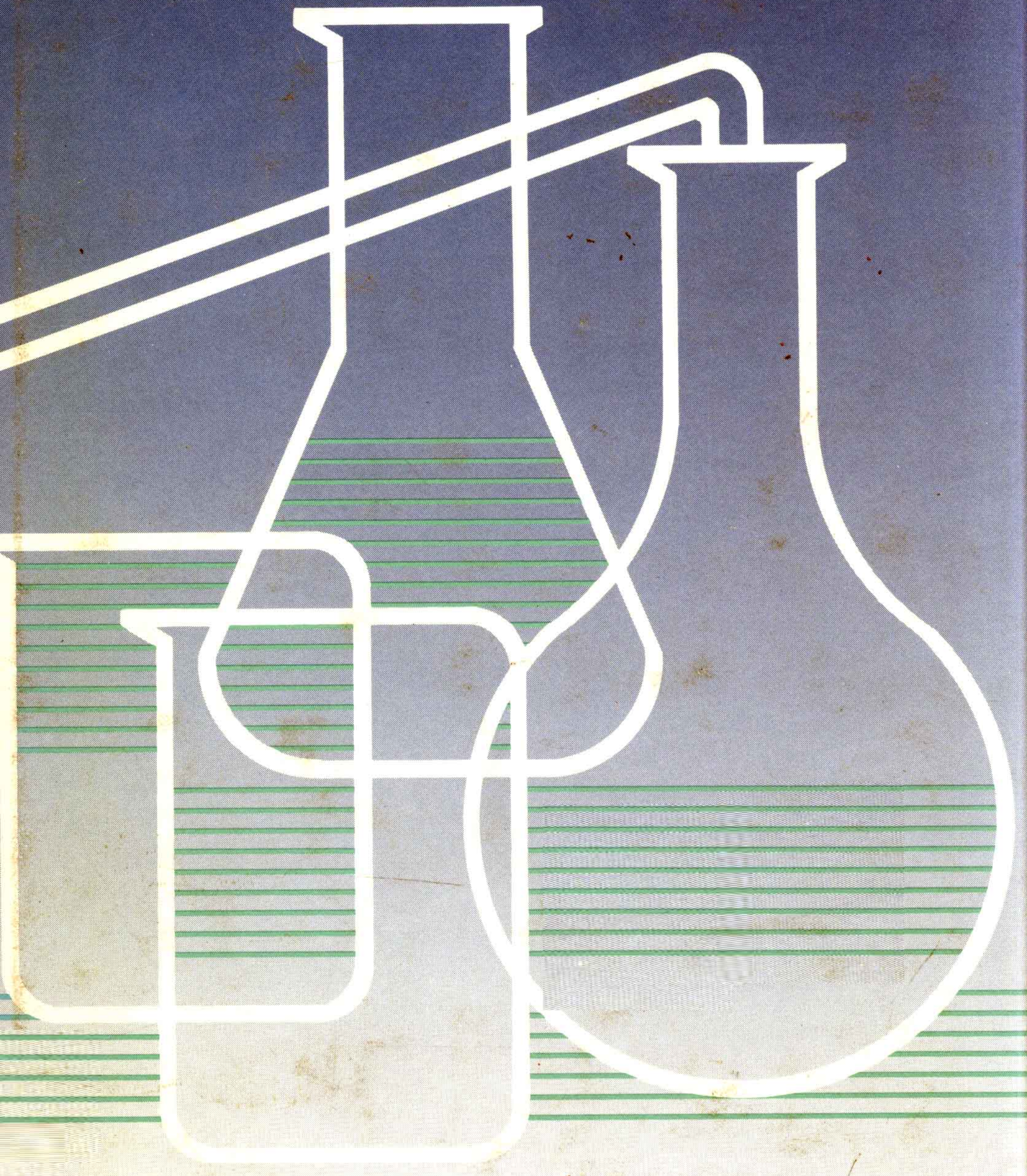
High-Quality Industrial Water Management Manual



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Foreword

This is not a text on water treatment. There are no guides contained describing specifically how to modify water. This is, however, a sourcebook that describes the kinds of problems encountered with water, where to look for answers, how to recognize the potential of water for specific uses. Above all, it is a manual to provide information to executives and operators regarding the management of water resources.

