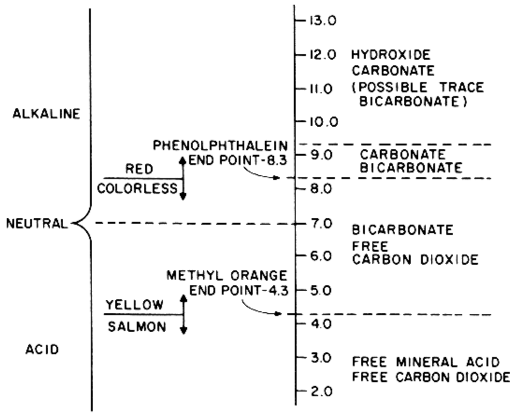
1. Phenolphthalein alkalinity is a measure of the carbonate and caustic or hydroxyl ions. It is determined by titrating down to a *pH* of 8.3. In natural waters phenolphthalein alkalinity is usually absent; however, it is sometimes found in water which has been softened by lime or soda ash.
2. Methyl orange (total) alkalinity is a measure of all the alkaline substances, including the phenolphthalein alkalinity. It is determined by titrating down to a *pH* of 4.3.

The difference between the two kinds of alkalinity is represented by the presence of the bicarbonate ion.

The phenolphthalein and methyl orange tests are commonly used in water conditioning control. *Figure 2* indicates a *pH* scale showing which constituents can exist at various *pH* values.

Methyl orange and phenolphthalein alkalinities may be interpreted as follows:

1. When there is no indication of phenolphthalein alkalinity, this means that all of the alkalinity is caused mainly by calcium, magnesium and sodium bicarbonates. This water has a *pH* value less than 8.5.



From Betz Handbook of Industrial Water Conditioning, 1962.
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Fig. 2-pH SCALE FOR CONSTITUENTS EXISTING IN NATURAL AND TREATED WATERS

2. When twice the phenolphthalein alkalinity is less than or equal to the methyl orange alkalinity, the alkalinity is assumed to be caused by calcium, magnesium and sodium carbonates and bicarbonates. This water has a pH greater than 8.5.
3. When twice the phenolphthalein alkalinity exceeds the methyl orange alkalinity, there is no bicarbonate alkalinity. In this case the alkalinity is caused by calcium, magnesium and sodium hydroxides and carbonates. Such water has a pH value greater than 8.5.

The amount of alkalinity and its type in a water determine to a large extent the type of water conditioning required. Examples of how the above rules may be used follow.

Example 1-Bicarbonate Alkalinity

Methyl orange (MO) alkalinity=100 ppm as $CaCO_3$
Phenolphthalein (P) alkalinity= 0 ppm as $CaCO_3$

Since this analysis indicates 0 ppm of phenolphthalein alkalinity, all of the alkalinity in the water is caused by bicarbonates.

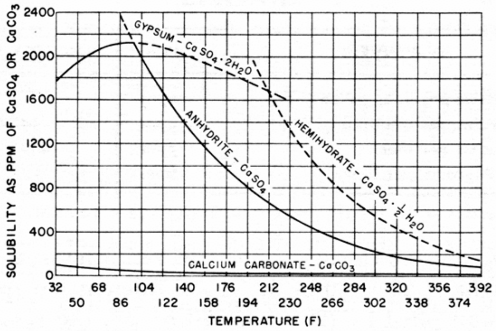
Example 2-Bicabonate and Carbonate Alkalinity

Methyl orange (MO) alkalinity = 100 ppm as $CaCO_3$
Phenolphthalein (P) alkalinity = 5 ppm as $CaCO_3$

Twice the phenolphthalein alkalinity is less than the methyl Orange alkalinity. Therefore, the alkalinity is caused by bicarbonates and carbonates.

Two times the phenolphthalein alkalinity (2×5)=10 ppm carbonate alkalinity as $CaCO_3$.

Bicarbonate alkalinity equals total alkalinity minus carbonate alkalinity (100-10)=90 ppm as $CaCO_3$.



NOTE: $CaCO_3$ in equilibrium with normal CO_2 content of the atmosphere.

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Fig. 3 – COMPARISON OF SOLUBILITIES OF CALCIUM SULFATE AND CALCIUM CARBONATE

Example 3- Carbonate and Hydroxide Alkalinity

Methyl orange (MO) alkalinity=100 ppm as $CaCO_3$
Phenolphthalein (P) alkalinity= 55 ppm as $CaCO_3$

Since twice the phenolphthalein alkalinity (2×55) exceeds the methyl orange alkalinity, there is no bicarbonate alkalinity present. All of the alkalinity is present as carbonates and hydroxides.
Two times phenolphthalein alkalinity minus methyl orange alkalinity (110-100)= 10 ppm hydroxide alkalinity as $CaCO_3$.
Methyl orange alkalinity minus hydroxide alkalinity (100-10)=90 ppm calcium alkalinity as $CaCO_3$.

Examples 1 and 2 are commonly encountered in both once-thru and recirculating condersing water systems. *Example 3* is seldom encountered.

Hardness

Hardness is represented by the sum of calcium and magnesium salts in water although it may include aluminum, iron, manganese, strontium, or zinc.

Carbonate (temporary) hardness is attributed to carbonates and bicarbonates of calcium and/or magnesium expressed in ppm as $CaCO_3$. The remainder of the hardness is known as noncarbonate (permanent) hardness which is due to the sulfates, chlorides, and/or nitrates of calcium and/or magnesium expressed in ppm as $CaCO_3$.

Noncarbonate hardness is not as serious a factor in water conditioning because it has a solubility which is approximately *70* times greater than the carbonate hardness. In many cases, water may contain as much as 1200 ppm of noncarbonate hardness and not deposit a calcium sulfate scale *(Fig. 3).*

Water hardness may be classified as follows:

HARDNESS (ppm as $CaCO_3$)	CLASSIFICATION
less than 15	very soft
15 to 50	soft
50 to 100	medium hard
100 to 200	hard
greater than 200	very hard

Hardness is sometimes reduced at the municipal water distributing plant by the use of a cold lime, cold lime soda, or by a sodium cation exchanger (zeolite) water process. The last method is used also in the home for domestic softening.

In domestic use hardness is recognized by the difficulty in obtaining lather without an excessive consumption of soap. The insoluble sticky curd is the result of action of the soap with the hardness. With hard water a scale is formed in vessels when water is boiled.

The most accurate method for determining the hardness of a water is by calculation from complete chemical analysis of the water. Many determinations of hardness made at water treatment plants are made with soap solutions. These results tend to be lower and less accurate than those based on laboratory tests. Alkalinity tests may be used to determine the amount of carbonate and noncarbonate hardness for control purposes as follows:

1. When the methyl orange or total alkalinity exceeds the total hardness, all of the hardness is caused by bicarbonates and carbonates.
2. When the medthyl orange or total alkalinity is less than the total hardness:
   a. Carbonate hardness equals the alkalinity.
   b. Noncarbonate hardness equals the total hardness less the methyl orange alkalinity.

Examples of interpretation of hardness are given here.

Example 4-Carbonate Hardness

Methyl orange (MO) alkalinity=100 ppm as $CaCO_3$
Total hardness=95 ppm as $CaCO_3$.

Methyl orange alkalinity in this case exceeds the total hard- ness; therefore, all of the hardness is presen as carbonate hardness.

Example 5-Carbonate and Noncarbonate Hardness

Methyl orange (MO) alkalinity=100 ppm as $CaCO_3$
Total hardness=150 ppm as $CaCO_3$
Total hardness exceeds the methyl orange alkalinity. The carbonate hardness, therefore, equals the alkalinity, and is equal to 100 ppm as $CaCO_3$.
Noncarbonate hardness equals total hardness minus methyl Orange alkalinity (150-100) or 50 ppm as $CaCO_3$.

Specific Conductance

The specific conductance of a water, defined in *Chapter 6*, indicates whether galvanic corrosion may be a problem. See *Chapter 3*.

METHOD OF ANALYSIS AND EXPRESSION OF RESULTS

Water contains a wide variety of dissolved solids or compounds which are mostly metals joined to acid radicals. When a sample is analyzed in the laboratory, it is not feasible to measure the compound. The metal and acid radicals are, therefore, determined separately. Results are expressed in parts per million (ppm).

When a salt, i.e., sodium chloride, NaCl, is dissolved in water, the two ions of which it is composed may be considered as existing separately; Na and Cl can thus be measured independently. It is practical to determine the metal (calcium) separately, irrespective of its combination with the bicarbonate radical, HCO_3, forming calcium bicarbonate, $Ca(HCO_3)_2$, or with the sulfate radical, SO_4, forming calcium sulfate, $CaSO_4$. Similarly the acid radicals are determined separately; the bicarbonate, HCO_3, the sulfate, SO_4, and the choride, Cl, are measured irrespective of the metals combined with them. In the ionic form, each element or radical is separated individually. This method is convenient and easy to interpret and use.

Results are expressed in parts per million (ppm), although grains per gallon (gpg) or equivalents per million (epm) are sometimes used. References 2, 3, and 4 describe the entire procedure for making water analyses and several methods of reporting results. When units are expressed in grain per gallon, multiply gpg by (*Table 3*).

It is common practice to report some of the constituents on a common unit or equivalent weight basis. The unit weight of the individual substance is calculated by the unit weight of another substance. For example, calcium is usually expressed in terms of calcium carbonate, $CaCO_3$. When constituents are measured by the same unit weight basis, they can be added or subtracted directly for convenience in calculating the amount of chemicals required for treatment. Another reason to report some of the constituents on a common unit basis is to simplify the calculation in order to obtain the noncarbonate hardness when the total hardness and alkalinity are known.

The equivalent weight method is illustrated here. Basic chemistry states that 20 parts (by weight) of calcium, Ca, combine with 30 parts of carbonate, CO_3, to form calcium carbonate, resulting in a total weight of 20+30 or 50. If the calcium ion (ppm) is multiplied by (20+30)/20 or 2.5, the result is ppm of calcium as calcium carbonate. Thus, 100 ppm of calcium ion represents the same quantity of calcium as does 250 ppm of calcium expressed as calcium carbonate, $CaCO_3$. In a similar manner, substances other than calcium and carbonate may be expressed as calcium carbonate by dividing the calcium carbonate total equivalent weight (20+30) by the equivalent weight of the other substance. For example, 12.16 parts of magnesium combine with the same quantity of any acid radical as does 20 parts of calcium. The factor for magnesium is (20+30)/12.16 or 4.12. Thus, 50 ppm of magnesium ion is the same quantity as 206 ppm (4.12 × 50) of magnesium expressed as $CaCO_3$. Factors for determining equivalent weights are found in References 2, 3 and 5. (The unit equivalent weight of an element is numerically equal to the atomic weight divide by the valence of the element. Equivalent weight of an acid radical such as CO_3, HCO_3, etc., is numerically equal to the molecular weight of the radical divided by the valence of the radical.)

TABLE 3-CONVERSION FACTORS FOR WATER ANALYSES

TO CONVERT	INTO	MULTIPLY BY
Grains per U.S. gallon	ppm	17.1
Grains per Imperial gallon	ppm	14.25
Grams per liter	ppm	1000
Milligrams per liter	ppm	1

Normally the metals and acid radicals are expressed in the ionic form. Hardness (both carbonate and noncarbonate), phenolphthalein alkalinity, and methyl orange alkalinity are normally given as ppm of $CaCO_3$. The undissolved or suspended solids are expressed in ppm. Usually, analysis of dissolved gases is not made in water conditioning but, if required, it is reported as parts per million of the dissolved gas.

WATER ANALYSIS DATA TABLE

Table 13 in *Chapter 5* was compiled from *The Industrial Utility of Public Water Supplies in the United States,* U.S. Geological Survey Water Supply Papers 1299 and 1300. With this information and the expected water temperature encountered in a system, it is possible to arrive at a reasonable guide to the problems that may be expected on a specific installation. Notes accompanying the table explain the source for each column.

APPRAISAL OF WATER SYSTEMS

System appraisal includes the number and types of water circuits, materials of construction, and equipment location. Each type of water circuit requires a different kind of water conditioning.

ONCE-THRU SYSTEM

A once-thru system may pose either a scaling or corrosion problem, but usually not both. If extensive water conditioning is required, it may be more economical either to design equipment with a large scale factor and to clean it frequently or to use expensive corrosion resistant materials rather than use water conditioning. Slime and algae may also be a problem in this system.

CLOSED RECIRCULATING SYSTEM

Conditioning to prevent corrosion is required, but seldom is scaling or slime and algae a problem.

OPEN RECIRCULATING SYSTEM

This system invariably has both a scaling and corrosion problem. During the warmer months slime and algae need control.

CHARACTERISTICS OF OPEN RECIRCULATING WATER SYSTEMS

Although there are no special characteristics of once-thru and closed recirculating systems to interest the water conditioning engineer, there are several characteristics of open recirculating water systems to cause concern. They are evaporation, windage, cycles of concentration, and control by bleed-off.

Evaporation

The evaporation loss in a cooling tower or evaporative condenser is approximately 1% of the water quantity circulated per 10 degree drop in water temperature thru the tower. This is accurate enough for most calculations. The following equation is a more precise method.

$$gpm_e = \frac{tr \times hrf \times 24}{h_{fg}}$$

Where:

gpm_e = water evaporated
tr = refrigerating capacity (tons)
hrf = heat rejection factor of refrigeration machine
h_{fg} = heat of evaporation of water, normally 1050 Btu/lb

Compression refrigeration machines in normal air conditioning evaporates approximately 0.03 gpm per ton for cooling towers and evaporative condenser equipment.

Windage

Windage, a characteristic of spray systems, consists of small droplets of water carried away from the tower, spray pond or evaporative condenser by the wind. Dissolved minerals as well as water are lost by windage. The amount of windage varies with each type of cooling tower, but these percentages may be taken as typical windage losses, based on the rate of circulation.

HEAT REJECTION EQUIPMENT	WINDAGE LOSS (%)
Spray ponds	1.0 to 5.0
Atmospheric towers	0.3 to 1.0
Mechanical draft towers	0.1 to 0.3
Evaporative condensers	0.0 to 0.1

Cycles of Concentration

Cycles of concentration is the ratio of dissolved solids in the recirculating water to the dissolved solids in the make-up water. For example, with three cycles of concentration the dissolved solids in the recirculating water are three times as great as in the make-up water.

The evaporative process, used to cool water in open recirculating systems, concentrates the dissolved solids in the water. This is a characteristic of cooling towers, evaporative condensers and spray ponds. For example, a 50 ton system using make-up water having a hardness of 110 ppm and other scale-forming salts has an evaporation of about 1 1/2 gallons per minute. Approximately 10 grains of mineral salts (equivalent to two aspirin tables) enter the system each minute. Assuming a 50% load factor, one pound of salt enters the system every 24 hours, or 30 pounds per month. It is important to carry away the scale forming salts before they deposit on the equipment. Therefore, salt concentration is controlled by bleed-off. Windage loss removes some of the dissolved salts.

A typical flow diagram for an open condenser water cooling system is illustrated in *Fig. 4*. The cycles of concentration *C* may be calculated as follows:

$$C = \frac{gpm_e + gpm_b + gpm_w}{gpm_b + gpm_w} \qquad (2)$$

where:

gpm_b = water lost by bleed-off
gpm_e = water lost by evaporation
gpm_w = water lost by windage

All quantities may be expressed either as shown or as a percent of recirculated water, providing all are represented in the same units.

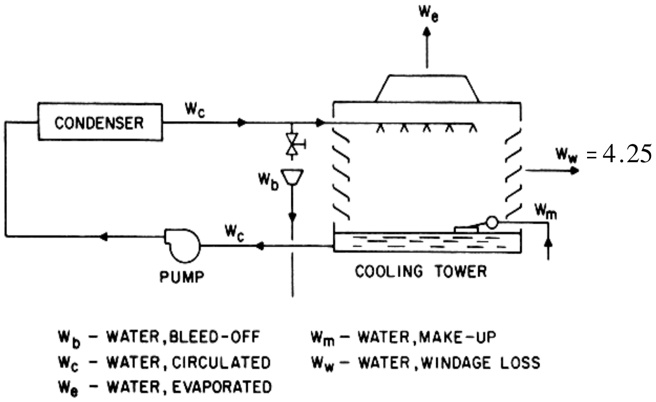


FIG. 4-TYPICAL FLOW DIAGRAM OF OPEN CONDENSER WATER COOLING SYSTEM

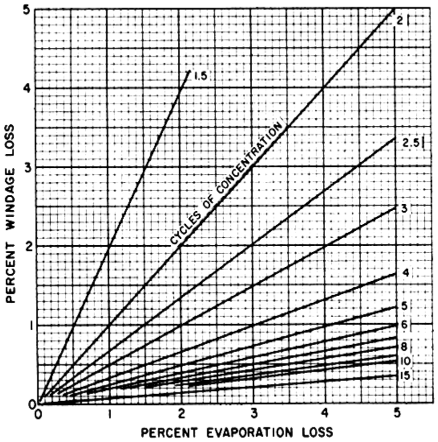
The equation may be simplified by combining losses due to bleed-off and windage.

$$C = \frac{gpm_e + gpm_{bw}}{gpm_{bw}} \qquad (3)$$

where:

gpm_{bw} = water lost by bleed-off and windage (gpm)

CHART 4-RELATIONSHIP BETWEEN EVAPORATION LOSS, WINDAGE LOSS AND CYCLES OF CONCENTRATION



NOTE: Windage loss and evaporation loss are a percentage of the recirculation rate of condensing water.

The relationship between evaporation loss, windage loss, and cycles of concentration is shown in *Chart 4*. For an example, assume a 10 degree drop in water flow thru the tower and no bleed-off. This corresponds to an evaporation loss of 1.0% of the recirculated water quantity. From the typical windage losses (1-5%) illustrated for the spray pond,assume a loss of 2%. From *Chart 4* the cycles of concentration is 1.5. If the tower is an atmospheric type and a 0.6% windage loss is assumed, the cycles of concentration is 2.7. In the case of a mechanical draft tower with a windage loss of 0.2% and the same temperature drop, the cycles of concentration is 6.0.

The chloride test[2] is used to determine the concentration of solids in both make-up and recirculated water. It is not an effective test for make-up water when the chloride content is low (0.5-1.0 ppm).

Control of Cycles of Concentration by Bleed-off

Bleed-off is normally required from all open recirculating systems to limit the concentration of solids. Bleed-off is more readily obtained by calculating the combined windage and bleed-off, and then subtracting the windage as follows. See *Equations 2 and 3* for definition of symbols.

$$gpm_{bw} = \frac{gpm_e}{C-1} \qquad (4)$$

$$gpm_b = gpm_{bw} - gpm_w \qquad (5)$$

Bleed-off can be obtained in one step by this formula:

$$gpm_b = \frac{gpm_e + gpm_w(1-C)}{C-1} \qquad (6)$$

Examples 6 and 7 illustrate the use of cycles of concentration and evaporation losses to determine the required bleed-off.

