Table 8 .... Alkalinity Interpretation for Natural Waters

P Alk[a]	Carbonate	Bicarbonate	Free Carbon Dioxide
<0	0	= M Alk	Present
½M Alk[b]	= 2 P Alk	= M Alk − 2 P Alk	0
= ½M Alk	(= 2 P Alk (= M Alk	0	0
> ½M Alk[a]	= 2 (M Alk − P Alk)	0	0

[a] Treated waters only. Hydroxide also present.
[b] P Alk = Phenolphthalein Alkalinity.
[b] M Alk = Methyl Orange (Total) Alkalinity.

content of the water. The hardness, particularly the calcium is one of a group of factors which influence scale formation.

Alkalinity is a measure of the capacity of a water to neutralize strong acids. In natural waters, the alkalinity will almost always consist largely of bicarbonate, although there may also be some carbonate present. In treated waters, hydroxide, phosphate, and other constituents, if present, will be included to some extent in the alkalinity measurement. The alkalinity is another contributing factor toward scale formation. In water chemistry a rough qualitative interrelationship provides that factors which tend to increase scale formation also tend to decrease corrosion, and vice versa.

Alkalinity is measured using two different end-point indicators. The *phenolphthalein alkalinity* (or *P* alkalinity), roughly speaking, measures the strong alkali present. The *methyl orange alkalinity* (or *M* alkalinity), also called the *total alkalinity*, measures all of the alkalinity present in the water. Note carefully that the total alkalinity includes the phenolphthalein alkalinity. For most natural waters, in which the concentration of phosphates, borates, and other noncarbonate alkaline materials is small, the actual chemical species present may be estimated from the two alkalinity measurements, as shown in Table 8.

pH is often confused with alkalinity or acidity. Such confusion may be avoided by keeping in mind that the *pH* is essentially an intensity factor (strength of acidity or alkalinity present), whereas the ppm of alkalinity or acidity is a quantity measurement (amount of alkalinity or acidity present). A rough parallel to this may be seen in a hydraulic system in which pounds per square inch is an intensity factor and gallons is a quantity factor.

Generally, lower *pH* waters tend to be more corrosive and higher *pH* waters tend to be more scale forming, although many other factors affect both properties.

The *total dissolved solids* content of a water will also affect both corrosion and scale formation. Higher dissolved solids tend to increase scale formation. The effects upon corrosive tendencies are ambivalent. Because low solids waters have less tendency to deposit scale, they are generally corrosive. On the other hand, a high solids water which is nonscaling will tend to produce more intensive corrosion because of its high conductivity.

Sulfates also contribute to scale formation in high calcium waters. Calcium sulfate scale, however, forms only at much higher concentrations than the more common calcium carbonate scale. High sulfates also contribute toward increased corrosion because of their high conductivity.

Chlorides have no effect upon scale formation but do contribute toward corrosion because of their conductivity and because the small size of the chloride ion permits the continued flow of corrosion current when surface films are porous.

Chlorides are a useful measuring tool in evaporative systems. Virtually all other constituents in the water increase or decrease as a result either of the addition of common treatment chemicals or of chemical changes which take place in the normal operation of the water system. With few exceptions, chlorides are changed only by evaporation, so that the ratio of chlorides in a water sample from an operating system to those of the makeup water provides a measure of the number of times that the water has been concentrated in the system.

Sodium, potassium, and nitrate contribute to corrosion problems only through their conductivity.

Iron can form heat-insulating deposits by precipitation of iron hydroxide. Technically, this is not a scale, but a water-formed deposit.

Silica can form particularly hard to remove scales if permitted to concentrate sufficiently. Fortunately, silicate scales are far less common than others.

In addition to dissolved solids, waters, particularly unpurified waters from surface sources or those which have been circulating in open equipment, frequently contain *suspended solids*, both organic and inorganic. Organic matter in surface supplies may be present as colloidal solutions. Natural coloring matter is usually in this form.

Biological Characteristics. Bacteria, algae, and fungi are present in many waters and their growth can cause operating problems. The usual bacteriological examination of water for sanitary purposes establishes the probable presence or absence of pathogens. In cooling systems, nonpathogenic organisms are more important as causes of operating difficulties. Living organisms are rarely a problem in heating systems because of the sterilizing action of higher temperatures. Bacteriological tests of the water are seldom satisfactory diagnostic tools for biological problems in industrial systems. Examination of deposits taken from the equipment is generally more useful in the selection of proper preventive measures.

Heating and Cooling Water Systems

In order to evaluate the probable effects on a system of a water supply or, more important, the boiler water or circulating water, the water treatment specialist needs, in addition to the actual or anticipated water analysis, much additional information. This includes data on the size, construction, operating pattern, and other characteristics of the system. Therefore, a review of the various types of water-containing systems utilized for heating or cooling, together with some of the changes occurring in these systems that influence water-caused difficulties, would be helpful.

All heating and cooling systems, of course, involve a temperature change and this influences the rates at which water-caused problems can develop.

In steam heating systems, the concentration of dissolved solids in the boiler water will increase as boiler water is converted to steam. In the ordinary space heating system this change is limited because substantially all of the steam is, or should be, condensed and returned to the boiler. On the other hand, the nature of the water changes taking place within the boiler are drastically altered if the percentage of condensate returning to the boiler is reduced for any reason. The condensate itself has characteristics quite different from those of the boiler water, because it is substantially free of any dissolved solids and creates different problems when there is an opportunity to dissolve air or carbon dioxide.