Water, a compound of hydrogen and oxygen, is, in its pure state, a tasteless, odorless, colorless liquid. In its normal, less than pure state, it constitutes our rivers, lakes, oceans, ground aquifers, and rain. It is our most universal compound without which there would be no life as we know it, on earth, and very little chemical activity. In this text, we are interested in biological and industrial uses. While the role of water in industry is less important than its role in supporting life, where it is indispensable, it is both ironic and fortunate that industry requires the chemically purer water.

With the expansions of urban centers in populated areas, and the proliferation of industry in the same areas, it is becoming more and more difficult to find water of the quality and quantity needed to adequately supply the combined biologic and industrial requirements. Impurities in the water can result in ill health in humans and animals, and in corrosion, fouling and failure of equipment in industry. The degree to which natural water must be treated to become suitable for its varied uses, is the subject of past and present concern.

Management of water resources is a very broad subject that cannot be treated comprehensively in any one volume such as this text. This manual, however, is intended to provide plant managers and engineers with an appreciation of water quality related problems, and with some techniques for providing acceptable solutions to these problems.

Virtually every industry, in some way, requires or benefits from properly treated water for use as a solvent, cleaning medium, heat exchange agent, thermodynamic fluid, ingredient, or catalyst.

It would be difficult to find a product or a process, to which tainted water would not be detrimental. Rayon, cotton, silk, wool, glass, paper, leather, hard and soft beverages, ice, pharmaceuticals, electronics, ceramics, plastics, and innumerable other products, all require water in their manufacture. And in processes, such as metal-plating, laundering, food preparation, mirror silvering, television tube production, and photography, water quality is equally important—just as it is in steam plants, engines, and power plants.

For chemically acceptable water, all of these depend on water treatment. Water treatment to remove or alter the character of impurities is an essential process without which the industrial progress of the past century would have been impossible.

This text contains a discussion of water-related problems and their mitigation with respect to all these uses. The reader may note some duplication of information. This is useful to present the material from more than one viewpoint.

There are also some older articles included. This has been done because the information is so well presented that the reader may gain insight into the way in which different problems are related.

Contents

1

Overview

Water, in the various aspects of the hydrologic cycle, is indeed the basis for all life on the planet. The primordial soup in which life first originated was largely water. Today, animal and vegetable life are sustained by this essential fluid. Next to air, water is the substance with which we are most intimately acquainted. It is a solvent without equal. Because it is so familiar, we readily overlook the fact that it is a unique substance. Behaving unlike any other liquid, it has the rare property of being denser as a liquid than as a solid, being most dense at 4 degrees Celsius; this property makes it possible for fish to exist at the lower levels of a frozen pond, since water at the bottom normally does not freeze.

The elements of which water is composed—oxygen and hydrogen—are chemically exceptional. Both are unusually reactive. Pure water, chemically labelled as H_2O, is the product of the combination of two hydrogen atoms (H_2) and one oxygen atom (O). The H_2O molecules are joined together so that, in effect, the whole mass of water in a vessel can be considered to act as a single molecule. Because of this bonding, one might expect the viscosity of water to be unusually high. Not so, however, since each hydrogen bond is shared, usually between two other molecules, and one of these bonds is easily broken.

Water rarely exists in a pure form. All natural waters contain varying amounts of dissolved and suspended matter. The type and amount of matter in water varies with the source. The pure form probably is represented by the moisture in clouds. When moisture is precipitated as rain, however, on the way down it collects atmospheric dust, carbon dioxide, and atmospheric gases, chiefly oxygen and nitrogen. Water on the surface picks up organic material from plant life, as well as various microorganisms. Percolating through the soil, it dissolves and picks up in suspension and solution many minerals. Even ground water may absorb volatile organic material. Consider that eons ago, when the oceans were new, all water was fresh. In the ensuing billions of years, minerals leached out of the soil and were washed down into the oceans. Common ocean water contains about 32,000 parts per million (ppm) of minerals, the largest component being sodium chloride (common salt). A lesser content of dissolved salt, say about 7,000 ppm, is termed "brackish."