Example 6-Compressor System

Given:

Mechan draft cooling tower
Refrigeration load = 100 tons
Heat rejection factor = 1.25
Condensing water temperature rise = 10 degrees
Make-up water methyl orange alkalinity
= 40 ppm as $CaCO_3$
Methyl orange alkalinity in recirculated water,
Not to exceed 170 ppm as $CaCO_3$

Find:

Cycles of concentration
Recirculated water quantity (gpm)
Evaporation loss (gpm)\Windage loss (gpm)
Bleed-off requirements (gpm)
Make-up water (gpm)
Bleed-off requirements (gpm)
Make-up water (gpm

Solution:

Cycles of concentration, assuming the air does not affect the alkalinity

$$=\frac{\text{MO alkalinity in recirculated water}}{\text{MO alkalinity in make-up water}}=\frac{170}{40}=4.25$$

Condensing water quantity

$$=\frac{tr\times hrf\times 24}{\text{temp rise}}=\frac{100\times 1.25\times 24}{10}=300$$

Evaporation loss

$$=\frac{tr\times hrf\times 24}{h_{fg}}=\frac{100\times 1.25\times}{1050}$$

= 2.85 gpm, equivalent to 2.85/300×100 or 0.95% of the recirculated water flow.

The evaporation loss may also be calculated as 1% of the recirculated water quantity for each 10 degree drop in water temperature at the tower, i.e. 300 × 0.01 = 3.0 gpm. This is accurate enough for the usual calculation.

Windage loss = 0.1-0.3% of the recirculated water quantity; assume 0.2%.

0.002 × 300 = 0.6 gpm.

Bleed-off requirement (*Equations 4 and 5*)

$$gpm_{bw}=\frac{gpm_e}{C-1}=\frac{2.85}{4.25-1}=0.88\ gpm$$

$$gpm_b=gpm_{bw}-gpm_w=0.88-0.60=0.28\ gpm$$

Make-up water = evaporation+windage+bleed-off
= 2.85+0.60+0.28=3.73 gpm

Example 7-Absorption System

Given:

Absorption refrigeration machine
Refrigeration load = 100 tons
Heat rejection factor = 2.6
Condensing water temperature rise = 15 degrees
Make-up water methyl orange alkalinity=40 ppm as $CaCO_3$
Recirculated water methyl orange alkalinity, not to exceed 170 ppm as $CaCO_3$.

Find:

Cycles of concentration
Recirculated water quantity (gpm)
Evaporation loss (gpm)
Windage loss (gpm)
Bleed-off requirement (gpm)
Make-up water (gpm)

Solution:

Cycles of concentration
= 170/40=4.25 (as in *Example 6*)

Recirculated water quantity

$$=\frac{100\times 2.6\times 24}{150}=417\,\text{gpm}$$

$$gpm_e=\frac{100\times 2.6\times 24}{1050}=5.95\,\text{gpm}$$

$$gpm_w=.002\times 417=0.83\,\text{gpm}$$

$$gpm_{bw}=\frac{gpm_e}{C-1}=\frac{5.95}{4.25-1}=1.83\,\text{gpm}$$

$$gpm_b=gpm_{bw}-gpm_w=1.83-0.83=1.0\,\text{gpm}$$

Make-up water = evaporation+windage+bleed-off
= 5.95+0.83+1.00 = 7.78 gpm

CHAPTER 2. SCALE AND DEPOSIT CONTROL

This chapter reviews the causes of scale and deposits and methods used to determine scale-forming tendencies and systems to prevent their formation.

When water is heated or evaporated, the formation of insoluble scale causes serious difficulty in air conditioning systems (*Chapter 1*). Scale forms a protective coating, reducing corrosion, but at the same time reduces heat transfer efficiency and capacity. It also increases the power requirements.

The most common scale deposit found in air conditioning equipment is calcium carbonate, although there may be small amounts of magnesium carbonate and calcium sulfate present. Some waters having a high iron content leave an iron oxide deposit. Polyphosphates which are sometimes used to prevent a calcium carbonate scale deposit may precipitate and form a sludge of calcium phosphate.

TYPES AND CAUSES OF SCALE AND DEPOSITS

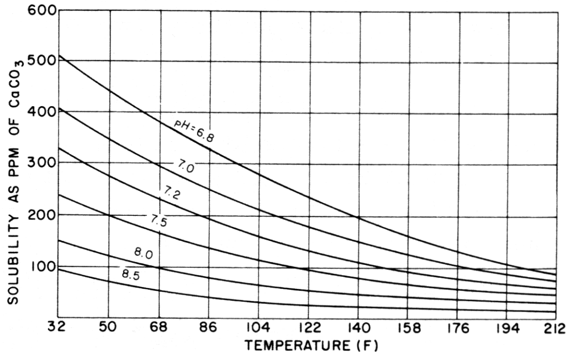
Calcium carbonate and calcium sulfate, two of the materials dissolved in water, have decreasing solubilities with rising temperature (*Fig. 3 and 5*). High temperature surfaces such as condensers are more susceptible to scale formation than the low temperature surfaces in the same water system.

CALCIUM CARBONATE SCALE

The primary factors causing calcium carbonate scale in a water system are:

1. High methyl orange alkalinity, ppm as $CaCO_3$.
2. High calcium content, ppm as $CaCO_3$
3. High *pH*
4. High temperature
5. High dissolved solids, ppm

Normally, methyl orange alkalinity is a good measure of the amount of calcium bicarbonate in the water. Calcium carbonate is formed by the decomposition of calcium bicarbonate according to the chemical reaction:



NOTE: pH values at approximately 73 F.

From ASHRAE Guide and Data Book, 1961. Used by permission.

FIG. 5 — SOLUBILITY OF CALCIUM CARBONATE IN DISTILLED WATER CONTAINING CARBON DIOXIDE

$$Ca(HCO_3)_2 + heat \rightarrow CaCO_3 + CO_2 + H_2O$$

$$\begin{matrix}\text{calcium}\\\text{bicarbonate}\end{matrix} + \text{heat} \rightarrow \begin{matrix}\text{calcium}\\\text{carbonate}\end{matrix} + \begin{matrix}\text{carbon}\\\text{dioxide}\end{matrix} + \text{water}$$

Conversely, carbonates are readily converted to the more soluble bicarbonates by the addition of carbon dioxide or other acidic materials. (Carbon dioxide gas in water forms carbonic acid.) This explains the apparent increase in solubility of calcium carbonate with a lowering of *pH* (*Fig. 5*), the carbonate going into solution as bicarbonate. Calcium bicarbonate is several times more soluble than calcium carbonate. The addition of acid (explained in this chapter) also produces another effect by changing the bicarbonate and carbonate effect by changing the bicarbonate and carbonate to a more soluble compound, thus allowing a higher concentration of chemicals in the water. Thus, a high methyl orange alkalinity and a high calcium content aid the deposition of calcium carbonate.

As illustrated in *Fig. 5*, a low *pH* increases the solubility of calcium carbonate, whereas a high *pH* aids the deposition of calcium carbonate.

A high temperature decreases the solubility of calcium carbonate and aids the scale deposit (*Fig. 5*).

Dissolved solids of high concentration increase the scale deposit; however, the effect is not great.

CALCIUM SULFATE SCALE

Calcium sulfate has a high solubility (*Fig. 3*), and is seldom a problem in water conditioning unless there is a high sulfate in the make-up water. It may be formed (1) by the action of sulfur dioxide gas from the air dissolving in water to form sulfurous, H_2SO_3, or sulfuric, H_2SO_4, acid which in turn combines with calcium carbonate, or (2) by feeding sulfuric acid for calcium carbonate scale control. Calcium sulfate is limited to 1200 ppm as $CaCO_3$ (1630 ppm as $CaSO_4$). Bleed-off is used to control this concentration.

IRON OXIDE DEPOSIT

In the case of well waters possessing a high natural iron content, deposition of iron oxide from the decomposition of ferrous bicarbonate takes place in accordance with the following reaction:

$$4Fe(HCO_3)_2+O_2 \rightarrow 2Fe_2O_3+8CO_2+4H_2O$$

$$\text{ferrous bicarbonate} + \text{oxygen} \rightarrow \text{iron oxide} + \text{carbon dioxide} + \text{water}$$

SLUDGE

Sludge may be caused by the products of corrosion in the system. Polyphosphates which are used to prevent calcium carbonate scale formation may cause a precipitation of calcium phosphate whenever the concentration of orthophosphate is too high. (Refer to the discussion of scale inhibitors in this chapter.) A sludge may settle out in the water boxes or tubes. Consequently, a minimum velocity for a solution to prevent sludge settling in the tubes is three fps.

PREDICTION OF SCALE-FORMING TENDENCIES

Water which forms a mild scale can be corrosive, whereas water which forms a heavy scale is less likely to be corrosive. Corrosive waters usually do not form a scale. If a correct balance is found in water conditioning, the water will be neither corrosive nor scale-forming, or only mildly so. Two indexes can be used to predict scale-forming tendencies.

LANGELIER SATURATION INDEX

Professor W.F. Langelier[6] advanced the idea, now widely accepted, of using a calculated saturation index for calcium carbonate for predicting the scaling or corrosive tendencies of a natural water. Calcium carbonate is usually the chief ingredient of scale found on heat transfer surfaces in cooling water systems. The scale that forms under moderate temperature conditions (50-130 F) is caused by the conversion of a bicarbonate into calcium carbonate upon heating; the scale is also affected by an increase in alkalinity sufficient to cause supersaturation with respect to the calcium carbonate. *PH* has a marked effect on the solubility of calcium carbonate.

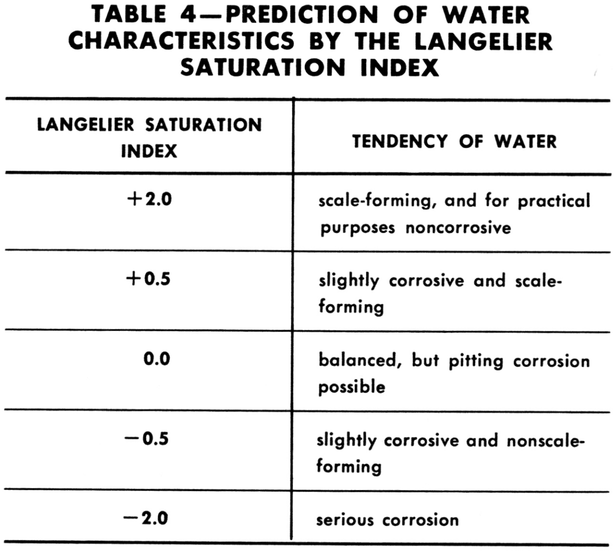


TABLE 4—PREDICTION OF WATER CHARACTERISTICS BY THE LANGELIER SATURATION INDEX

LANGELIER SATURATION INDEX	TENDENCY OF WATER
+2.0	scale-forming, and for practical purposes noncorrosive
+0.5	slightly corrosive and scale-forming
0.0	balanced, but pitting corrosion possible
−0.5	slightly corrosive and nonscale-forming
−2.0	serious corrosion

The Langelier Saturation Index (I_s) is determined by the following:

$$I_8=pH-pH_8 \qquad (7)$$

where:

pH = pH from test

pH_8= calculated pH of saturation of the calcium carbonate.

When I_8 equals zero, saturation equilibrium exists; there is no scale formed or little corrosion.

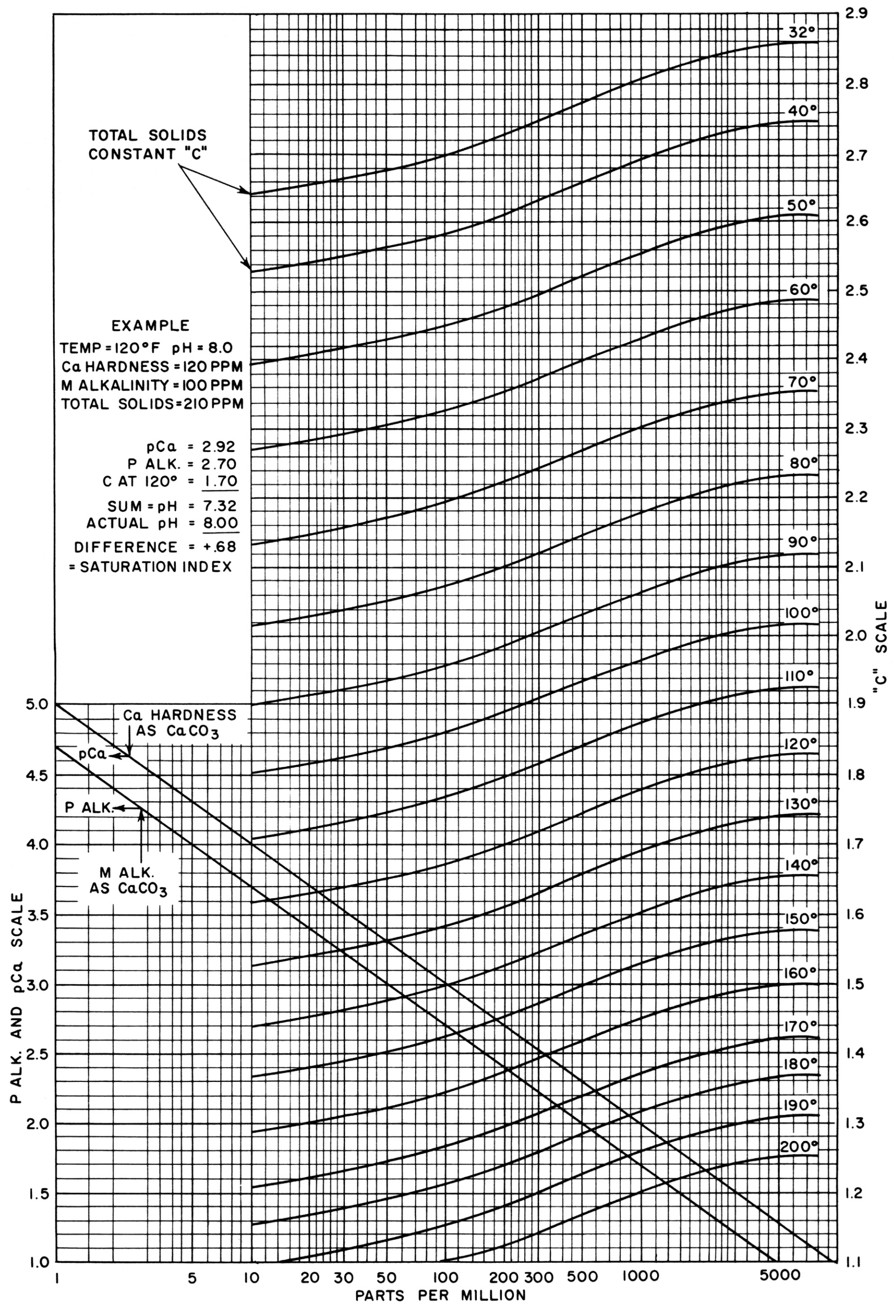
When I_8 is negative (pH less than pH_s), corrosion of bare metal occurs and any small scale is dissolved.

When I_8 is positive (pH greater than pH_s), there exists a condition of supersaturation which tends to deposit scale on the hottest part of the system. These characteristics are shown in *Table 4.*

When the Langelier Index is +0.5 or greater, scaling usually occurs. The severity of scale formation increases in logarithmic proportion to the increase in Langelier Index values. For example, a water having an I_8 of 2.0

theoretically results in approximately 33 times as much scale as an index of +0.5 in the same system. Even though this relation may not be strictly true on a quantitative basis, it indicates that scaling can be very heavy when I_8 is 2.0.

CHART 5—LANGELIER SATURATION INDEX



From Water Conditioning For Industry, by Sheppard T. Powell, McGraw-Hill Book Co. Inc., 1954. Used by permission.

Tables prepared by Nordell[5] are more convenient for making repetitive calculations of pH_s in determining the Langelier Index. The method used by Powell[4] is presented in *Chart 5* because the relative effect of the variables is readily apparent by an ex-amination of the curves. Three curves represent log factors of calcium, alkalinity, and combined total solids and temperature. These three factors when added together give the pH_s. An example is demon-strated on the figure. A second example illustrates the Langelier Saturation Index for a water used in a once-thru condenser.

Example 8-Langelier Index and Scaling Tendency

Given:

A once-thru condenser
Methyl orange alkalinity = 70 ppm as $CaCO_3$
Calcium hardness = 75 ppm as $CaCO_3$
Total solids = 221 ppm
pH = 7.1
Condensing water temperature = 100 F

Find:

Langelier Saturation Index (I_s)
Scaling tendency

Solution:

From *Chart 5*:

$$pH_s = \text{pALK} + \text{pCa} + \text{“c” scale}$$
$$= 2.85+3.13+1.89 = 7.87$$
$$I_s = pH - pH_s = 7.1-7.87 = -0.77$$

This water is mildly corrosive and nonscale-forming.

The use of the Langelier Saturation Index indicates the tendency of a water to be either corrsive or scale-forming, and is intended only to serve as a guide in prescribing water conditioning for a given job. It is *not* a measure of the capacity to scale. A water having a high hardness and positive saturation index definitely causes a calcium carbonate scale, whereas a low hardness water with the same positive saturation index may not form any appreciable calcium carbonate scale.

RYZNAR STABILITY INDEX

The Ryznar Stability Index[7] is an empirical method for predicting scaling tendencies, and is based on a study of operating results with water of various saturation indexes.

$$\text{Stability Index} = 2pH_s - pH \qquad (8)$$

where:

pH_s = calculated pH of saturation of the calcium carbonate
pH = pH from test

TABLE 5—PREDICTION OF WATER CHARACTERISTICS BY THE RYZNAR STABILITY INDEX

RYZNAR STABILITY INDEX	TENDENCY OF WATER
4.0 - 5.0	heavy scale
5.0 - 6.0	light scale
6.0 - 7.0	little scale or corrosion
7.0 - 7.5	corrosion significant
7.5 - 9.0	heavy corrosion
9.0 and higher	corrosion intolerable

This index (always positive) is often used with the Langelier Index to assist in predicting more accurately the scaling or corrosion tendencies of a water. *Table 5* illustrates how to predict water characteristics with this index.

PREDICTION OF pH, OPEN RECIRCULATIO SYSTEMS

The Langelier Saturation Index and the Ryznar Stability Index are useful in predicting scaling tendencies for once-thru systems. They also are useful for open recirculating systems. However, there is a problem in predicting the *pH* for various cycles of concentration.

When water recirculates thru a heat exchanger and cooling tower or other aerating device, the *pH* is usually different from the *pH* of the make-up water because the alkalinity of the water, aeration in the cooling tower, and contamination of the atmosphere by sulfur dioxide, carbon dioxide and other gases all influence the pH. Generally, contamination from the air tends to lower both the *pH* and the alkalinity. The *pH* for a cooling tower or for an evaporative condenser in the majority of systems falls within the shaded area in *Chart 6*. The solid line is used as an average. Cooling towers operating in a clean atmosphere normally have a *pH* higher than the average line.