In hot water heating and other closed circulating systems, there should, in theory, be no water-caused problems because there should be virtually no makeup water and no opportunity for significant changes in the composition of the water within the system. Experience has shown, however, that a

substantial proportion of such systems do not behave in accordance with this theory[15] and the need for water treatment in both ordinary hot water heating systems and high temperature hot water systems is now commonly accepted by engineers.

Like hot water heating systems, closed cooling systems (chilled water, chilled-hot water, brine, or glycol) perform differently in practice than in theory. As a result, treatment of the circulating water or solution in these systems is desirable.

Condensers and other heat exchangers in refrigeration and air-conditioning systems may be cooled by water passing through the equipment and going to waste. In such cases, the water-caused problems will be directly related to the chemical composition of the cooling water. As a result of increasing water shortages, such once-through cooling is becoming less common and is being replaced by open circulating systems which use cooling towers, evaporative condensers, or spray ponds. In these, the makeup water composition is drastically changed as a result of evaporation, aeration, and other chemical and physical processes which depend upon the contaminants present in the air to which the water is exposed in the open circuit.

Humidification and dehumidification equipment presents several types of water problems. During humidification, water circulating in the equipment is subjected to essentially the same exposure conditions and composition changes as those which take place in open circulating systems. During dehumidification, however, there is a combination of dilution, which may result in a water as low in dissolved solids as is steam condensate, plus exposure to aeration and the scrubbing of contaminants from the air.

Materials of Construction. The seriousness of corrosion in heating and cooling systems will depend, in part, upon the nature of the materials of construction present, their degree of proximity, their relative areas and other physical factors, as well as the chemical composition of the water.[6]

Ferrous metals comprise the largest single group of materials used for the construction of heating and cooling systems. Steel is used for structural elements, boiler drums and tubes, condenser shells, and many other components. Cast iron is used for low pressure boilers, convectors, and condenser heads, etc. Galvanized steel is a common component of the smaller sizes of cooling towers, evaporative condensers, humidifiers and dehumidifiers. Various alloy steels are also used in these systems.

Copper tubes are widely used in air conditioning and refrigeration condensers and in heating system exchangers, but tubes of modified brasses such as admiralty, stainless steel, mild steel, aluminum, and cupronickel are also employed. Tube sheets may be made of steel, Munts metal, or other alloys.

Nonmetallic materials of construction are used as well. Large cooling towers are usually constructed of wood and smaller cooling towers may include a considerable amount of asbestos-cement siding or fill. Various plastics are being used more extensively in the construction of smaller cooling towers.

Water-Caused Troubles

The operator of a heating or cooling system becomes aware of water-caused troubles with the appearance of one or more of three symptoms, each of which may also be produced by causes other than the water. Several different conditions may act together in the production of any given symptom.

The first of these symptoms is a reduction in heat transfer rate. In this case, the formation of an insulating deposit on a heat transfer surface generally significantly reduces the cooling or heating capacity of the equipment. The second symptom is reduced water flow, which results from a partial or complete blockage of pipe lines, condenser tubes, or other openings. The third symptom is damage to, or destruction of, the equipment. This may result from corrosion of metals or deterioration of wood or plastics. It may also be caused by excessively rapid wear rates of moving parts, such as pumps, shafts, or seals.

Corrosion contributes to all three symptoms. Heat transfer rates can be reduced and water flow blockages can be created by deposits of corrosion products. The damage or destruction of equipment is most often the result of metallic corrosion and the somewhat parallel phenomenon of wood delignification.

Scale formation also contributes to all three symptoms. Even a small buildup of scale on a heat exchange surface will reduce heating or cooling capacity. Further buildup will reduce water flow. Finally, scale buildup in boilers may continue until it reaches the point at which heat transfer is so low that the metal overheats permitting rupture of tubes under the operating pressure. Scale particles can also accelerate the wear of moving parts.

Biological growths, such as slime, can act as insulators to reduce cooling capacity. Algae growths often accumulate to the point at which they interfere with water flow in cooling towers. The poultice effect created by accumulations of organic matter can cause localized corrosive attack resulting in premature equipment failure. Wood destruction, too, can occur as a result of fungus action.

Suspended solid matter, such as dirt scrubbed from the air or finely divided mill scale, can also contribute to all three symptoms. Deposits of such material can reduce heat transfer or reduce water flow depending upon where they accumulate. Like local deposits of organic matter, such dirt deposits tend to localize corrosion and, of course, suspended solids cause rapid wear of moving parts.

Water Treatment

General Considerations. The complexity of water-caused problems and their correction in heating and cooling systems makes it important to obtain the advice of a water treatment specialist as early as possible in the design stage of any system and to follow his advice regularly thereafter during design, construction, and operation. Often, factors considered to be irrelevant by the layman are actually quite important in securing effective protection against operating troubles. The improper use of water treatment chemicals can even result in the development of problems more serious than those which would have occurred had no treatment at all been used.

More than one solution is frequently possible for the same water treatment problem. The selection from among various alternatives may be dictated by economic considerations or by considerations such as available space or labor. In any event, it cannot be emphasized too strongly that the choice of a water treatment program for any given system should be made only after due consideration of the various factors mentioned in this chapter. It is important to carry out the selected treatment program diligently. No water treatment program can be any more effective than the consistency and control with which it is applied.

The use of chemicals for water treatment, as for other applications, involves certain safety considerations with which building, operating, and maintenance personnel are not ordinarily familiar. It is important that the potential safety hazards associated with any particular water treatment chemical or program be well understood beforehand, that suitable safety rules be formulated, that appropriate safety