Solid material dissolved in water does not always retain its molecular status. It may break up into its constituent atoms, which are then known as "ions." Each ion, characterized by an electrical charge, called "valence," is either positive (+) or negative (−). Negative charges are called "cations," while positive ions are termed "anions." When removed from water, the various ions unite in combinations which result in a net electrical charge of zero. For instance:

Cations	*Combination*	*Anions*
Hydrogen, H, +1	H_2O	Hydroxide, OH, −1
Sodium, Na, +1	NaCl	Chloride, Cl, −1

There are many other examples of chemical combinations. The exact numbers of participating ions can be worked out on the basis of experience and analysis. It should be noted that all ions are not single atoms. Frequently combinations develop, such as the hydroxide ion, which is more commonly referred to as a "radical." Other radicals may be HCO_3, the bicarbonate radical, CO_3, and a host of others.

Suspended solids are those which are not dissolved in water and can be removed by settlement or filtration. Examples are mud, silt, clay, and metallic oxides. Dissolved solids are those in solution which cannot be removed by ordinary filtration or settlement. Major dissolved materials in water are silica, iron, calcium, magnesium, potassium, and sodium, in various compounds. Metallic constituents occur as bicarbonate, carbonate, sulfate, and chloride radicals.

Practically all commercial, industrial, and sanitary processes require water. The grade or purity may vary, depending on the ultimate use, but almost all commercial and industrial uses require some degree of treatment for optimum process use. High-purity water is required for activities such as steam generation and manufacturing processes. Relatively high concentrations of impurities can be tolerated for many uses, if the user is willing to accept the concomitant problems. For example, relatively high concentrations may be found in open cooling water recirculating systems. High levels of impurities, however, in cooling water systems can result in serious operating problems: deposit formation in heat exchangers, corrosion of metals, biological fouling, and wood deterioration in cooling towers. To minimize such problems significant costs may be incurred for internal chemical treatment.

Water treatment methods, therefore, require attention since:

- contamination cannot be tolerated in many processes;
- energy conservation benefits can result from appropriate treatment;
- the frequency of operational problems and the need for repairs caused by "bad" water can be significantly reduced;
- environmental pollution that may result from water treatment system discharges must be addressed;
- in nuclear uses, radiation may occur from irradiated solids in the water; and
- water treatment requirements and treatment programs for steam generators, air compressors, engines, condensers, cooling towers, and refrigeration systems are usually poorly defined.

In general, the processes that subject water to the greatest temperatures and pressures usually require the highest quality of water. Note the specific uses, in decreasing order of required purity are:

- electronic manufacturing processes, medical and nuclear uses;
- high pressure steam plants;
- industrial process systems;
- medium and low pressure steam systems;
- human uses; and
- open recirculating cooling water and cooling tower systems.

The direct results of poor quality water are corrosion, fouling, and scale deposits. All water-related problems stem from these factors.

Corrosion is an electrochemical process that dissolves metal. Deterioration and deposits caused by corrosion can result in failure of essential components such as boiler tubes, steam lines, air compressor coolers, and cooling water systems, to name but a few of the systems affected. Problems that result from inadequate water treatment, or improper treatment, are the cause of significant costs in avoidable repair work and equipment downtime.

Scale deposits are solids and organic growths that adhere to all surfaces wetted by the water, such as boiler tubes. In a heat transfer application, as in a heat exchanger or a boiler tube, scale acts as an insulator and reduces the rate of heat transfer. Refer to Figure 1-1. Inhibiting heat transfer causes two problems: loss of efficiency, with resulting increase in fuel consumption, and possible elevation of tube temperatures to the point where the metal weakens, and the tube ruptures. Scale build-up also increases pressure drop, and decreases water flow in a pipe. This clogging effect results in an increase of pumping power required to circulate the water, again with loss of efficiency.

Figures 1-2 through 1-5 illustrate corrosion and scale problems in steam plants and cooling tower components. Table 1-1 displays difficulties caused by water impurities, and means of treatment. Table 1-2 illustrates general problems caused by impurities in water with regard to specific uses. Table 1-3 generically illustrates the treatment of water from rivers, ponds, and wells.

Various degrees of water quality are required by specific uses. Figure 1-6 indicates the grade required for various uses, based on conductivity. Figure 1-7 illustrates the molecular/atomic spectrum of water impurities, and indicates the type of equipment used for removal of dissolved and particulate solids.

The impurities which must be removed from water depend, naturally, upon the water source, and the intended uses. All raw water, whether drawn from wells, rivers, lakes or other sources, contains chemical and bacterialogical contaminants, dissolved and suspended solids washed from the land, from sewer outlets, factory drainage, or dissolution of plant material in marshes and swamps.