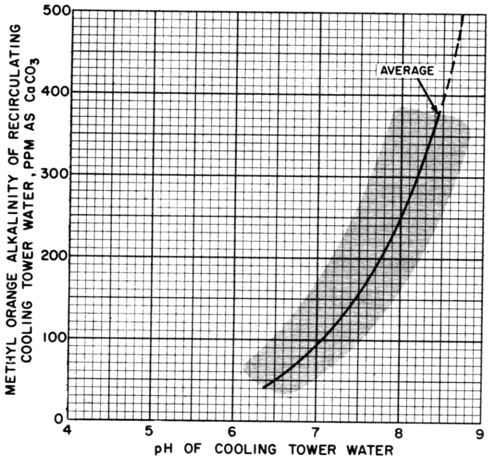
In industrial areas there is sometimes enough sulfur dioxide and carbon dioxide gases in the air to neutralize the alkalinity in the make-up water, resulting in a *pH* down to 4.0 or 5.0 in some cases. This is particularly true when the methyl orange alkalinity in the make-up water is lower than 50 ppm. When this condition exists, there is no scaling; however, corrosion is a problem. Refer to *Chapter 3, Corrosion Control.*

Special curves and data based on experience are available from some water treatment companies for predicting *pH* values in recirculating water systems.

EFFECT OF SCALE INHIBITORS ON LANGELIER AND RYZNAR INDEXES

The Langelier and Ryznar Indexes are for waters without scale inhibitors. A water with scale inhibitors gives the same index as untreated water. Consequently, the index for a treated water may show heavy scaling although it may not be scale-forming. Ryznar reports that with 1.7 ppm of polyphosphate there is little scale formed with an index of 4.0, whereas this indicates a heavy scale deposit in untreated water.

CHART 6—EXPECTED pH OF COOLING TOWER WATER



NOTE: Normally, pH for 90% of towers is within shaded area.

From Betz Laboratories

Example 9-Scaling Tendency of Cooling Tower System

Given:

A cooling tower system
Make-up water methyl orange alkalinity, ppm as $CaCO_3$ = 94
Calcium hardness, ppm as $CaCO_3$ = 85
Total solids, ppm = 128
Total hardness, ppm as $CaCO_3$ = 109
pH = 7.8
Water temperature (F) = 115

Find:

Scale-forming tendency

Solution:

Assume 1, 1½ , 2 and 3 cycles of concentration and determine the Language and Ryznar Indexes.

Multiply the concentration of chemicals in the make-up water by cycles of concentration to obtain the concentration for the various cycles.

CYCLES OF CONCENTRATION	I	1 1/2	2	3
Methyl orange alkalinity, ppm as $CaCO_3$	94	141	188	282
Calcium hardness, ppm as $CaCO_3$	85	128	170	255
Total solids, ppm	128	192	256	384
Total hardness, ppm as $CaCO_3$	109	163	218	327
pH	7.8			
Results				
pH using the average line (*Chart 6*)	7.0	7.4	7.7	8.1
pH_s (*pH* of saturation Of $CaCO_3$, *Chart 5*)	7.54	7.22	6.97	6.63
Langelier Index ($pH-pH_s$)	-.54	+.18	+.73	+1.47
Ryznar Index ($2pH_s-pH$)	8.08	7.04	6.24	5.16

The alkalinity may not vary directly as the cycles of concentration because some of the alkalinity is neutralized by acid formed when sulfur dioxide and carbon dioxide gases in the air are absorbed in the water. However, this is accurate enough for an estimate. Note also that the expected *pH* (*Chart 6*) is a rough approximation.

An examination of the Langelier and Ryznar Indexes in the example and *Tables 4 and 5* leads to the following conclusions.

1. With 1½ cycles of concentration the Langelier Index is +0.18, very slight scaling. The Ryznar Index is 7.04, very little scale or corrosion. Therefore, 1½ cycles may be satisfactory without any conditioning chemicals. However, experience may indicate that a corrosion inhibitor is desirable.
2. With 2 cycles of concentration the Langelier Index is +0.73 which is scale-forming. The Ryznar Index is 6.24 indicating little scale or corrosion. Two cycles may be satisfactory, but may result in some scale deposit.
3. With 3 cycles of concentration the water is definitely scale-forming. Scale may readily be controlled by adding 2-5 ppm of polyphosphate. Since the alkalinity at 4 cycles is only 376, polyphosphate treatment is satisfactory.

SCALE DEPOSIT PREVENTION

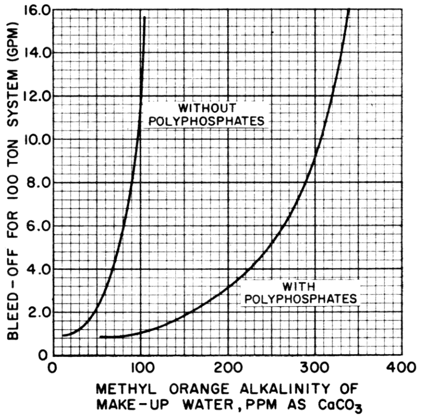
Several methods may be used to avoid or lessen the deposition of scale.

1. The increase in total solids caused by evaporation in a recirculating may be controlled by bleeding off some of the water, accompanied by additional make-up water.
2. The tendency of calcium carbonate to precipitate may be inhibited by the addition of chemicals, i.e.

polyphosphates, which tend to hold the calcium carbonate in solution.

CHART 7—BLEED-OFF REQUIRED TO PREVENT SCALE FORMATION

100 Ton System



3. The *pH* of the water may be lowered by adding an acid (usually sulfuric) to reduce the alkalinity, but not enough to develop an acid condition which may cause corrosion.
4. The water may be treated before use to remove the elements of calcium, magnesium and iron which form relatively insoluble compounds.

BLEED-OFF METHOD

Bleed-off is used in all open recirculating systems where water is evaporated. This may be sufficient in some cases, but additional conditioning is usually required for either scale or corrosion control, or both.

SCALE INHIBITOR METHOD

Some materials inhibit crystal growth and thereby prevent scale formation. These surface active agents increase the solubility of the scale-forming salts and permit an oversaturated condition to exist without precipitation from solution. Some of these materials are polyphosphates, tannins, lignins and starches. A combination of several of these surface active agents may be more effective than a single material alone.

Polyphosphates in concentrations of 2-5 ppm are used to prevent or reduce scale formation. *Chart 7* shows the bleed-off required to prevent scale formation, both with and without polyphosphates. The bleed-off in this figure is the sum of bleed-off and windage loss (*Chapter 1*); subtract the windage loss to obtain the amount of bleed-off wasted to the drain. This is an approximate curve which can be used for rough estimating for the average air conditioning installation where the condensing temperature is between 100 F and 120 F. It is based on a maximum methyl orange alkalinity of 125 ppm as $CaCO_3$ without polyphosphate treatment, and on 400 ppm as $CaCO_3$ when 2-5 ppm of polyphosphates are used. The actual *pH,* calcium content, and temperature all have a marked effect on the deposit of calcium carbonate. Specialience have developed data and curves from experience which show values both above and below those shown in *Chart 7*. These curves normally include the calcium content and *pH* in addition to the alkalinity.

Polyphosphates which are molecularly dehydrated phosphates revert eventually to the inaffective orthophosphates when dissolved in water; this reversion takes place in the recirculating water system. For this reason polyphosphates must be stored in the dry form. Too great a concentration of the orthophosphate in the system can result in the deposition of calcium orthophosphate sludge, particularly when high calcium waters are involved. The orthophosphate content of the water is limited to two or three times the polyphosphate content by the use of bleed-off. This is particularly important when high polyphosphate residuals are carried for corrosion control. A method of determining the *pH* of saturation of calcium phosphate is described in Reference 8.

ACID METHOD

Polyphosphates may be used alone or with acid treatment and corrosion inhibitors. A greater concentration of total solids is permitted when acid is added to the system. The calcium bicarbonate is converted to the more stable and soluble calcium sulfate as illustrated in the following reaction:

$$Ca(HCO_3)_2+H_2SO_4 \rightarrow CaSO_4+2CO_2+2H_2O$$

$$\genfrac{}{}{0pt}{}{calcium}{bicarbonate}+\genfrac{}{}{0pt}{}{sulfuric}{acid}\rightarrow\genfrac{}{}{0pt}{}{calcium}{sulfate}+\genfrac{}{}{0pt}{}{carbon}{dioxide}+water$$

Thus, acid treatment reduces the alkalinity and, by virtue of this reaction, minimizes the over-saturation of the calcium carbonate. Also, calcium sulfate is much more soluble than calcium carbonate. The use of acid permits a greater concentration of dissolved solids without precipitating calcium carbonate. For estimating purposes in recirculating systems, one ppm of sulfuric acid is required to neutralize one ppm of methyl orange alkalinity as $CaCO_3$ in the make-up water. *Figure 3* illustrates the far greater solubility of calcium sulfate over calcium carbonate.

When sulfuric acid is added to a once-thru system, only enough acid is added to neutralize the methyl orange alkalinity to lower it to the permissible concentration. It is necessary to use only about one-half of the theoretical sulfuric acid for a once-thru system, whereas the full amount is required for an open recirculating system. In the once-thru arangement, the acid is introduced upstream of the condenser where both sulfuric and carbonic acids reduce the alkalinity (carbonic formed by carbon dioxide and water). In the open recirculating system the acid is introduced downstream of the condenser. Carbon dioxide gas is removed by deaeration in the cooling tower.

Occasionally, inhibited sulfamic acid, HSO_3HN_2 is used in place of sulfuric acid. Sulfamic acid (a white crystalline material) is safe to handle when dry, is more convenient for some applications, but is much more costly than sulfuric acid. To prevent formation of ammonium compounds which are very corrosive to copper, the temperature of the acid solution should not exceed 160 F.

REMOVAL OF HARDNESS IN MAKE-UP WATER

Removal of hardness in make-up water for condenser water cooling systems is seldom necessary although this is common practice for steam boiler make-up water. In the ion exchanger (zeolite) softening process, the calcium is replaced by sodium which is very soluble. However, zeolite softening does not decrease the alkalinity of the make-up water; a large bleed-off rate still may be required to prevent scaling. This is one of several types of water softening processes.

WATER CONDITIONING METHOD FOR SCALE CONTROL

The most common practice is to control the chemistry slightly on the corrosive side to prevent scale formation and then add corrosion inhibitors.

The choice of a particular method or methods for water conditioning depends upon the chemical composition of the water, the cost of various methods, and the economics of the various combinations. Sometimes a heavy bleed-off may be the only requirement for a recirculating system, but

Sometimes a heavy bleed-off may be the only requirement for a recirculating system, but

but is may be more economical to add water conditioning and save on water cost. Where bleed-off is required, it may be controlled by a meter which measures the conductivity of the water rather than by using a constant rate of bleed-off. The conductivity may be a good indicator of the scaling ability of the water if the majority of the impurities are calcium and bicarbonates. When there is no corrosion problem, a simple or partial treatment to prevent scaling may be selected which may require an occasional acid cleaning of the condenser rather than a complete water conditioning program. This partial treatment is more applicable to the small system when the cost of feeding equipment and consulting services may be large compared to the cost of an occasional cleaning of the condenser tubes. In many locations there is a severe corrosion condition and water conditioning for corrosion prevention is necessary, even though scaling is not a problem.

Chapter 5 gives details for water conditioning to prevent scale formation for the several types of systems.

CHAPTER 3. CORROSION CONTROL

This chapter includes a discussion of the types and causes of water circuit corrosion and methods used to prevent corrosion in a system. Corrosion monitoring and problems external to the conventional water system are also presented.

Corrosion cause and prevention is a large field which is briefly discussed here.

Corrosion in an open water recirculating system in which water sprays come in contact with air is a greater problem than scale deposit. In some industrial areas, it is not uncommon for pipes or parts of a cooling tower system to corrode thru in two to three years; in severely corrosive atmospheres pipes may perforate in less than a year.

Corrosion products reduce the capacity of the lines, increase frictional resistances, and increase pumping costs. The products of corrosion have a volume several times that of the metal they replace. Often they may obstruct or stop flow and clog nozzles in small lines.

TYPES OF CORROSION

An air conditioning system may have several types of corrosion in the water system, as characterized by one or more of the following:

1. Uniform corrosion
2. Pitting corrosion
3. Galvanic corrosion
4. Concentration cell corrosion
5. Erosion-corrosion

UNIFORM CORROSION

Corrosion due to acids such as carbonic or others effect a uniform metal loss. It is the most common type of corrosion encountered in acid environments, and the easiest to predict and control.

PITTING CORROSION

Pitting corrosion is a nonuniform type, the result of a local cell action which is produced when particles are deposited on a metal surface either as flakes, solids or bubbles of gas. The pitting is a local accelerated attack, causing a pit or cavity around which the metal is relatively unaffected. Centralized corrosion in pits creates deeper penetration and more rapid failure at these points. Oxygen deficiency under a deposit sets up anodic areas to cause pitting. Sometimes oxygen causes pitting corrosion as does galvanic cell action.

GALVANIC CORROSION

Galvanic corrosion occurs when dissimilar metals are present in a solution capable of carrying an electric current. It is a form of electrochemical corrosion where a difference in potential associated with the metals themselves causes a small electric current to flow from one metal to the other thru the electrolyte.

Table 6 is a galvanic series of metals and alloys. It is based on corrosion tests in the laboratory under plant operating conditions, and has basic characteristics which make it analogous to the electromotive series in textbooks. However, the metals are not exactly in the same order. When who metals in the same group are joined together, they are relatively safe. Conversely, the coupling of two metals from different groups causes accelerated corrosion in the less noble or the metal higher in the list. The greater the difference in position in the table, the greater the accelerated corrosion. For example, when iron and zinc are joined together, the zinc is corroded and the iron is not affected. Corrosion is accelerated on the zinc, but not on the iron. When copper and steel are joined together, corrosion is accelerated on the

TABLE 6—GALVANIC SERIES OF METALS AND ALLOYS

Corroded end (anodic, or least noble)

- Magnesium
  - Magnesium alloys
- Zinc
- Aluminum 2 S
- Cadmium
- Aluminum 17 ST
- Steel or iron
  - Cast iron
- Chromium-iron (active)
- Ni-Resist
- 18-8 Stainless (active)
  - 18-8-3 Stainless (active)
- Lead-tin solders
  - Lead
    - Tin
- Nickel (active)
  - Inconel (active)
- Brasses
  - Copper
    - Bronzes
      - Copper-nickel alloys
        - Monel
- Silver solder
- Nickel (passive)
  - Inconel (passive)
- Chromium-iron (passive)
  - 18-8 Stainless (passive)
    - 18-8-3 Stainless (passive)
- Silver
- Graphite
  - Gold
    - Platinum

Protected end (cathodic, or most noble)

By permission of International Nickel Co., Inc.

steel but not on the copper. The greater the copper area in relation to the steel, the faster is the rate of corrosion. On systems in which all piping and coils are made of copper except for a few steel nipples, the steel parts are subject usually to a rapid corrosive attack and failure in a short time. In such a situation a nonferrous metal should be used instead of steel. Corrosion inhibitors reduce the corrosion rate but do not eliminate galvanic corrosion.

CONCENTRATION CELL CORROSION

Concentration cell corrosion is similar to galvanic action. However, the difference in potential arises from differences in the electrolyte. This potential may be produced by differences in ion concentration, oxygen concentration or *pH*, or may be caused by dirt, foreign matter or a gas bubble adhering to the metal surface.
Each pit in a pitting corrosion represents a concentration cell or anode. The metal surrounding the pit is the cathode.

TABLE 7—MAXIMUM WATER VELOCITY TO MINIMIZE EROSION

NORMAL OPERATION (hr)	WATER VELOCITY (fps)
1500	12.
2000	11.5
3000	11.
4000	10.
6000	9.
8000	8.

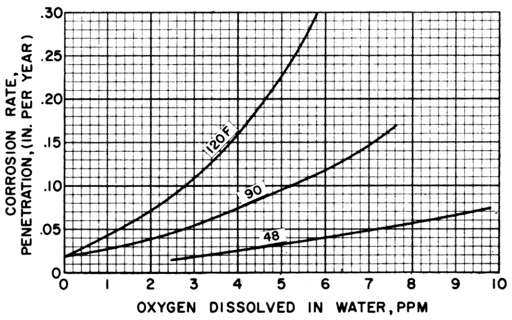
EROSION-CORROSION

The impingement of rapidly moving water containing entrained air bubbles and/or suspended matter, i.e. sand, may remove or prevent the formation of coatings to permit general corrosion of the metal. This action commonly occurs near the tube inlet ends, or it may extend along the entire tube length. Unfortunately, experimental data is unavailable to determine the maximum allowable water velocity without damage to the protective film. The circulation of solid matter in the system may cause complete deterioration of the tube or pipe walls, particularly on the bottom surface and at the elbows. Abrasive solid matter can be removed by filters.

Since erosion is a function of operating hours, water velocity and suspended materials in the water, the selection of a design water velocity is a matter of judgment. *Table 7* lists the approximate maximum velocity thru copper tubes of a heat exchanger (a cooler or a condenser) to minimize erosion. The values are not intended to be top values. They are based on many years of experience, and permit the attainment of optimum equipment life under normal conditions. Use only 70% of these velocities for heat exchangers where the water temperature ranges from 140-180 F.

Erosion of a centrifugal pump impeller caused by cavitation pitting[9] can occur in a corrosive hot water system when the pump is operated at the bottom end of the pump curve. Although not a normal selection point, this condition may occur when too great a safety factor is

CHART 8—EFFECT OF OXYGEN CONCENTRATION ON CORROSION AT DIFFERENT TEMPERATURES



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used for the estimated pipe friction, particularly since the loss in new pipe is less than the loss obtained in design tables.

OTHER TYPES OF CORROSION

Sometimes corrosion is caused by the dissolution of the more noble metal which is plated out on the anodic member, thus setting up small galvanic cells and causing pitting corrosion. Such corrosion is difficult to control by use of inhibitors. Water tends to pick up small amounts of copper while passing thru cuprous parts of the system and to deposit this copper on steel parts. Only a small amount of copper, i.e. 0.1 ppm in the water, is sufficient to cause this type of corrosion. It can usually be controlled by maintaining the *pH* above 6.7. An acidic condition or presence of chloride or bromide salts in the water is necessary for this type of corrosion. Copper is satisfactory if the chloride content of the water does not exceed 200 ppm. If 200 ppm is exceeded, the decision of whether to use copper should be determined by experience and consultation with a corrosion engineer. The concentration of the inhibitor should be increased when chlorides are present. Certain inhibitors,[10] i.e. BTT (2-benzothiazolethiol), may be used to prevent dissolution of the copper.

Other types of corrosion[11, 12, 13, 14, 15] are dezincification, corrosion fatigue, and stress corrosion. How ever, since these are uncommon, they are not discussed here.

TABLE 8—DATA TYPIFYING THE DELETERIOUS GAS CONTENT OF DIFFERENT ATMOSPHERES

Gas	Chem. Form.	AIR			
		Rural		Metropolitan	
		% by Volume	Partial Pressure (psia)	% by Volume	Partial Pressure (psia)
Oxygen	O_2	21.	3.143	21.	3.143
Carbon Dioxide	CO_2	0.03	0.004	0.06	0.009
Sulfur Dioxide	SO_2	None	None	0.003	0.004

Gas	Chem. Form.	FLUE GASES					
		Bitum. Coal		Fuel Oils		Natural Gas	
		% by Vol.	Partial Press. (psia)	% by Vol.	Partial Press. (psia)	% by Vol.	Partial Press. (psia)
Oxygen	O_2	2.	0.299	7.	1.048	10.	1.497
Carbon Dioxide	CO_2	15.	2.245	13.	1.946	10.	1.497
Sulfur Dioxide	SO_2	0.07	0.010	0.03	0.004	0.0001	0.0015

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CAUSES OF CORROSION

Although many factors contribute to corrosion in cooling systems, the chief factor is dissolved oxygen in the cooling water. The reaction of dissolved oxygen with ferrous metal is accelerated with temperature as illustrated in *Chart 8*. The chief variables controlling the corrosive characteristics of a water are:

1. Dissolved oxygen concentration
2. Temperature
3. Carbon dioxide content
4. *pH*
5. Dissolved solids
6. Suspended solids
7. Velocity

Neutral water (*pH* of 7.0) saturated with air corrodes iron at a rate three times that of air-free water. Hot water containing oxygen corrodes iron three or four times faster than cold water.

Most natural waters contain dissolved substances such as carbon dioxide, oxygen, chlorides and sulfates, all of which corrode metal that is in contact with water. Corrosion affects the heat exchangers, pumps, cooling towers, air washers and piping. In an open recirculating system such as a cooling tower, evaporative condenser or air washer, most of the corrosion is due to the absorption of acidic impurities from the air thru which the water has passed. This is particularly true in a large city with a low alkalinity water supply. Here, the combustion of carbon and sulfur in fuels produces large amounts of sulfur dioxide, SO_2, and carbon dioxide, CO_2, in the flue gases from boiler plants. *Table* 8 illustrates the amount of carbon dioxide and sulfur dioxide gases in the atmosphere.

The *pH* is affected directly by the concentration of carbon dioxide which forms carbonic acid. A low *pH* increases the corrosion. Corrosion of iron decreases as the *pH* of water increases, and practically ceases at a *pH* of 11. However, a high *pH* cannot be tolerated because of scale formation in heat wood.

Dissolved solids, particularly chlorides and sulfates, intensify the corrosive effect of oxygen and carbon dioxide. Higher solid particularly affect corrosion when there are dissimilar metals in the water circuit.

Suspended solids may wear away metal or prevent the maintenance of a protective film by the corrosion inhibitors.

An increase in the flow rate generally increases corrosion.

CORROSION CONTROL

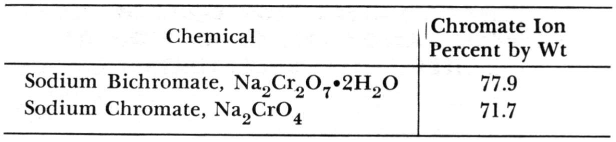
A coating of zinc on steel can be used to prevent the corrosion of steel. Various organic and inorganic coatings can also be used, but not in a piping system because the coating cannot be readily maintained. Certain chemicals in small concentrations protect metal by forming a thin monomolecular film or barrier on its surfaces to prevent the electrochemical process. These corrosion inhibitors greatly reduce the rate of corrosion.

Corrosion may be minimized by several methods:

1. Use of organic or inorganic corrosion inhibitors.
2. Formation of a thin film of calcium carbonate on metal surfaces.
3. Control of *pH* in the range of 7.0 to 8.5.
4. Use of mechanical deaeration of water.

CHROMATE INHIBITORS

The chromates are used extensively to inhibit corrosion and are effective in the water of air conditioning systems in concentrations of 200-500 ppm at a *pH* of 7.0 to 8.5. For corrosion prevention the optimum range in *pH* is 7.5 to 9.5, but there is a greater problem of scaling at the higher *pH*. Consequently, the *pH* is held to the lower side where corrosion protection is excellent. Sodium bichromate, $Na_2Cr_2O_7 \bullet 2H_2O$, is the most commonly used chromate compound because it is more economical. Sodium chromate, Na_2CrO_4, is also used. Chromate concentration is stated in ppm as chromate ion although some treatments may describe concentration in ppm as sodium chromate. The percent of chromate ion in these chemicals is illustrated in the following table:



Chemical	Chromate Ion Percent by Wt
Sodium Bichromate, $Na_2Cr_2O_7 \bullet 2H_2O$	77.9
Sodium Chromate, Na_2CrO_4	71.7

Sodium bichromate is acidic and, when dissolved in pure water at common concentration, has a *pH* of less than 5.0. Sodium carbonate (soda ash, Na_2CO_3) or sodium hydroxide (caustic soda, NaOH) is added to raise the *pH*. To completely neutralize 100 pounds of sodium bichromate requires 36 pounds of soda ash or 27 pounds of caustic soda; the resulting compound is sodium chromate which has a *pH* of about 8.0 in the normal concentration. On small systems the more costly sodium chromate is sometimes used to avoid the addition of the alkali. Some treatments may require the mixing of soda ash with sodium bichromate in various proportions, depending upon the alkalinity of the treated water. Unless packaged in vapor tight containers, caustic soda absorbs moisture from the air and tends to form lumps if premixed with the bichromate.

Chromate Inhibitors in Hot Water Systems

A greater concentration of chromate is required for high temperatures. Hot water heating systems[16] are treated with 1000-2000 ppm of chromate. In cooling water for natural gas and diesel engines, 800-1200 ppm of chromate are used.

Low Chromates with Other Inhibitors

Much lower concentrations of chromates may be used to obtain a satisfactory over-all corrosion rate, but this may lead to pitting. Conversely, pitting corrosion does not occur when high concentrations are used. A treatment permitting pitting is unsatis-factory. To reduce the cost of conditioning chemicals, other systems[17,18] have been developed, using low concentrations of chromates and high concentrations of phosphates. Concentrations having a total mixture of 30-60 ppm of chromates and polyphosphates have been used to effect a substantial reduction in corrosion and pitting. When high concentrations of polyphosphates are used, there may be some calcium phosphate sludge precipitated as explained in *Chapter 2*.

Low chromate concentrations with other inhibitors are becoming more popular for air conditioning systems. The petrochemical and chemical industries use these inhibitors for large systems where optimum life of equipment may be only seven to ten years due to obsolescence of process. Research is improving this blend of inhibitors.

There are many proprietary formulations of several generic compositions[19] in total treatment concentrations of 20-80 ppm. Usually there is some chromate mixed with one or more other compounds of polyphosphates, zinc, fluorides or organic synergizing agents. A controlled range of *pH* is required for each formulation; these are sometimes narrow and call for a relatively low *pH*. The following are examples of the particular ranges of these formulations: 6.0-6.5; 6.4-6.8; 6.8-7.4; 6.7-7.7; 6.5-7.5.

The narrow range indicates the application of an automatic *pH* controller which is costly and may be justified only on large systems. Pitting corrosion may occur if the *pH* is not maintained within the recommended limits. Accelerated laboratory tests[19] at 140F show that there is pitting with some formulations in the recommended *pH* range.

Disadvantages of Chromates

The characteristic yellow color of chromates which stains the sides of the tower, building or cars in the adjacent parking lots is objectionable. However, it is advantageous because it permits an approximate control check on the chromate concentration by a color comparison of a water sample with a set of color standards. Another objection may arise from service operation of control valves or coils in executive offices, hotels or apartments when water spilled on rugs leaves a yellow stain.

Disposal of the treated water to sewage systems or streams may be subjected to ordinances or may be objectionable because of its yellow color.

POLYPHOSPHATE INHIBITORS

A low concentration of polyphosphates (2-4 ppm) is effective in preventing tuberculation. These compounds maintain cleanliness of the pipes although they are not very effective in preventing corrosion, except when used with chromates. Polyphophates are used for scale control primarily.

NITRITE INHIBITORS

Colorless sodium nitrite has had widespread use as a corrosion inhibitor where chromate staining is objectionable. It is not as effective as the chromates, and it is difficult to maintain effective concentrations because of water infection with organic slimes or bacteria which feed on the nitrite. Periodic treatment of the water with biocides can control the problem of these nitrite-feeding bacteria. The concentration for air conditioning systems is 200-500 ppm of nitrite ion. When the chloride ion is present, nitrite concentration[22] should be maintained at a higher level.[20] Also, sulfates affect the performance of nitries adversely. Some water treatments recommend a nitrite concentration approximately twice as great as chromates to provide equivalent protection. Generally, the *pH* should be maintained above 7.0 to make the treatment effective.

INHIBITORS FOR ALUMINUM COOLING TOWERS

Aluminum cooling towers[21] constructed of an alloy such as Alclad 3S or Alclad 4S can be protected adequately by the use of 200-500 ppm chromate accompanied by a *pH* of 7.0 to 8.5. Contact between dissimilar metals must be avoided. It is particularly important that aluminum be cleaned regularly. Painting of the pan or basin interior and other surfaces on which dirt can settle is necessary to minimize concentration cell corrosion. It is important to keep the *pH* above 7.0 because traces of copper, iron and other metals in an acidic water can lead to rapid and serious pitting of aluminum. See Reference 21 for detailed recommendations. Another method of treating aluminum towers or piping is the use of a mixture of polyphosphates, citrate and mercaptobenzothiazole.[22]

DEPOSITION OF CALCIUM CARBONATE FILM

The deposition of a controlled thin calcium carbonate film on a heat exchanger and piping can be used to prevent corrosion. However, it is seldom used except in once-thru systems. The amount of deposit is adjusted by control of the Langelier Saturation Index, above+0.5 (*Chapter 2*). Since temperature is one of the variables, a deposit forms on the surfaces at higher temperatures but not at lower temperatures. An adjustment for *pH* is made by the use of an inexpensive alkali such as line, caustic soda, or soda ash to increase the scale formation or by the addition of acid to decrease it.

CONTROL OF pH

In industrial areas the atmosphere contains large amounts of sulfur dioxide and carbon dioxide gases which, when absorbed in the cooling tower water, tend to make it an acidic solution.[23] Although the make-up water may be neutral, the acidity picked up from the air may be sufficient to neutralize the alkalinity in the water and to form an acid condition. The *pH* of the recirculating water may be as low as 4.0 or 5.0; in extreme cases, even lower. The addition of alkali such as caustic soda or soda ash is used to raise the *pH*. If the *pH* is too high, sulfuric acid is normally added to reduce it. The upper limit of *pH* of a water system is selected to prevent scale formation, not for control of corrosion.

MECHANICAL AND CHEMICAL DEAERATION

Mechanical and chemical deaeration may be applied to once-thru systems to remove oxygen or other corrosive gases; however, these methods are not normally applied to air conditioning systems.

CORROSION MONITORING

Corrosion may be monitored with test coupons, made of the identical materials to be checked and installed in the system. Accurate results are provided by a minimum exposure of thirty days. Corrosion rate is normally expressed as mils per year (mpy) and is calculated on the basis of initial weight, final weight after cleaning and drying, surface area and density of metal.

Thirty days exposure of mild steel coupons in a steel piping system of approximately ¼-inch wall thickness, may be rated as follows:

CORROSION RATE	CORROSION CONTROL
above 5 mpy	poor
2 to 5 mpy	good
0 to 2 mpy	excellent

These ratings apply to uniform corrosion. When pitting attack occurs even with less than a 2 mils per year corrosion rate, there is not sufficient protection. If wall thickness is less than ¼ inch, the acceptable corrosion rates are decreased proportionally.

When copper tubes are used in a system, the corrosion rate on the corresponding test coupons must be less than I mil per year. Pitting cannot be tolerated. The corrosion rate on copper is generally much lower than on steel in the same system unless chlorides or some compound corrosive to copper is in the system.

INSTALLATION OF TEST COUPONS

Samples of mild steel approximately 3” x 3/8” x 1/8” thick are accurately weighed in the chemical laboratory, then carefully wrapped and placed in tight containers until installed in the water system. *Figure 6* illustrates how the test coupons are installed. They are mounted in plastic holders to insulate the coupon from the pipe; they must not touch the pipe. Flow is parallel to the coupon at a velocity approximately 3 feet per second. If the system is a closed type, or if the required bleed-off is less than that removed by the test installation, the water is pumped back into the system. An alternate piping arrangement used is shown in *Figure 6*. The coupon is made of the identical material which is to be checked in the system. When two metals such as steel and copper are used in the system, a couple or a special coupon can be made by bolting together a strip of steel and copper, using a stainless steel bolt and nut. The coupons are returned to the chemical laboratory where they are cleaned, dried and weighed.

ELECTRICAL RESISTANCE METHOD

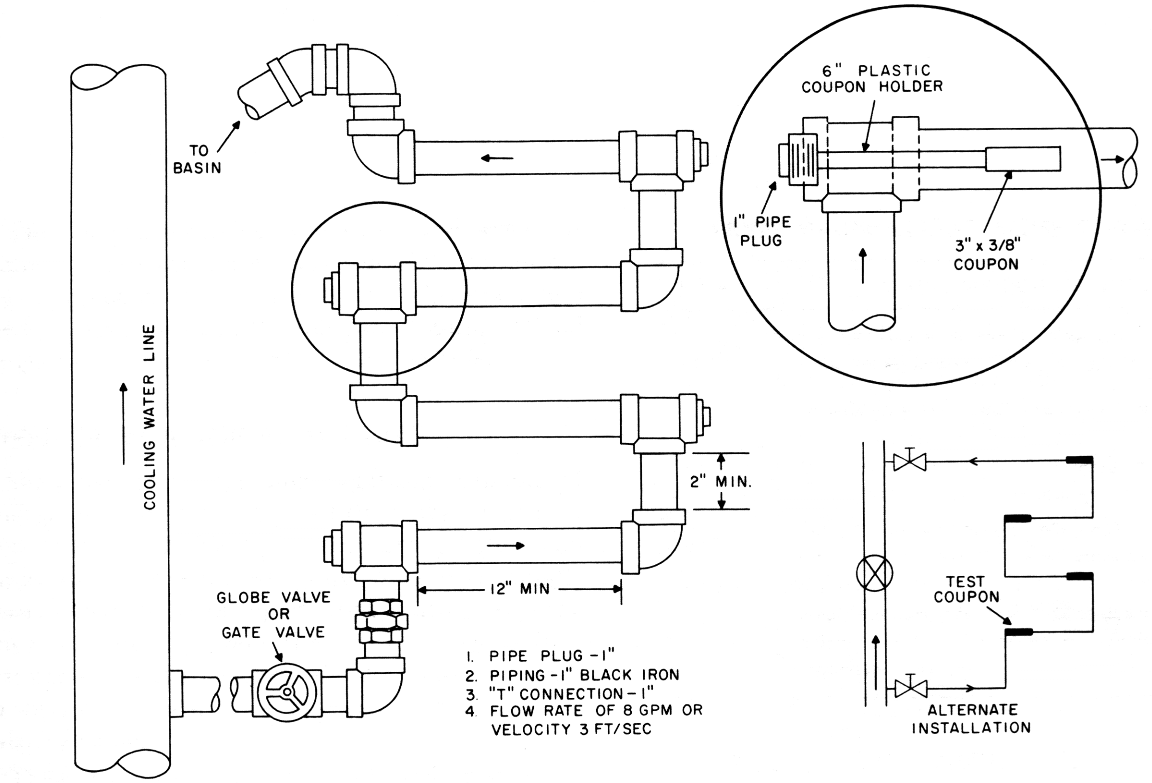
Another method of corrosion monitoring which has been used for the past few years is the electrical resistance method. With this method corrosion rates can be measured as the corrosion occurs and a corrosive condition can be detected and corrected before any harm has been done. The corrosion is measured by determining changes in the resistance ratio of a measuring element immersed in the water and a reference element of the same metal protected by a coating. As corrosion occurs the electrical resistance of the measuring element increases. This increase can be measured by a bridge circuit by balancing an adjustable resistance with the measuring element and the reference element. The change in resistance required to rebalance the circuit is an indication of the corrosion rate.

EXTERNAL WATER CIRCUIT CORROSION

Corrosion can also occur on sprayed coils and underground piping unless precautions are taken.

COIL CORROSION OF AIR HANDLING UNITS

Target sprays, sometimes used in a once-thru system for humidification in air handling units, leave no appreciable concentration of chemicals in the condensate pan. Aluminum fins on copper tubes are commonly used for cooling coils. A corrosive attack can occur on the aluminum fins whenever the water sprayed over the coil has a high electrical conductivity; this corrosion is due to galvanic action. Based on several years experience, aluminum fins may be used on copper tubes with once-thru city water sprays when the specific



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conductance of city water is less than 500 micromhos. The specific conductance for city waters for all major cities is shown in *Table 13, Chapter 5*. If 500 micromhos is exceeded, copper fins on copper tubes are used. Normally, copper fins on cooling coils are dipped in solder.

Aluminum fins on copper tubes are never used when humidification is accomplished by a recirculating spray water system.

CORROSION OF PIPES BURIED IN THE GROUND

Chilled water and condenser water lines are sometimes buried in the ground. Chilled water lines are not normally insulated because of insufficient temperature difference between the ground and pipe. Cast iron in the ground has good resistance to corrosion, but steel pipe needs protection. A bituminous coating applied in a molten condition over a prime coat such as red lead provides adequate protection. A wrapping of asbestos fabric saturated With bitumens over this coating gives additional protection because it prevents movement and displacement of the coating. Galvanized wrought iron or steel pipe in the ground is corrosion resistant when the zinc coating is 3 ounces or more per square foot. Zinc is on the electrochemical protective side of iron; as the zinc corrodes, it is changed into zinc compounds before the iron is attacked.

It is good practice to ovoid embedding pipe in earth of high salt content

CHAPTER 4. SLIME AND ALGAE CONTROL

This chapter describes the slime and algae organisms which affect the operation of air conditioning equipment, and discusses the chemicals and methods used to control biological fouling. Wood deterioration and its control is also included.

TYPES OF BIOLOGICAL FOULING

Slime and algae are microorganisms capable of multiplying rapidly and producing large masses of plant material. *Table 9* presents a group listing and description of the slime-forming organisms usually encountered only in open recirculating systems. Slime and algae prevent the maintenance of heat transfer in condensers because they readily attach to surfaces to form slime deposits with a high insulating value.

These organisms are classified with respect to type, as algae, fungi and bacteria.

The species of algae which are of prime importance in cooling water systems are found in locations where they have access to light and air. In the presence of sunlight these microscopic plants carry on processes of photosynthesis to manufacture food and release oxygen. Masses of living algae on metal surfaces can accelerate corrosion in the form of pitting. Dead algae lodged in heat transfer units can cause corrosion cell action to effect pitting of the metal.

The second type of biological fouling known as fungi lack chlorophyll so they cannot manufacture their own food. Molds and yeasts are in this group. They are dependent on food to be found in water, and use a wide variety of nitrogenous and cellulose material as food sources.

The third type is bacteria which form slimes, although not all are slime formers. One group reduces the sulfate content of water to the corrosive sulfide ion. Another group utilizes soluble iron, and deposits insoluble iron oxide in a slimy sheath around their cells. Some types of bacteria feed on nitrites used as corrosion inhibitors. The growth of this particular group must be kept under control when sodium nitrite inhibitor is used.

TABLE 9-PRINCIPAL SLIME FORMERS

PHYLA	ROUGH DIVISION OF PHYLA
Algae	Single celled, sometimes forming slimy sheets. Many celled in either sheets or fronds.
Fungi	Bacteria (Schizomycetes) frequently forming slimy Surface coatings. Slime Molds (Myxomycetes) forming slimy sheets as One stage of their life history. Sac fungi (Ascomycetes) of which one division, the Yeasts, occasionally form slimy aggregates. The alga-like fungi (Phycomycetes) and the stalked Fungi (Basidomycetes) rarely form slimes but their Filaments may hold together the slimes of other organisms.

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CONTROL OF BIOLOGICAL FOULING

Chemical treatment, rather than removal by mechanical cleaning, is a more satisfactory method of combating these organisms because of the inaccessibility of many of the areas in pipes and equipment. Fungi and bacteria live in dark areas of the system such as heat exchangers and piping, as well as in light areas such as cooling towers or evaporative condensers. If slime and algae are allowed to form an appreciable deposit, it should be removed where practical by mechanical means, and flushed from the system before chemical treatment.

CHEMICALS

Table 10 gives a list of common chemicals used for slime control.

Frequently, microorganisms build up an immunity to a particular algaecide, but not to chlorine. This characteristic makes it necessary to change to other compounds periodically.

Chlorinated Phenols

The most widely used chemicals are the chlorinated phenols, particularly sodium pentachloro-phenate, because they are easy and safe to use. These compounds control most slime and algae conditions.

TABLE 10-COMMON CHEMICALS USED FOR SLIME CONTROL

CHEMICAL	TRADE NAME	PHYSICAL STATE*
Chlorime	Chlorine	Gas
Hypochlorites	Calcium Hypochlorites Sodium Hypochlorites	Crystalline
Chlorinated Phenols, Sodium--	Chlorophenylphenate	Briquettes
	Tetrachlorophenate	Briquettes
	Pentachlorophenate	Briquettes
Potassium Permanganate	Permanganate of Potash	Crystalline
Copper Sulfate	Blue Vitriol	Crystalline

*As shipped.

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Concentrations of 200 ppm of sodium pentachlorophenate are enough for shock feeding. The alternate use of the chlorinated phenols and chlorine is often the best control.

Copper Sulfate

Copper sulfate may be considered a specific algaecide for algae since 0.5 ppm kills most of the common forms. Surface active agents are included to prevent precipitation of the copper ion at a high *pH*. Wetting agents are also included. Other toxicants are used with copper sulfate for control of bacteria because it alone does not kill many types of bacteria. Copper sulfate is corrosive to steel.

Potassium Permanganate

Potassium permanganate is a powerful oxidizing agent and is highly toxic toward many microorganisms. However, dead as well as live organic matter consumes this compound, thus increasing chemical consumption.

Chlorine

Chlorine is one of the most effective chemicals for control of slime and algae. However, it is not often used in the smaller or medium size installations because of handing difficulties. A residue of only 0.5-1.0 ppm kills bacteria and most micro-organisms, but since chlorine acts on all oxidizable matter, organic matter, hydrogen sulfide, ferrous iron, etc., the demand must be satisfied before the required residual can accumulate. When large amounts of chlorine are required, it is obtained in liquid form and fed to the system by a chlorinator. Generally, liquid chlorine with a chlorinator is used only on large systems, 2000 tons and up. Special handling equipment and safety precautions[4, 24] are required for liquid chlorine. When small amounts of chlorine are needed, compounds such as calcium or sodium hypochlorite can be used.

When chlorine is used continuously in a system, a concentration of 0.3-.5 ppm is sufficient. When intermittent chlorination is practical, the concentration is raised to 1.0 ppm for several hours; then feeding is discontinued for several hours. The chlorine is held at a maximum of 1.0 ppm to minimize attack on the cooling tower wood. The *pH* should not exceed 8.0 during chlorination and should be held preferably in the range of 6.0 to 7.0. Chorine is measured in the recirculated water to the tower, not after the water cascades over the tower. The water passing thru the tower has its chlorine residual decreased or nearly depleted as some of the chlorine is absorbed into the wood.

Quaternary Ammonium Compounds

Some of these compounds in high concentrations are toxic to slime and algae growths. Certain quaternaries react with or are absorbed by organic matter in recirculated water systems, thus losing some of their effectiveness. Volatilization of some compounds occurs when the water passes over a cooling tower.

Other Compounds

There are many proprietary algaecides and biocides available to control biological growths. They may be mixtures of some of the previously mentioned chemicals or other compounds depending on the supplier.

METHODS OF TREATMENT

No toxic agent is effective for the control of all types of biological fouling. Selection of the toxicant is based on the microorganism present and the chemicals used for scale and corrosion control. The methods and frequency of feeding must be varied to suit the individual problem. Compounds may be used to clear the cooling tower of algae, but there may still be active bacteria producing slime in the heat exchanger. Chromates used as corrosion inhibitors also inhibit the growth of some slime-forming organisms. The compatibility of the toxicants with other treatments used for scale and corrosion must be known. This illustrates again the need for the services of a water conditioning specialist.

Feeding of algaecides and biocides in shock doses is more effective and economical than continuous feedings.

Chapter 5 gives some details of water conditioning to prevent biological growth in several types of water systems.

For a comprehensive treatment of slime and algae control, see References, 2, 25 and 26.

WOOD DETERIORATION AND ITS CONTROL

Wood in cooling towers is subject to three main types of deterioration: physical, chemical and biological. The three types occur simultaneously.

Wood is composed of cellulose, lignins and natural extractives. The cellulose is similar to cotton fibers and gives wood its strength. The lignins provide the cementing agent which holds the fibers together. The extractives create wood resistance to decay. It is these substances which make redwood so durable. However, the extractives are soluble and are leached from the wood by water. Although this action does not seem to affect the strength of wood, decay may take place more rapidly.

Chemical deterioration usually causes delignification, indicated by the bleached appearance of wood. The chemicals commonly responsible for this attack are oxidizing agents such as chlorine, and alkalies such as calcium bicarbonate, calcium carbonate and sodium carbonate. Chemical attack most frequently takes place in the fill and in the flooded portions of the tower.

Chemical deterioration is controlled by maintaining the *pH* below 8.0, preferably in the range of 6.0 to 7.0. The free chlorine residue should be maintained at less than 1.0 ppm when using intermittent chlorination.

Biological attack occurs as surface rot and as internal decay. The organisms feed on the cellulose, leaving the lignins; consequently the wood loses much of its strength. Internal decay in cooling towers occurs in the plenum areas, cell partitions, doors and fan housing and supports; surface rot occurs in the flooded area.

The agents which prevent chemical deterioration of wood also minimize biological deterioration of the surface type. Periodic addition of nonoxidizing biocides to the water minimizes the attack. In the areas subject to internal decay, lumber is sprayed with preservatives that are toxic to the organisms. This protective measure must be taken before serious infection starts. A regular spray procedure should be considered for preventative maintenance. A periodic examination of the tower should be made by sending samples of wood to a qualified micro-biological laboratory. These studies serve as a basis to determine the beginning of a preventative spraying program.

CHAPTER 5. WATER CONDITIONING SYSTEMS

This chapter describes how water conditioning is applied to the three types of water circulating systems.

Several over-all considerations apply to both large and small air conditioning systems. However, the Guide Specifications presented in this chapter apply primarily to large systems.

The application of water conditioning is classified with respect to refrigeration capacity of the system:

1. Large systems (75 tons and up) for which the customer can afford the services of a water conditioning company for appraisal and administration.
2. Small systems (5 to 75 tons) for which it may not be economical to procure a complete water conditioning service.
   The cost of complete services and conditioning may be greater than an occasional acid cleaning of the condenser or its replacement.

DESIGN CONSIDERATIONS

Although a complete water conditioning program has a direct bearing on system life, operating efficiency and maintenance, it must be accompanied by good engineering practice to accomplish desirable results. Water conditioning alone is insufficient. Some of these important practices are:

1. Adjustable bleed-off devices with an adequate open site drain to permit easy measuring of the bleed-off flow rate.
2. Access for cleaning and servicing equipment.
3. Use of water velocities to minimize corrosion (*Table 7*).
4. Use of materials in construction compatible with environment and type of water conditioning.
   Both local experience and the counsel of a corrosion engineer should be considered when specifying the type of pipe for a particular water supply.
5. Application of design practices for dirt traps, valves, etc., described in *Part 3, Piping Design*.
6. Use of sumps large enough to prevent overflow when pumps are shut down.
7. Use of equalizer lines with twin cooling towers or other units connected in parallel to prevent overflow waste to a drain at one unit while make-up water is required at the other.
8. Proper physical location of cooling towers and evaporative condensers. Locations near smoke stacks or other sources of acid gases may cause serious corrosion problems. The exhaust from some photoprinting machines contains ammonia which is very corrosive to copper. In food storage areas, slime and algae problems are more serious.
9. Adequate space for chemical feeding devices, such as pumps and tanks including piping and wiring. Provide piping, or at least tees in the main lines of the piping, for the insertion of test coupons (*Chapter 3*). For large installations a control room with sink is convenient for the making of routine chemical tests.
10. Use of packing glands on pumps for open systems since some bleed-off is necessary.
    Sand or other abrasive materials shorten the life of mechanical seals. Mechanical seals are preferred for closed systems to prevent the loss of conditional water.
    Chemicals added to a recirculated water system should not create problems with valve packing or pump seals or packing. A check should be made with the pump and valve manufacturers to obtain materials suitable for use with the selected chemical treatment.

FOULING FACTORS

The deposit of scale or other foreign material in the tubes of heat exchangers decreases the heat transfer (*Chapter 1*). Therefore, appropriate fouling factors must be included when equipment is selected if a satisfactory performance is to be maintained over a sustained operating period. Otherwise, excessive system shutdown periods may be required to clean fouled heat exchangers if loss of capacity cannot be tolerated. A fouling factor should be included when selecting equipment for all water systems. Even freshly cleaned equipment can usually have a quick build-up of a heat retardant film. Hence, high fouling factors can usually be expected after the equipment goes into operation. The change may not be a slow steady function of time as many believe.

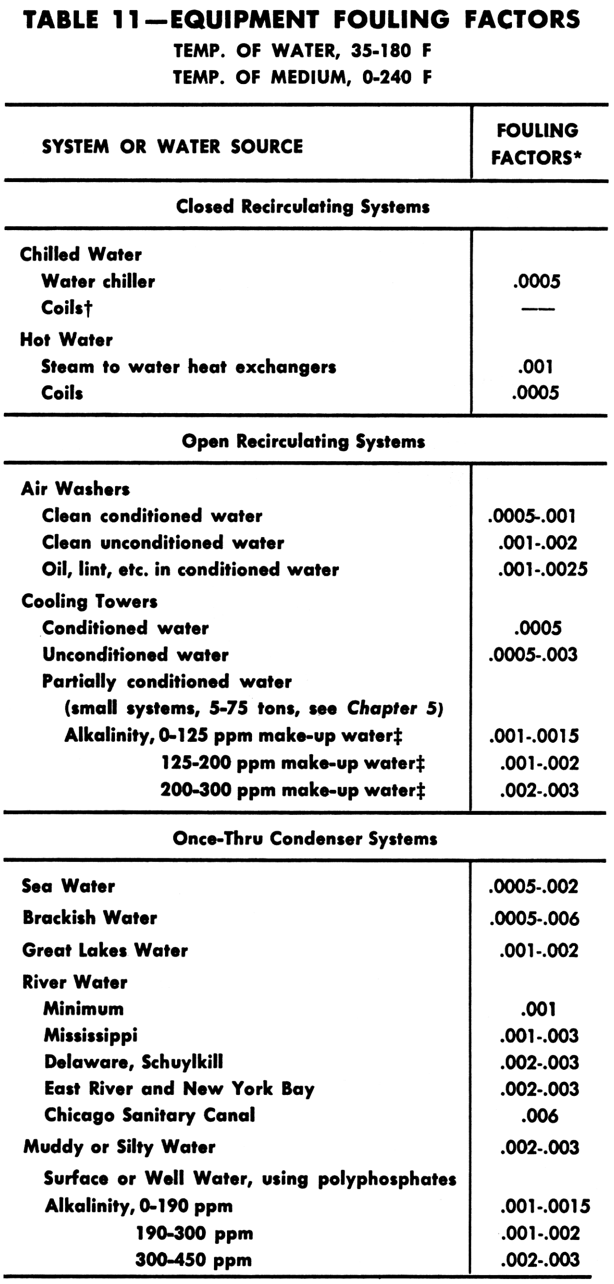


TABLE 11—EQUIPMENT FOULING FACTORS

TEMP. OF WATER, 35-180 F
TEMP. OF MEDIUM, 0-240 F

SYSTEM OR WATER SOURCE	FOULING FACTORS*
Closed Recirculating Systems	
Chilled Water	
Water chiller	.0005
Coils†	——
Hot Water	
Steam to water heat exchangers	.001
Coils	.0005
Open Recirculating Systems	
Air Washers	
Clean conditioned water	.0005-.001
Clean unconditioned water	.001-.002
Oil, lint, etc. in conditioned water	.001-.0025
Cooling Towers	
Conditioned water	.0005
Unconditioned water	.0005-.003
Partially conditioned water (small systems, 5-75 tons, see *Chapter 5)*	
Alkalinity, 0-125 ppm make-up water‡	.001-.0015
125-200 ppm make-up water‡	.001-.002
200-300 ppm make-up water‡	.002-.003
Once-Thru Condenser Systems	
Sea Water	.0005-.002
Brackish Water	.0005-.006
Great Lakes Water	.001-.002
River Water	
Minimum	.001
Mississippi	.001-.003
Delaware, Schuylkill	.002-.003
East River and New York Bay	.002-.003
Chicago Sanitary Canal	.006
Muddy or Silty Water	.002-.003
Surface or Well Water, using polyphosphates	
Alkalinity, 0-190 ppm	.001-.0015
190-300 ppm	.001-.002
300-450 ppm	.002-.003

*Fouling factors are for either the cooler or for the condenser.

†Fouling factors are normally not used for chilled water coils.

‡Using bleed-off of 1½ to 2 times the evaporation rate (cycles of concentration 1.66 to 1.50).

NOTES:

Use for nonferrous and stainless steel tubes, water velocity exceeding 3 feet per second.

Based on Carrier experience, and some data from Standards of TEMA (Tubular Exchanger Manufacturer's Association), Fourth Edition, 1959.

Table 11 contains a range of suggested fouling factors for various types of water systems used with heat exchangers. The lower value shown is for systems on which cleaning on a seasonal basis is not objectionable from a cost standpoint or a drop-off of capacity will not seriously affect desired end results. The higher value shown is suggested for industrial applications, and this value may even be exceeded on systems where excessive fouling may occur or the expense of cleaning is high. For example, systems which require a complete shutdown of plant production to accommodate the normal maintenance may use the higher values for fouling factors.

Fouling can be caused by a scale deposit of calcium carbonate, calcium sulfate, or by the products of corrosion; it can also be caused by an oily film or by a deposit of lint, silt, etc. A film of oil or grease offers greater resistance to heat transfer than does calcium carbonate because the former has a lower thermal conductivity.

Fouling can be significant even with a thin film; after cleaning a heat exchanger with acid and detergents, a film can quickly form on surfaces. Whenever a performance test is run, even directly after cleaning, the fouling factor cannot be assumed to be zero. For field capacity tests, a *minimum* fouling factor of one-half of the value used in selecting the equipment is suggested for test performance. In any instance this value should not be below .00025.

WATER CONDITIONING CHEMICALS

Chemicals introduced into a water system may require special feeding devices and care in handing.

FEEDING EQUIPMENT

The type of equipment used for feeding chemicals can vary greatly, depending on the size of installation, variation in load, variation in the composition of make-up water, and the amount of manual adjustment by operating personnel. Automatic feeding requires more costly equipment.

Large Systems, 75 tons and up

Chemicals packaged dry are usually dissolved in water and introduced as a liquid.

Positive displacement chemical feed pumps of the plunger or diaphragm type producing a uniform flow rate are the most common and dependable means of continuous introduction of chemical treatment solutions. Other types of pumps have either a variable speed drive, variable stroke, or variable speed motor.

Proportional feed can be achieved by means of a special water meter equipped with a contact head which makes an electric contact upon entry of a prescribed quantity of make-up water into the system. A preset timer activates the pump and feeds chemicals for a predetermined period.

A less costly proportional feeder for small installations consists of a measuring column with an electrical probe placed in a pipe between two electric solenoid valves. It is controlled by a timer which permits the treating solution to flow by gravity into the measuring column and discharge a metered amount of solution to the system by gravity into the measuring column and discharge a metered amount of solution to the system by gravity flow on a preset time cycle. The time cycle as well as the quantities of solution admitted to the measuring column can be adjusted to vary the quantity of conditioning chemical.

Pumps and devices for feeding acids use corrosion resistant construction such as stainless steel or plastics. Completely automatic control devices for acid feed consist of a *pH* recorder-controller and a variable speed acid pump.

Equipment is available to perform automatically a chemical analysis of any colorimetric determination performed in the laboratory. This equipment can also be made to transmit signals for control of the chemical feeder.

Small Systems, 5 to 75 tons

Chemical feeders used on large systems may be used also on small installations, but the cost cannot normally be justified.

Various types of feeding devices, particularly for the small systems, are available. One type consists of bags of chemicals suspended on the side of the spray chambers above the water. Water flows over the bags whenever the sprays operate, and gradually dissolves the chemicals. Another is a metal can with two openings in the top. The can is placed in the basin of the cooling tower where movement of the water causes flow in one opening and out the other. A third device consists of a metal container with a collecting pan on top which is normally full of water when the sprays are operating. A replaceable orifice in the pan meters a constant flow of water to the chemicals located in the bottom of the container. A fourth device uses a vertical plastic cylinder into which is placed a number of briquettes one on top of another. A controlled amount of water from the pump discharge flows in and out, thru the bottom two or three briquettes. As one dissolves, another drops to take its place.

METHODS OF FEEDING CHEMICALS

The method of feeding chemicals is different for the three classes of water systems. Discussion of both the large and small systems follows.

Once-Thru Systems

Chemical feed (large and small systems) for scale and corrosion control is continuous for once-thru systems. The feeder operates at a constant rate whenever the water pump operates. Batch feed is normally used for slime and algae control.

Open Recirculating Systems

For the small system the chemical feed method for scale and corrosion is the replacement of chemicals or containers periodically, once very two to eight weeks or longer. There is no control check by chemical analysis.

For the large system a daily or regularly scheduled control analysis indicates whether the chemical feed rate should be increased or decreased. Feeding tanks are filled daily or weekly.

Closed Recirculating Systems

Chemicals are added by a batch method for all sizes of closed systems. Chemicals are added periodically, every one to six months or more often, depending on the loss of water from the system.

HANDLING OF CHEMICALS

Some chemicals cause severe skin irritation while others burn the flesh. Precautions should be taken to prevent skin contact with these chemicals; persons handing chromates sometimes complain of chromitch. The chlorophenol compounds used in water conditioning (even in low concentration) have been reported to cause dermatitis. Concentrated sulfuric acid, caustic soda and lime will burn the flesh.

Chlorine gas irritates the skin and eyes, and is very dangerous if inhaled; liquid chlorine requires special handling.[24,26]

Water conditioning chemicals cause injury if taken internally in large doses.

CLEAN SYSTEM REQUIRED

On new systems the piping and units should be chemically cleaned to remove cutting oil, pipe thread compound, and other construction debris before starting the water conditioning. Cleaning prevents mechanical clogging and localized corrosion from dirt left in the system. Cleaning agents commonly used include polyphosphates, synthetic detergents, or combinations of these. Water is circulated at approximately 100F for a day or two, after which the system is drained, flushed and refilled. The maximum water temperature is limited to a temperature safe for the refrigerant contained in the refrigeration equipment. It is important to start the corrosion protection immediately after cleaning since metal surfaces are particularly vulnerable.

If water conditioning is started on an old system not previously treated, the water conditioning specialist usually recommends cleaning before treatment.

CORROSION INHIBITORS, INITIAL CONCENTRATION

Several days may be required to build up a protective film using a normal concentration of inhibitors. This may allow corrosion to start on steel. The rate of film build-up is a function of the concentration. An initial concentration of two to ten times the normal treatment of corrosion inhibitor can be used to form a protective film more quickly. After several hours of operation, the concentration is reduced to normal levels.

WATER CONDITIONING BY NONCHEMICAL METHODS

There are available for water treatment several types of devices which require no technical control and use nonchemical means to prevent corrosion and formation of scale. Some of these devices are made of special processed metal which acts as a catalyst. Others use permanent magnets placed so that water flows thru the magnetic field. An investigation[27] of several of these devices which claim to control corrosion and scale discloses that these particular devices have no significant effect upon scale and corrosion problems.

ORDINANCES AND GOVERNMENT REGULATIONS

In some states water used for humidification is required to meet drinking water standards regarding bacteriological quality. The United States Department of Agriculture Meat Inspection Division prohibits the use of chromates for air washing where the air contacts foodstuffs. Public Health officials are becoming more aware of the need for protection of the public water supplies. An ordinance presently in effect in Detroit states that no physical connection can be made between lines carrying city water and pumps, pipe and tanks from any other source; there must be an atmospheric gap between the city water line and the equipment. This regulation which applies also in other cities is good engineering practice.

WATER CONDITIONING OF LARGE SYSTEMS 75 TONS AND UP

Chapter 1 describes three types of water systems and three kinds of water problems. The various detailed treatments are described in *Chapter 2, 3 and 4.*

Water conditioning for these systems is summarized in *Table 12*. This section discusses the various methods of water treatment utilized in practice and summarized as mentioned. A more general discussion[28] of scale and corrosion emphasizes the need for a water conditioning specialist.

Water conditioning for the three types of systems and three kinds of water problems is discussed under the following heading.

ONCE-THRU SYSTEM

Since no water is recirculated, the cost of water conditioning chemicals for scale and corrosion control can be prohibitive. Therefore, the objective should be to obtain satisfactory protection with low levels of treatment.

Scale Control

The Langelier Saturation Index is most useful in predicting whether water is scale-forming. If the index is positive and less than +0.5, scale is probably not a problem. If greater than +.5, scale may be controlled by the addition of 2 to 5 ppm of polyphosphates unless the index is greater than +1.5 to +2.0, or a limit determined by the water conditioning specialist. If the index is too great, sulfuric acid may be added in addition to polyphosphates to reduce alkalinity and *pH*.

If the Langelier Index is negative (a nonscaling indication), the water is likely to be corrosive. Lime, soda ash or caustic soda may be added to increase the *pH*.

Corrosion may be prevented on heat exchangers by the intentional build-up of a thin film of calcium carbonate. This condition is accomplished by *pH* control with acid or alkali, but is not a common method for air conditioning systems.

Iron (as ferrous bicarbonate) is found in some well water; it decomposes to form a scale of ferrous oxide. Although polyphosphates are used to prevent this type of scale formation, proprietary compounds are available which are more effective.

Corrosion Control

The use of chromates in concentrations of 200-500 ppm is very effective in controlling corrosion, but it is not economical in a once-thru system. Sufficient protection

TABLE 12—SUMMARY OF WATER CONDITIONING CONTROLS*

	ONCE-THRU	OPEN RECIRCULATING	CLOSED RECIRCULATING
Scale Control	1. Surface active agents, such as polyphosphates 2. Addition of Acid 3. pH adjustment Other considerations Adequate fouling factor Surface temperature Water temperature Clean system	1. Bleed-off 2. Surface active agents such as polyphosphates 3. Addition of acid 4. pH adjustment 5. Softening Other considerations Adequate fouling factor Surface temperature Water temperature Clean system	No control required
Corrosion Control	1. Corrosion inhibitors in low concentrations 2. Deposit of protective scale of calcium carbonate 3. pH control 4. Proper materials of construction	1. Corrosion inhibitors in high concentrations (200 - 500 ppm) 2. Corrosion inhibitors in low concentrations, (20-80 ppm) 3. pH control 4. Proper materials of construction	Corrosion inhibitors in high concentrations (200 - 500 ppm) Proper materials of construction
Slime and Algae Control	Chlorinated phenols Other biocides Chlorine by hypochlorites or by liquid chlorine	Chlorinated phenols Other biocides Chlorine by hypochlorites or by liquid chlorine	No control required

*Abrasive materials must be kept out of the water system, and maximum velocity must not be exceeded in the tube. See *Table 7*.

at low treatment levels is the chief problem.

Low chromates mixed with other corrosion inhibitors are used in total treatment levels of 20-80 ppm. Control may be required by adding soda ash to raise, or by adding sulfuric acid to lower, the *pH*.

Frequently, well water contains dissolved gases such as carbon dioxide, CO_2, or hydrogen sulfide, H_2S, which may be very corrosive. Iron compounds and chlorides are also troublesome, and require special treatment.

Corrosion can be prevented by the controlled build-up of a thin film of calcium carbonate, as explained under scale control.

Occasionally it may be more economical to use corrosion resistant materials such as cupro-nickel, admiralty brass, stainless steel, or nickel instead of corrosion inhibitors in at least the more critical parts of the system.

Slime and Algae Control

Biological fouling may occur in once-thru systems when the source is polluted surface water. Well water does not normally produce slime formation. Chlorine is commonly used to control slime either by the use of hypochlorites or chlorination. The feed may be either intermittent or continuous.

OPEN RECIRCULATING SYSTEM

Most of the water conditioning problems due to the evaporation of large quantities of water and subsequent concentration of solids are prevalent with this type of system, particularly in cooling towers, evaporative condensers and spray ponds.

Air washers require little water conditioning because in summer there is some water condensed from the air and added to the system. In winter, only a small amount of water is evaporated. Bleed-off is normally required for all open recirculating systems.

Water conditioning is usually designed to be non-scale-forming, a condition which is slightly corrosive. Corrosion inhibitors are added to minimize corrosion.

Scale Control

Three methods to prevent scale formation are described in *Chapter 2*. These involve the use of:

1. Bleed-off.
2. Bleed-off plus scale inhibitors such as polyphosphates.

3. Bleed-off plus scale inhibitors plus acid.

Bleed-off – General rules have been developed for the use of bleed-off to prevent scale formation. When the methyl orange alkalinity of the make-up water does not exceed 100 ppm as $CaCO_3$ and the recirculating water does not exceed a methyl orange alkalinity of 125 ppm, bleed-off alone may be satisfactory. This is illustrated in *Chart 7 (Chapter 2)* which shows the bleed-off rate for a 100 ton air conditioning compressor system based on the above limits of alkalinity.

Accurate determination of the rate of bleed-off is usually accomplished by the use of the Langelier and Ryznar Indexes. These indexes take into consideration the five variables influencing scale formation of which alkalinity is one.

The Langelier Index is determined for several cycles of concentration *(Chapter 2).* Although bleed-off alone control scale formation, there is usually a need for corrosion inhibitors.

Bleed-off Plus Scale Inhibitors - Since scale inhibitors such as polyphosphates allow a much higher concentration of solids without scale formation, the amount of make-up water can be greatly reduced, thus saving water costs. Another important factor is the saving of corrosion inhibitors since less chemical is required to maintain the treatment level. The amount of bleed-off required when polyphosphates are used *(Chart 7)* is based on an arbitrary limit of 400 ppm alkalinity. In practice, some systems may have a limit exceeding 400 ppm; others may have a lower limit. Scaling depends on all five properties; alkalinity, calcium, *pH*, temperature and total solids *(Chapter 2).* All of these factors are evaluated to determine when scaling starts, as scaling cannot be determined by the use of one or even three of these factors alone.

Polyphosphates in concentration of 2-5 ppm are used to prevent scale formation. Scale inhibitors frequently contain polyphosphates mixed with other compounds which also prevent scale formation.

Polyphosphates prevent the formation of tubercules in the piping system and thus help to keep the water system clean.

Bleed-off Plus Scale Inhibitors Plus Acid - Bleed-off may be reduced by the addition of acid to the system where the water is costly and/or high in concentrations of solids. Sulfuric acid, commonly used because of economics, changes the carbonate ion to the more soluble sulfate ion *(Chapter 2).* Only enough acid is added to reduce the alkalinity sufficiently to permit scale control by the use of the polyphosphates.

Automatic *pH* control of acid feed, although costly, is recommended because of the hazard involved. A low *pH* due to excess feed of the acid is corrosive.

Air conditioning systems in offices and manufacturing areas of industrial companies often use non-automatic *pH* control. However, daily or even more frequent checks must be made on the chemical control analysis, and adjustment must be made in rate of chemical feed as necessary.

Corrosion Control

System corrosion is controlled by one or both of the following methods.

Corrosion Inhibitors - Chromates are extensively used, and are very effective in controlling corrosion in concentrations of 200-500 ppm at a 7.0-8.5 *pH*.

A mixture of chromates and other corrosion inhibitors with a total treatment in the range of 20 to 80 ppm is sometimes used. Usually the *pH* needs to be held within a narrow range; these are examples of such ranges: 6.0-6.5, 7.0-7.8, 6.5-7.5 *(Chapter 3).*

When yellow staining due to chromates is objectionable, sodium nitrite can be substituted in the same concentration as the chromates, but the concentration should be approximately twice as great as that of chromates to obtain equal protection, and the *pH* must be maintained above 7.0. Several problems in the use of nitrites are described in *Chapter 3.*

Control of pH - Acid gases in the atmosphere sometimes cause water in cooling towers and air washers to become acidic, even though the make-up water may be neutral. The *pH* in some cooling towers[29] may be as low as 4.0 or 5.0. Addition of an alkali such as soda ash is used to raise the *pH*. If the *pH* is too high, sulfuric acid is commonly added to lower the value. When the *pH* is low, there is no problem with scale.

Slime and Algae Control

Cooling Towers - Slime and algae are usually controlled by chlorinated phenols fed in shot fashion. This may be required at daily, weekly or even longer intervals. Application of chlorine gas by chlorinators or by hypochlorites may be used. Chlorine gas with chlorinator equipment is used only in very large systems.

Air Washers - The more effective substances such as trichlorophenates and chlorine cannot be used because of objectionable odors. Sodium pentachloro-phenate may be used. Proprietary biocides have combinations of toxicants for this service. Periodically, the air washers should be sterilized by stopping the air flow and circulating a solution of hypochlorites or a nonoxidizing biocide. The washer is then cleaned with a hose, and slime and dirt removed from the pan.

CLOSED RECIRCULATING SYSTEM

Closed systems require little make-up water unless there is some unusual condition such as a leak at the pump gland or overflow at the expansion tank. Water can also be lost at automatic air vents. Generally, there is no control problem for scale or slime and algae.

Corrosion Control

For chilled water systems chromates in treatment levels of 200-500 ppm at a *pH* of 7.0 to 8.5 are commonly used.

Where yellow staining is a problem, i.e. discoloring of rugs during service on valves and strainers, sodium nitrite may be used in the same concentration as the chromate. Some of the contaminating influences which cause decomposition of sodium nitrite in open systems are absent in closed systems.

In some instances an alkali or acid may be added to keep the *pH* within limits.

Since the cost of the chemicals is small because of little make-up water, the full chromate treatment is used. There is no need to use low chromates with other inhibitors (sometimes utilized in an open system).

The treatment for hot water systems is in the range of 1000-2000 ppm of chromate, the higher concentration being used for water at 212 F. A system which circulates chilled water in summer and hot water in winter should carry a higher concentration of corrosion inhibitors in winter.

WATER CONDITIONING OF SMALL SYSTEMS 5 TO 75 TONS

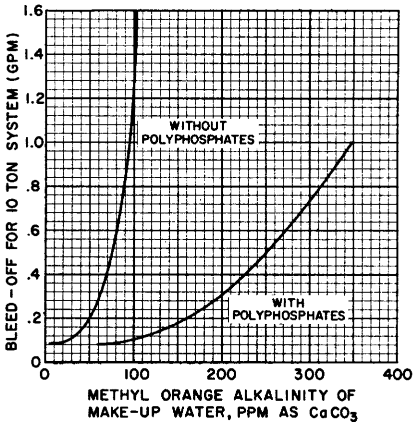
In small systems where water conditions are poor, an air-cooled condenser is often used to eliminate the water problems. However, it is not always feasible to accomplish this, or the cost of changing to this type of equipment may be too great.

ONCE-THRU SYSTEM

Water conditioning for scale, corrosion, slime and algae is essentially the same as for large systems. Polyphosphate treatment can be used for scale control. Acid treatment is seldom used because of high cost of feeding equipment and controls required.

If corrosion is a problem, use of corrosion resistant materials for the critical components should be considered. Low concentrations of corrosion inhibitors in the range of 20-80 ppm are used, such as mixtures of chromates and other corrosion inhibitors.

CHART 9—BLEED-OFF REQUIRED FOR A 10 TON AIR CONDITIONING SYSTEM



OPEN RECIRCULATING SYSTEM

The open system has all three water problems.

Scale Control

Packages of chemical treatments can be purchased by the consumer thru air conditioning service organizations or directly from the supplier. *Chart 9* illustrates how the bleed-off required varies with the methyl orange alkalinity of the make-up water. This curve is based on a maximum of 125 ppm alkalinity as $CaCO_3$ in the recirculating system without chemical treatment.

The curve for bleed-off with polyphosphates is representative of bleed-off rates recommended by packaged chemical treatments for scale prevention. When the alkalinity of make-up water is in the range of 0-250 ppm as $CaCO_3$, the bleed-off rate is based on maintaining a maximum alkalinity of 400 ppm in the recirculated water. When the alkalinity in the make-up water exceeds 250 ppm, the maximum alkalinity maintained in the recirculated water is 450 ppm as $CaCO_3$.

The use of polyphosphates greatly reduces the bleed-off, and is recommended where the alkalinity in the make-up water exceeds 100 ppm. Generally, when using polyphosphates, a satisfactory scale control can be expected when the methyl orange alkalinity of make-up water does not exceed 150 ppm. When the alkalinity of make-up water is in the range of 150-250 ppm, some scale build-up can be expected. This scale is removed by acid cleaning during equipment shutdown. Depending upon conditions, cleaning may be carried out yearly or once every several years. When the alkalinity exceeds 250 ppm, more scaling may be expected and, therefore, mor frequent cleaning. Some advantage can be gained by increasing both the rate of bleed-off and the chemical feed.

The bleed-off *(Chart 9)* is the total lost from the system. The windage loss *(Chapter 1)* is subtracted from the bleed-off to obtain the actual water quantity to be discharged to the drain. For example, if the tower is 30 tons, multiply bleed-off *(Chart 9)* by three. If the alkalinity of make-up water does not exceed 100 ppm, it is possible to adjust bleed-off so no treatment is needed to prevent scale formation.

When packaged treatment chemicals are used, the recommended bleed-off for the particular treatment should be followed, rather than that illustrated in Chart 9. If trouble is suspected, consult the manufacturer of the packaged chemicals.

Corrosion Control

Although water conditioning may not be required for scale control, it may be necessary to prevent corrosion or the growth of slime and algae.

Polyphosphates have some effect in reducing corrosion; when scale is not a problem, the concentration may be increased to 10-15 ppm. This is accomplished by increasing the feed rate 2 to 4 times and by reducing the bleed-off to one-half the rate shown in *Chart 9*.

Chromates in concentrations of 200-500 ppm are very effective. Packages of chromates and polyphosphates are available for small systems. Generally, the bleed-off rate is lower where chromates are used because scale is no problem and a lower bleed-off allows higher chromate concentration in the system.

Low level treatment of 20-80 ppm of mixtures of chromates with other inhibitors may be used but, since this generally requires *pH* control, this method is not practical for small installations.

In some areas where the *pH* is too low, an alkali such as soda ash may be mixed with the chromates.

Slime and Algae Control

Shock feeding once a month or oftener is sufficient to control biological growth. Compounds described in this chapter for large systems are commonly used. A continuous drip feed consisting of a plastic bottle and capillary plastic tube is sometimes used.

CLOSED RECIRCULATING SYSTEM

Water conditioning for small closed systems is the same as for large closed systems.

SUGGESTED GUIDE SPECIFICATIONS FOR WATER CONDITIONING

Suggested guide specifications are presented to aid the engineer, contractor and owner to understand what constitutes an adequate water conditioning program.[30] They help evaluate proposals made by water conditioning companies.

GENERAL CONDITIONS

An adequate water conditioning program to control corrosion, scale, algae, slime and sludge shall be provided for a period of_____years for open and closed water and brine systems, commencing with the start-up of the refrigeration and/or air conditioning equipment. Recirculated water in wooden cooling towers shall be so conditioned as to prevent delignification of wood.

The chemicals used for water conditioning and the methods used to feed chemicals shall comply with local health codes, where applicable.

Chemicals used for water conditioning shall have no detrimental effect on nonmetallic materials such as rubber, etc. used in the system.

The water conditioning program shall be administered by a competent water treatment company acceptable to both the customer and the contractor.

TERMS OF PROPOSAL

The water conditioning company shall submit a complete proposal with its bid.

A complete analysis of the water to be used for make-up in the several systems to be treated shall be included in the proposal.

The chemical names of the water conditioning compounds to be used shall be stated.

The concentration of chemicals to be maintained in the several systems shall be stated.

The estimated amount of continuous bleed-off from recirculating water systems such as cooling towers, evaporative condensers, humidifiers, etc. shall be stated.

Type and frequency of service by the water treatment company shall be stated.

CORROSION CONTROL

Corrosion control shall be provided for all water and brine circuits by using suitable corrosion inhibitors and *pH* control.

Corrosion shall be judged under control when the over-all corrosion rate or maximum depth of pitting does not exceed_____inches of penetration per year of the thickness of any metal component of the circuit in continuous contact with the conditioned water or brine.*

Over-all corrosion and pitting rates shall be measured by using suitable corrosion test coupons representing the metals in the circuit. ASTM corrosion test procedures D 935-49 and A 224-46 or other equally suitable procedures shall be followed.

Corrosion tests shall be conducted at locations in the circuit as specified by the contractor.†

If over-all corrosion and/or pitting exceeds the maximum allowable rates, an immediate retest shall be made. If the results of the retest are within the maximum allowable rates, corrosion shall be judged under control.

SCALE CONTROL

Formation of adherent mineral deposits which cannot be easily flushed from heat transfer surfaces shall be prevented.

A continuous bleed-off shall be specified for all devices which evaporate water, such as cooling towers, evaporative condensers and humidifiers. †

Internal chemical treatment of water in the circuit and/or external treatment of the make-up water shall be provided when bleed-off alone is inadequate to prevent scale formation or when bleed-off alone is uneconomical because of excessive use of corrosion inhibitors.

ALGAE AND SLIME CONTROL

Algae and slime growths shall be prevented in all circuits by using suitable algaecides. Copper, mercury, or other algaecides which may cause damage to equipment shall not be used.

CHEMICAL FEEDING

Chemicals shall be fed to circuits requiring continuous make-up by automatic proportional feeding devices. †

Acid feeders, when used, shall be controlled by an electronic *pH* controller. †

SERVICE PROCEDRE

The water conditioning company shall provide (complete with alternate a or b, whichever applies):

a. Oral and written instructions and suitable test kits for operating personnel for the maintenance and control of the water conditioning program.
b. The addition of all chemicals and all control testing by its own personnel.

Periodic service calls, water analysis, and corrosion test checks shall be made at intervals as necessary to insure proper control of corrosion, scale, algae and slime.

A written report of each service call, water analysis, and corrosion check test shall be submitted by the water conditioning company (complete with alternate a or b, whichever applies):

a. Upon request.
b. In accordance with a prearranged schedule.

BASIS OF TABLE 13

Water Analysis for Supplies in United States Cities

Data is taken from *The Industrial Utility of Public Water Supplies in the United States*, 1952 Geological Survey Water Supply Paper 1299 (states east of the Mississippi River) and 1300 (states west of the Mississippi River), U.S. Government Printing Office, Washington, D.C.

General

Data is for finished water after treatment at the water plant. When there is one source, averages are given, rather than maximum and minimum. When there is more than one source, the averages are given if available. When the composition is given only for the individual sources, i.e. 6 wells, two figures are included, one for the low level and another for the high level concentration. The water from various sources may be mixed together in some systems; in others, they may be grouped in several systems just like different systems. The composition in one section of the city may, therefore, be considerably different from another section.

Consult the local water companies for more specific data.

Total Hardness

Total hardness is a rough measure of scale-forming properties. It includes both carbonate and non-carbonate hardness *(Chapter 2)*. Average values are given, except for those cities having an asterisk (*) in the alkalinity column. For these cities the hardness is for a

*Commonly accepted maximum corrosion rate and depth of pitting is .005 inches per year (5 mils per year, mpy). This usually applies to metals having a thickness greater than 0.25 inches. Where metal thickness is less, proportional lower values should be used.
For copper tubing the maximum corrosion rate is .001 inches per year (one mil per year). See *Chapter 3*.

†The contractor responsible for piping and/or electrical work should provide suitable fitting and connection for corrosion testers and continuous bleed-off, and should also provide necessary facilities for the installation and operation of automatic feeders and their controls.

ness is for a particular day. Hardness may be classified in this manner:

HARDNESS (ppm as $CaCO_3$)	CLASSIFICATION
less than 15	very soft
15 — 50	soft
50 — 100	medium hard
100 — 200	hard
greater than 200	very hard

Bicarbonate (HCO_3)

Concentration of bicarbonate (HCO_3) ion has been multiplied by 0.82 to give the equivalent expressed as $CaCO_3$ (*Table 13*). Generally, this is the chemical analysis taken on a particular day, and is not an average. It may be higher or lower than the average.

Calcium (Ca)

Concentration of calcium (Ca) ion has been multiplied by 2.5 to give the equivalent as $CaCo_3$ (*Table 13*). For example, Ithaca, New York, calcium ion = 22×2.5 = 55 ppm of calcium as $CaCO_3$. Generally, this is the chemical analysis taken on a particular day, and is not an average. It may be higher or lower than the average.

Total Alkalinity

Total alkalinity (methyl orange alkalinity, *Chapter 2*) is the average, except where indicated by an asterisk (*). No value for alkalinity is given in Papers 1299 and 1300 for these cities. The values shown have been approximated by use of the bicarbonate and carbonate ion; these are given for a particular day and are not average values. Data has been approximated in *Table 13* as follows:

Bicarbonate (HCO_3) ion ppm×0.82 =
plus
Carbonate (CO_3) ion ppm×1.66 =
equals
Total alkalinity, ppm as $CaCO_3$ =

pH

Values for *pH* are average, except for those cities having an asterisk (*) in the alkalinity column. For these cities the *pH* is for a particular day.

TYPICAL WATER ANALYSIS

An example of water analysis from this publication is shown for Ithaca, New York, one of the less complicated analyses. Many of the cities do not have the regular determinations of alkalinity, *pH* and hardness as shown in the bottom section of the table.

ITHACA, NEW YORK

Ownership: Municipal; also supplies about 2000 people outside the city limits. Total population supplied, about 31,000.

Source: Six Mile Creek impounded. Emergency supply, connection with Cornell University supply.

Treatment: Superchlorination, coagulation with alum, sedimentation, rapid sand filtration, and dechlorination with sulfur dioxide.

Rated capacity, treatment plant: 4,000,000 gpd.
Raw water storage: 316,000,000 gal.
Finished water storage: 4,924,000 gal.

Analysis (ppm) by U. S. Geological Survey

	FINISHED WATER (city tap)		FINISHED WATER (city tap)
Silica, SiO_2	3.5	Carbonate, CO_3	0.
Iron, Fe	.08	Bicarbonate, HCO_3	46.
Manganese, Mn	.00	Sulfate, SO_4	29.
Calcium, Ca	22.	Chloride, Cl	5.8
Magnesium, Mg	2.9	Fluoride, F	.2
Sodium, Na	5.2	Nitrate, NO_3	1.6
Potassium, K	.8	Dissolved solids	96.
Hardness as $CaCO_3$			
Total	67		
Noncarbonate	29		
Color	1	Turbidity	0.5
pH	7.4	Temperature (F)	—
Specific Conductance (micromhos at 25 C)	163	Date of collection	

Regular Determinations at Treatment Plant

	ALKALINITY as $CaCO_3$ (ppm)			pH			HARDNESS as $CaCO_3$ (ppm)		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Raw water	72	113	44	7.5	7.7	7.3	93	129	63
Finished water	66	98	40	6.7	6.8	6.7	92	132	61

TABLE 13—WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES

STATE AND CITY	Source of Supply	Total Hardness as $CaCO_3$ (ppm)	Bicarbonate (HCO_3) as $CaCO_3$ (ppm)	Calcium (Ca) as $CaCO_3$ (ppm)	Total Alkalinity as $CaCO_3$ (ppm)	Dissolved Solids (ppm)	pH	Specific Conductance at 77 F (micromhos)
ALABAMA								
Anniston	S	104	102	55	102*	118	7.5	191
Birmingham	Ri, R, L	27-91	24-73	23-68	24-73*	46-118	8.3-9.0	73-193
Mobile	C	20	10	16	11	38	8.9	54
Montgomery	W	18-67	105-117	12-57	105-117*	154	7.0-7.5	283-257
ARIZONA								
Flagstaff	L	65	33	48	33*	88	8.0	139
Phoenix	Ri, R, W	190-422	126-222	100-205	126-222*	290-887	7.8	473-1490
Tucson	W	94-220	114-208	72-162	114-208*	117-484	8.0	264-736
Winslow†	C	221	172	110	177*	1110	8.4	2110
ARKANSAS								
Fort Smith	Ri, L	48	18	23	21	59	8.9	71
Little Rock	Ri, L	20	12	11	14	31	8.3	47
CALIFORNIA								
Bakersfield†‡	W	18-628	48-205	12-320	48-205*	108-1010	7.4	180-1620
Eureka	Ri	60	60-88	50	40	73-134	8.0	—
Fresno	W	72-163	83-165	37-85	83-165*	202-336	7.7	231-451
Long Beach	Ri, W	62	134	48	141*	338	8.5	—
Los Angeles	Ri, W	84-274	113-189	62-192	116-189*	200-478	7.7-8.3	317-724
Oakland	Ri	18-208	20-163	15-120	20-163*	37-316	7.9-9.1	—
Pasadena	Ri, W	65-179	81-177	50-117	81-177*	187-272	7.3-7.8	—
Sacramento	Ri, W	56	15	13	33	37	6.7	55
San Bernadino	W, C	67-169	104-200	60-130	104-200*	197-258	8.0-8.8	319-252
San Diego‡	Ri	170-295	64-193	185-187	79-193*	307-648	7.6-8.4	500-980
San Francisco	Re	59-99	6-86	3-63	6-86*	9-99	6.4-7.7	20-225
San Jose	W	194	182	105	182*	288	8.2	475
Metropolitan Water Dist. So. Cal.‡**	Ri	125	100	78	111	692	8.8	1100
COLORADO								
Denver	Ri, C	48-139	32-92	35-85	35-88	—	7.7-8.0	106-455
Fort Collins	Ri	22	13	30	24	77	7.2	94
Grand Junction	C	84	90	55	90	118	7.8	180
Pueblo‡	Ri	317	74	125	125	329	7.5	491
CONNECTICUT								
Bridgeport	Re	29	14	19	14*	46	7.2	76
Hartford	Re	15	6	9	7	27	6.4	40
New Haven	Re	20-69	5-50	14-57	32	36-111	6.8	64-169
Waterbury	Re	24	14	19	14*	42	7.1	68
DELAWARE								
Wilmington	C	52	22	30	27	89	6.5	137
DIST. OF COLUMBIA								
Washington	Ri	96	65	75	60	151	7.6	236
FLORIDA								
Jacksonville‡	W	274	134	168	134*	461	7.4	—
Key West	W	76	50	53	86	85	8.4	150
Miami	W	85	40	63	43	190	8.8	—
Pensacola	W	20	9	13	9*	56	7.1	87
Tallahasee	W	124-152	120-142	90-102	120-142*	164-173	7.8	287
Tampa	Ri	115	29-57	73	59	123	8.3	197

Sources of Supply — B-brook, C-creek, L-lake, P-pond, Re-reservoir, Ri-river, S-stream, Sp-spring, W-well

Note: See explanation of *Table 13* on *page 39*.

*Total alkalinity approximated, as described in explanation of *Table 13*.

†Chloride (Cl) ion concentration in excess of 100 ppm.

‡Sulfate (SO_4) ion concentration in excess of 100 ppm.

**Metropolitan Water District of Southern California supplies for a population of 3,500,000, to *portions* of Long Beach, Los Angeles, Pasadena, Beverly Hills, Burbank, Compton, Fullerton, Glendale, San Marino, Santa Anna, Santa Monica, Torrance, etc.

TABLE 13—WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES (Contd)

STATE AND CITY	Source of Supply	Total Hardness as $CaCO_3$ (ppm)	Bicarbonate (HCO_3) as $CaCO_3$ (ppm)	Calcium (Ca) as $CaCO_3$ (ppm)	Total Alkalinity as $CaCO_3$ (ppm)	Dissolved Solids (ppm)	pH	Specific Conductance at 77 F (micromhos)
GEORGIA								
Atlanta	Ri	19	13	15	16	44	8.7	60
Augusta	Ri	20	15	15	15	46	7.5	63
Brunswick	W	196-530	117	98-255	117*	283-1000	7.3	430-1450
Columbus	Ri	18	17	20	14	55	8.2	88
Macon	Ri	32	21	25	25	64	8.5	98
Savannah	W, C	37	28	30	23	67	7.9	108
IDAHO								
Boise	W	85	75	73	75*	157	7.3	228
Lewiston	Ri, W	32-66	35-122	30-43	26-122*	77-200	7.8	109
Pocatello	C, W	102-260	95-246	75-162	95-246*	136-368	7.9-7.5	219-629
Twin Falls	Ri	197	152	127	152*	293	7.4	483
ILLINOIS								
Chicago	L	121-138	113	93	107	148-168	8.1	242
Danville	Ri	183	180	118	144	265	7.3	465
Moline	Ri	150	25	55	84	104	7.6	166
Peoria	W	394-455	292-348	227-275	292-348*	448-583	—	—
Springfield‡	C	94	30	30	36	116	10.5	—
INDIANA								
Evansville	Ri	132	45	75	64	137	8.1	229
Fort Wayne	Ri	76	17	65	30	115	9.8	180
Indianapolis	Ri, C	222-294	155-227	125-190	155-227*	282	7.5	462
South Bend	W	298-544	240-292	180-352	240-292*	318-681	7.5	529-895
Terre Haute	Ri	278	111	140	154	257	7.1	421
IOWA								
Cedar Rapids	Ri	88	36	75	43	182	9.5	278
Davenport	Ri	144	67	90	107	196	7.0	291
Des Moines	Ri	83	4	30	39	212	10.1	341
Dubuque	W	282	264	142	264*	296	7.8	525
Fort Dodge‡	W	466	367	287	367*	692	7.6	1050
Keokuk	Ri	100	94	137	72	246	8.8	362
Sioux City‡	W	472	332	312	332*	672	7.5	982
Waterloo	W	241	193	167	193*	294	7.9	477
KANSAS								
Dodge City	W	248	192	157	192*	368	7.6	528
Salina‡	W	548	370	440	368	800	7.0	1150
Topeka‡	Ri, W	98	35	73	50	390	9.4	638
Wichita	W	106	69	48	136	260	8.0	418
KENTUCKY								
Lexington	C	84	85	90	76	128	7.4	224
Louisville	Ri	97	36	53	40	146	9.0	251
LOUISIANA								
Alexandra	W	4-544	174-490	3-242	174-490*	270-689	6.8-8.1	817-1130
New Orleans	Ri	75	20-30	40-50	35	162	10.1	280
Shreveport	L	63	33	45	32	162	9.0	270
MAINE								
Augusta	L, P	20	9	12	9*	34	6.5	47
Bangor	Ri	33	9	30	18	64	6.7	90
Portland	L	13	7	11	6	23	6.8	31
Presque Isle	S	82	21	40	47	71	7.1	105
Rumford	S	9	5	4	5*	22	6.1	25

Sources of Supply — B-brook, C-creek, L-lake, P-pond, Re-reservoir, Ri-river, S-stream, Sp-spring, W-well

Note: See explanation of *Table 13* on *page 39*.

*Total alkalinity approximated, as described in explanation of *Table 13*.

†Chloride (Cl) ion concentration in excess of 100 ppm.

‡Sulfate (SO_4) ion concentration in excess of 100 ppm.

TABLE 13—WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES (Contd)

STATE AND CITY	Source of Supply	Total Hardness as $CaCO_3$ (ppm)	Bicarbonate (HCO_3) as $CaCO_3$ (ppm)	Calcium (Ca) as $CaCO_3$ (ppm)	Total Alkalinity as $CaCO_3$ (ppm)	Dissolved Solids (ppm)	pH	Specific Conductance at 77 F (micromhos)
MARYLAND								
Baltimore	Ri, Re	52	40	35	40	81	8.0	—
Cambridge	W	32	384	12	404*	481	8.5	758
Cumberland	C, L	36	53	25	53*	93	7.2	158
Frederick	C	53	21	27	34	78	6.6	131
Salisbury	W	20	18	18	18*	81	7.1	104
MASSACHUSETTS								
Boston	Ri	14	6	10	7	29	6.6	41
Fall River	P	15	8	12	8*	42	7.1	66
Fitchburg	P, Re	6	3	4	3	23	6.2	30
Lowell	W	42	32	33	32	90	6.3	137
New Bedford	P	15	10	11	10*	35	6.5	55
Springfield	Re	12	6	10	6*	30	6.7	39
Worcester	Re	9	3	7	3*	33	6.7	31
MICHIGAN								
Battle Creek	W	201	224	175	222	316	7.0	504
Detroit	Ri	98	76	68	76	132	7.6	—
Escanaba	L, W	132-185	104-164	88-100	88-100*	156-245	7.2	282
Flint	Ri	86	0	58	33*	160	10.2	270
Grand Rapids	L	136	111	87	109	155	7.8	280
Kalamazoo	W	314-381	263-282	202-242	263-282*	357-460	7.6	581-711
Lansing	W	85	3	48	83	177	10.4	—
Marquette	L	46	41	33	41*	51	7.6	94
Saginaw	L	49	33	48	33	111	9.4	194
Sault Ste. Marie	L	43	40	33	40*	52	7.6	94
MINNESOTA								
Duluth	L	46	41	35	43	54	7.6	102
Minneapolis	Ri	77	25	50	42	126	8.0	182
St. Cloud	Ri	134	83	88	83*	190	7.0	287
St. Paul	Ri	72	48	53	57	92	8.6	148
MISSISSIPPI								
Jackson	Ri	50	24	38	25	85	9.0	122
Meridian	L, Sp	18	11	14	11*	38	6.8	50
Vicksburg	Ri	110	122	145	90	356	8.4	524
MISSOURI								
Columbia	W	270	302	143	302*	406	8.2	668
Kansas City‡	Ri	84	40	58	40	297	9.4	297
Kirkville	Ri	90	52	127	40	216	7.6	317
St. Joseph	Ri	232	177	177	160	462	7.8	678
St. Louis‡	Ri	97	17	58	37	238	9.2	—
Springfield	Sp, L	178	160	155	157	247	7.4	—
MONTANA								
Billings	Ri	168	120	95	122	257	8.2	407
Butte	Ri, R, C	56	52	40	52*	98	7.4	137
Great Falls	Ri	142	128	102	130	241	7.7	386
Havre‡	W	404	427	207	427*	1120	7.7	1640
Helena	C, Re, Sp	33-190	14-150	23-135	14-150*	76-259	7.1-7.7	93-395
Kalispell	Sp, W	145	148	107	148*	157	7.6	274
Miles City‡	Ri, W	60	70	33	68	422	8.2	663
Missoula	C	16	12	11	12*	22	7.5	27

Sources of Supply — B-brook, C-creek, L-lake, P-pond, Re-reservoir, Ri-river, S-stream, Sp-spring, W-well

Note: See explanation of *Table 13* on *page 39*.

*Total alkalinity approximated, as described in explanation of *Table 13*.

†Chloride (Cl) ion concentration in excess of 100 ppm.

‡Sulfate (SO_4) ion concentration in excess of 100 ppm.

TABLE 13—WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES (Contd)

STATE AND CITY	Source of Supply	Total Hardness as $CaCO_3$ (ppm)	Bicarbonate (HCO_3) as $CaCO_3$ (ppm)	Calcium (Ca) as $CaCO_3$ (ppm)	Total Alkalinity as $CaCO_3$ (ppm)	Dissolved Solids (ppm)	pH	Specific Conductance at 77 F (micromhos)
NEBRASKA								
Grand Island	W	189	136	155	136*	324	7.2	465
Lincoln	W	206-247	174-195	147-172	174-195*	310-396	7.8-7.3	500
Norfolk	W	310	254	234	254*	442	7.8	633
North Platte‡	W	326	206	248	206*	798	7.8	1100
Omaha	Ri	261	139	160	146	448	7.8	682
NEVADA								
Las Vegas	W	229	193	122	193*	266	7.6	439
Reno	Ri, C	40	24	24	24*	91	7.0	110
Winnemucca	W, Sp	224	234	150	234*	483	7.7	759
NEW HAMPSHIRE								
Berlin	B	10	7	8	7*	29	6.6	29
Concord	L	21	7	8	16	25	6.8	38
Keene	L	19	3	5	3*	20	7.2	25
Manchester	L	15	3	9	3*	36	6.5	44
Portsmouth	W	114-139	59-90	65-97	59-90*	153-191	7.1-7.5	204-231
NEW JERSEY								
Atlantic City	W, C	5	3	5	2	41	5.0	52
Bloomfield	Ri, Re	35	11	16	13	39	6.9	65
Camden	W	20-241	1-90	13-97	1-90*	59-460	4.6-6.8	80-444
East Orange	W	139	102	90	102*	194	7.8	304
Jersey City	Ri, Re	44	26	25	24	78	6.8	98
Newark	Ri, Re	33	11	19	14	44	7.3	66
Paterson	Ri, Re	50	23	30	25	86	7.4	—
Trenton	Ri	59	20	43	33	80	7.2	128
NEW MEXICO								
Albuquerque	W	85-116	133	60-85	133*	310-340	7.8	471
Roswell	W	588-664	179-194	420-468	179-194*	886-1160	7.8	1250-1740
Santa Fe	C, W	30-160	25-126	20-140	25-126*	58-217	7.9	72-347
NEW YORK								
Albany	C, Ri, Re	47	34	45	30	70	8.5	122
Binghamton	Ri	57	54	60	54*	91	7.2	153
Buffalo	L	124	89	90	90*	164	7.4	285
Cortland	W	168	139	132	139*	188	7.6	317
Glens Falls	S, Re	16	10	12	10*	29	6.7	41
Ithaca	C	92	38	55	66	96	6.7	163
Jamestown	W	103	82	80	82*	127	8.0	214
New York City	Ri, Re, C	20-50	7-30	13-32	7-30*	43-75	6.7-7.1	44-121
New York City	W	118-282	40-164	—	40-164*	202-392	6.3-7.7	260-432
Ogdensburg	Ri	131	94	95	94*	169	7.7	295
Oswego	L	140	94	105	94*	179	7.9	323
Rochester	L	79-130	48-90	55-95	48-90*	176	7.4	170-295
Schenectady	W	160	135	122	135*	197	7.7	342
Syracuse	L	109	94	85	94*	128	7.8	222
Watertown	Ri	52	58	68	36	124	7.1	201
NORTH CAROLINA								
Asheville	C, Ri	6	5	4	5*	19	5.8	19
Charlotte	Ri	20	15	17	19	45	8.6	75
Greensboro	C, L	33	39	30	36	70	8.6	104
Raleigh	C, L	30	16	24	27	61	9.2	100
Wilmington	Ri	42	25	28	28	68	8.0	116

Sources of Supply — B-brook, C-creek, L-lake, P-pond, Re-reservoir, Ri-river, S-stream, Sp-spring, W-well

Note: See explanation of *Table 13* on *page 39*.

*Total alkalinity approximated, as described in explanation of *Table 13*.

†Chloride (Cl) ion concentration in excess of 100 ppm.

‡Sulfate (SO_4) ion concentration in excess of 100 ppm.

TABLE 13—WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES (Contd)

STATE AND CITY	Source of Supply	Total Hardness as $CaCO_3$ (ppm)	Bicarbonate (HCO_3) as $CaCO_3$ (ppm)	Calcium (Ca) as $CaCO_3$ (ppm)	Total Alkalinity as $CaCO_3$ (ppm)	Dissolved Solids (ppm)	pH	Specific Conductance at 77 F (micromhos)
NORTH DAKOTA								
Bismark‡	Ri	90	39	70	72	244	8.8	338
Fargo	Ri	129	57	75	85	360	9.0	536
Grand Forks‡	Ri	81	37	90	67	248	9.4	363
Williston‡	Ri	137	73	102	55	374	8.9	553
OHIO								
Akron	Ri	119	59	83	69	136	8.3	225
Cincinnati	Ri	111	45	85	39	195	8.5	324
Cleveland	L	125	85	98	82	169	7.5	286
Columbus‡	Re, Ri, W	81	4	48-88	34	181-289	9.5-10.2	181-289
Dayton	W	358	284	226	284*	391	8.2	654
Lima	Ri, W	90	18	45	34	153	9.6	244
Sandusky	L	124	90	90	84	166	7.2	297
Toledo	L	146	113	127	89	228	7.8	378
Youngstown	C, Re	84	0	83	38	156	10.6	275
OKLAHOMA								
Ardmore	C, L	148	133	122	133*	181	7.7	313
Bartlesville	C, L	60	50	54	48	104	8.1	170
Oklahoma City	Ri, L	90	0	45	39	262	10.3	479
Tulsa	C, L	93	84	84	85	114	7.6	191
OREGON								
Baker	L, C	37	39	30	39*	56	7.4	80
Eugene	Ri	17	22	9	22*	48	7.5	51
Medford	Sp	35	46	18	46*	99	6.9	—
Pendleton	Sp, W	95	120	63	120*	203	7.2	—
Portland	Ri, Re	9	12	6	15*	30	7.0	—
Roseburg	Ri	43	27	38	27*	80	7.6	97
PENNSYLVANIA								
Altoona‡	S	228	0	50	0*	306	3.9	398
Bethlehem	C, Re	6	5	4	5	22	6.1	22
Erie	L	129	89	93	89*	177	7.8	300
Harrisburg	C, Re, Ri	33	7	9	11	24	8.1	33
New Castle	Ri	85	35	88	32	171	7.5	274
Oil City	W	83	61	65	61*	140	7.6	242
Philadelphia	Ri	52-152	10-25	35-60	22-31	84-151	6.2-6.6	145-238
Pittsburgh‡	Ri	75	2-38	100-150	7	373-554	6.3	569-822
Reading	C, L	87	39-76	50-87	60	102-152	8.0	204
Scranton	Re	26	5	20	5*	55	6.3	70
Williamsport	C	16	8	10	8*	24	6.7	37
RHODE ISLAND								
Pawtucket	Re	34	14	21	12	54	7.1	85
Providence	Re	27	11	22	15	52	9.4	75
SOUTH CAROLINA								
Charleston	C, Ri	21	19	17	17	68	8.4	119
Columbia	Ri	33	26	21	24	63	8.4	97
Greenville	S	1	15	3	15	30	8.4	45
SOUTH DAKOTA								
Huron	Ri	158	70	95	70*	384	7.3	559
Rapid City	Sp, W	193	173	107	173*	219	7.8	376
Sioux Falls‡	W	484	257	305	257*	646	7.6	921
TENNESSEE								
Chattanooga	Ri	62	30	48	58	88	7.6	138
Johnson City	Sp, C	61	57	33	46	70	8.5	122
Knoxville	Ri	112	71	95	71	188	7.8	275
Memphis	W	32-42	53-69	20-23	53-69*	84-98	7.4	119-145
Nashville	Ri	80	60	63	64	130	7.1	184

Sources of Supply – B-block, C-creek, L-lake, P-pond, Re-reservoir, Ri-river, S-stream, Sp-spring, W-well

Note: See explanation of Table 13 on Page 39.

*Total alkalinity approximated, as described in explanation of Table 13.

† Chloride (Cl) ion concentration in excess of 100 ppm.

‡ Sulfate (SO_4) ion concentration in excess of 100 ppm.

TABLE 13—WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES (Contd)

STATE AND CITY	Source of Supply	Total Hardness as $CaCO_3$ (ppm)	Bicarbonate (HCO_3) as $CaCO_3$ (ppm)	Calcium (Ca) as $CaCO_3$ (ppm)	Total Alkalinity as $CaCO_3$ (ppm)	Dissolved Solids (ppm)	pH	Specific Conductance at 77 F (micromhos)
TEXAS								
Abilene	L	194	192	100	185	361	8.2	640
Amarillo	W	258-549	236-360	80-145	236-360	372-530	7.4-7.8	511-799
Austin	Ri	71	14	28	46	220	9.9	412
Brownsville†‡	Ri	286	113	180	146	652	7.8	1,100
Corpus Christi	Ri, W	135	77	95	132	319	7.8	530
Dallas	L	67	14	48	39	184	10.4	331
Del Rio	Sp	218	206	185	206*	254	7.6	448
El Paso†‡	Ri, W	159	37	80	46	788	7.3	1,270
Fort Worth	L	130	129	113	117	203	7.8	374
Galveston†	W	115	275	75	275*	1,010	8.0	1,830
Houston	W	19-131	179-344	310	179-344*	298-576	7.5-8.0	475-1000
Palestine	W	7	185	5	185*	215	8.0	334
Port Arthur	Ri	50	57	25	45	211	8.3	348
San Antonio	W	182-240	144-200	125-162	144-200*	244-296	7.6-8.3	425-498
UTAH								
Logan	Sp	206	187	124	187*	202	8.1	365
Ogden	W, C	156-435	133-222	90-300	133-222*	188-1,120	7.5-8.1	334-2,070
Salt Lake City	W, C	75-233	49-203	55-192	49-203*	101-270	7.4-8.2	169-436
VERMONT								
Bennington	Sp	16	13	8	13*	27	7.2	40
Burlington	L	54	35	38	40	70	7.0	127
Rutland	B	42	33	24	33*	52	7.3	89
VIRGINIA								
Lynchburg	Ri, L	15	13	7	9	39	6.3	43
Norfolk	C, Re	61-78	40-44	65	36	111-134	8.0-8.3	169-205
Richmond	Ri	65	29	58	30	137	8.8	215
Roanoke	Sp, C, Re	18-133	15-124	9-68	12-130	28-127	7.5-9.5	39-228
WASHINGTON								
Seattle	Ri	18	18	16	18*	37	7.3	—
Spokane	W	118-161	103-143	73-97	103-143*	132-195	7.6-8.0	—
Tacoma	Ri, W	64-115	25-46	16-30	25-46*	64-115	7.1-7.8	—
Walla Walla	C, W	38	49	23	49*	89	7.6	102
Wenatchee	Ri	46	59	50	45	100	7.5	143
Yakima	Ri	21	25	15	25*	50	7.1	57
WEST VIRGINIA								
Bluefield	Sp, R	97	105	77	95	124	7.1	217
Charleston	Ri	37	16	24	21	52	9.0	89
Elkins	Ri	45	25	35	29	64	8.2	108
Huntington‡	Ri	70	25	98	30	239	8.4	374
Martinsburg	Sp	264	234	200	234*	279	7.5	468
Parkersburg‡	W	167	64	160	82	366	8.4	554
Wheeling‡	Ri	141	24	100	22	224	9.0	345
WISCONSIN								
Eau Claire	W	54	47	30	47*	86	7.4	122
Green Bay	W	208-272	159-225	125-150	159-225*	296-395	7.7-8.1	473-645
La Crosse	W	236-338	189-290	125-185	189-290*	290-362	7.3-7.8	433-576
Madison	W	300	275-345	137-234	275-345*	272-450	7.5	495-810
Milwaukee	L	128	103	85	104	152	7.5	265
WYOMING								
Casper‡	Ri	329	149	227	149*	615	7.7	869
Cheyenne	C, W	91	86	73	86*	134	7.8	207
Sheridan	C	26	28	17	28*	54	7.2	68

Sources of Supply – B-brook, C-creek, L-lake, P-pond, Re-reservoir, Ri-river, S-stream, SP-spring, W-well

Note: See explanation of Table 13 on page 39.

*Total alkalinity approximated, as described in explanation of Table 13.

+ Choloride (Cl) ion concentration in excess of 100 ppm.

++Sulfate (SO_4) ion concentration in excess of 100 ppm.

CHAPTER 6. DEFINITIONS

Definitions of the common terms used in water conditioning are presented here.

Algaecide is a substance used to kill algae.

Alkalinity[24] is expressed by the sum of the carbonate, bicarbonate and hydrate ions in water; other ions such as phosphate or silicate may contribute partially to alkalinity. Alkalinity is normally expressed as the number of parts per million (ppm) of calcium carbonate, $CaCO_3$. See further discussion on methyl orange and phenolphthalein alkalinities in *Chapter 1.*

Anode[24] is a positive electrode toward which negatively charged nonmetallic ions migrate and at which reduction occurs in an electrolytic cell. In corrosion processes, the anode is usually the electrode having a greater tendency to go into solution.

Biocide is a substance used to kill living organisms such as algae, bacteria and fungi. It may kill only one of these groups of organisms or only some specific bacteria, algae or fungi in these groups.

Biological Deposits[31] are water-formed deposits of biological organisms or the products of their life processes. These deposits may be microscopic in nature such as slimes, or macroscopic such as barnacles or mussels. Slimes are usually composed of deposits of a gelatinous or filamentous nature.

Bleed-off is the continuous ejection or draining of a portion of the concentrated water from a circulating system, which is replaced with water from the normal supply, thus causing a lowering of concentration. Bleed-off is normally expressed in gallons per minute (gpm).

Cathode[24] is a negative electrode toward which positively charged metallic ions migrate and at which reduction occurs in the electrolytic cell. In corrosion processes, the cathode is usually the electrode tending to resist corrosion.

Chlorinator is a device used to measure, dissolve, and feed liquid chlorine into a water system.

Closed Recirculating System is a system in which water flows in a repetitive (or continuous) circuit thru heat exchangers. There is no evaporation and no make-up except to compensate for leakage.

Corrosion[11] is destruction of a metal by chemical or electrochemical reaction with its environment. In the corrosion process, the reaction products formed may be soluble or insoluble in the contacting environment. Insolube corrosion products may deposit at or near the attacked area, or be carried along and deposited at a considerable distance away.

Cycles of Concentration is the ratio of dissolved solids in recirculating water to the dissolved solids in make-up water.

Delignification is the deterioration of lignin, the binding material which holds the cellulose fibers together in wood.

Dissolved Solids are in true solution in water and cannot be removed by filtration. Their presence is due to the solvent action of water in contact with the minerals in the earth.

Electrolyte is a solution thru which an electric current flows.

Erosion is the wearing away by action of rapidly moving water, particularly where entrained gas bubbles or suspended abrasive solids are present.

Free Mineral Acid may be sulfuric, nitric or hydrochloric acid, sometimes occurring in acid mine drainage or industrial waste.

Galvanic Corrosion[24] generally results from the presence of two dissimilar metals in an electrolyte. It is characterized by an electron movement from the metal of high potential (anode) to the metal of lower potential (cathode), resulting in corrosion of the anodic metal. Galvanic cell corrosion may also result from the presence of two similar metals in an electrolyte of nonuniform concentration.

Galvanic Series[12] is a list of metals and alloys arranged according to their relative potentials in a given environment.

Hardness is primarily the sum of calcium and magnesium salts in water, although it may include other elements, mainly aluminum, iron, manganese, strontium or zinc. Temporary or carbonate hardness is that portion of total hardness which can combine with the carbonate, CO_3, or bicarbonate, HCO_3, ions. The balance of the hardness is called noncarbonate or permanent hardness. This is principally caused by sulfates, chlorides and/or nitrates of calcium and/or magnesium (*Chapter 1*).

Inhibitor is a chemical substance added to a solution to reduce scale or corrosion or both.

Ion is an electrically charged atom or group of atoms.

Langelier Saturation Index is used to predict the scaling or nonscaling characteristics of a water. A plus value indicates scale-forming tendency; a negative value is nonscaling. The index is the algebraic difference between the actual *pH* from test and the calculated *pH* of saturation for calcium carbonate, $CaCO_3$. (See further explanation in *Chapter 2*.)

Make-Up Water is water from a normal supply which compensates for evaporation, windage and bleed-off losses.

Once-Thru System is a system thru which water passes only once and is discharged. There is no evaporation.

Open Recirculating System is a system thru which water flows in a repetitive circuit thru heat exchangers and reservoirs open to the atmosphere, such as cooling towers or air washers. Water is aerated and evaporated, or water vapor is condensed in the sprays. Some bleed-off is directed to the drain to limit a build-up of solids in the system.

Parts Per Million (ppm) represents the parts of a substance per million parts by weight of the solution. It is normally used to express the results of a water analysis. One ppm is equal to one ten thousandth of one percent (0.0001%).

pH represents the logarithm of the reciprocal of the hydrogen ion concentration of a solution. It denotes the degree of acidity or alkalinity of a solution. A value of 7.0 is neutral; values below 7.0 are increasingly acid; values above 7.0 are increasingly alkaline. Refer to *Chapter 1* for further discussions.

Ryznar Stability Index is a practical extension of the Langelier Saturation Index based on experience. This index (always positive) is equal to two times the calculated *pH* of saturation of $CaCO_3$ minus the actual *pH* from test. Index values above 6.5 indicate a corrosive tendency while values below 6.5 indicate a tendency to scale (*Chapter 2*).

Scale is a deposit formed from solution directly upon a confining surface. It is usually crystalline and dense, frequently laminated and occasionally columnar in structure.

Sludge[31] is a water-formed sedimentary deposit. It usually does not adhere sufficiently to retain its physical shape when mechanical means are used to remove it from the surface on which it is deposited. Sludge is not always found at the place where it is formed. It may be hard and adherent and baked to the surface upon which it has been deposited.

Specific Conductance is a measure of the ability of water to conduct an electric current. It is expressed as micromhos per cubic centimeter. A micromho is a millionth of a mho which in turn is the reciprocal of an ohm resistance.

Surface Active Agent is a substance that possesses stabilization characteristics tending to minimize deposition of calcium carbonate scale. A typical example are the polyphosphates.

Suspended Solids are solids not in true solution and can be removed from the water by filtration.

Synergizing Agent (water conditioning) is a substance which increases the effectiveness of a corrosion or scale inhibitor.

Titration is a process of adding a liquid of known concentration and of measured volume to a known volume of another liquid until a point is reached at which a definite effect is observed, usually a change in color of an indicator.

Total Solids are the sum of the dissolved and suspended solids.

Tuberculation[12] is the formation of localized corrosion products scattered over a surface in the form of knoblike mounds called tubercules.

Water Analysis is the chemical analysis of the dissolved materials in water. It also includes determination of pH and the amount of suspended solids.

Windage Loss is a loss of fine droplets of water entrained by circulating air. The amount varies with different types of equipment. This is a loss of water from the system and is replaced by make-up water. Windage loss tends to limit the cycles of concentration, and is usually expressed as a percentage of the rate of circulation.

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FIGURE PART 5 WATER CONDITIONING

TABLE PART 5 WATER CONDITIONING

TABLE. 13 – WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES (Contd)

TABLE. 13 – WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES (Contd)

TABLE. 13 – WATER ANALYSES FOR SUPPLIES IN UNITED STATES CITIES (Contd)