Inland waters differ from those in coastal regions; well water is different from river water, and river water from lake water. Two plants along the same body of water, perhaps separated by a few miles, may have water supplies of very dissimilar characteristics. Even the concentration and character of dissolved material may vary with changing seasons and weather in the same locality. Often raw water must be filtered, softened, as a minimum treatment, and perhaps dealkalized. In certain areas, sulfides and fluorides must be removed. Iron products are very common. In recent years, in many industrial locations, ground water has become contaminated with volatile organic compounds (VOC). For the most sophisticated uses, all ions must be removed by deionization, reverse osmosis, or some combination of treatments.

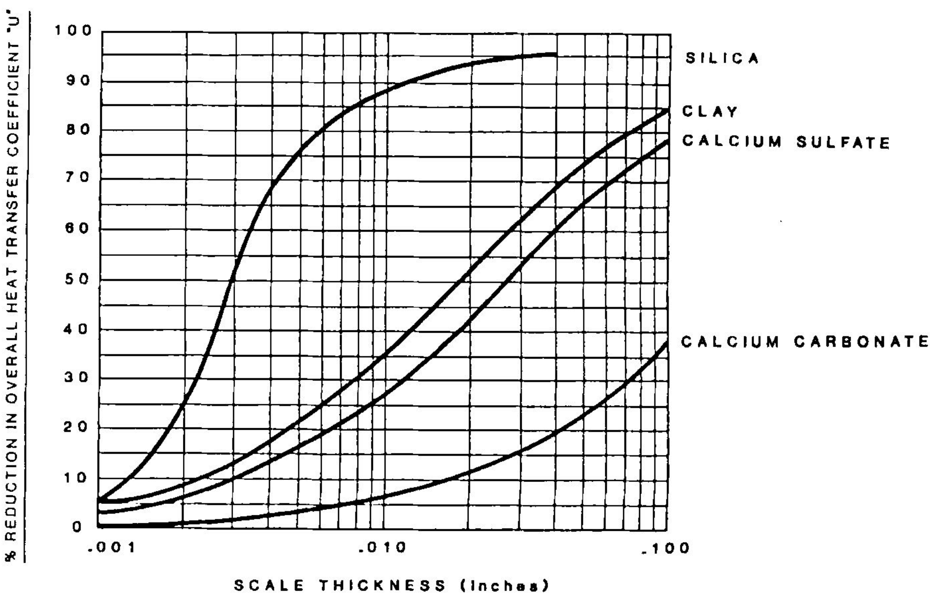

Figure 1-1. Influence of Scale on Heat Transfer

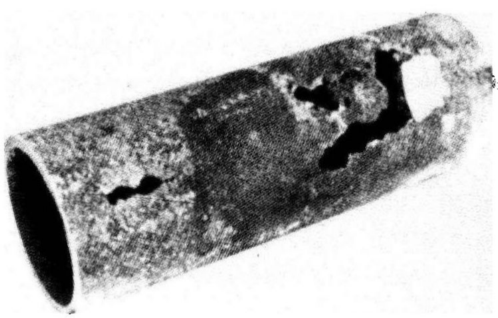

Figure 1-2. Section of Condensate Line Destroyed by Carbon Dioxide (Low ph) Corrosion. Metal destruction, resulting in thinning, is spread over a relatively wide area.

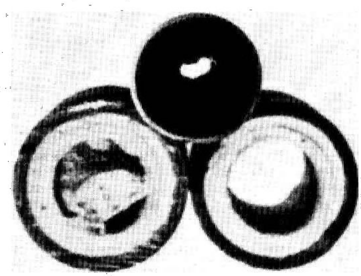

Figure 1-3. Scale Build-Up in Cooling Water Lines (High pH)

Figure 1-4. Calcium Phosphate Scale on Cooling Tower Fill Members

Figure 1-5. Tube Blister Due to Periodic Overheating
Note fissure and creep cracks, typical result of alternating overheating and cooling.

Table 1-1. Difficulties Caused by Water Impurities

Constituent	Chemical Formula	Difficulties Caused	Means of Treatment
TURBIDITY	None—expressed in analysis as units.	Imparts unsightly appearance to water. Deposits in water lines, process equipment, etc. Interferes with most process uses.	Coagulation, settling and filtration.
COLOR	None—expressed in analysis as units.	May cause foaming in boilers. Hinders precipitation methods such as iron removal and softening. Can stain product in process use.	Coagulation and filtration. Chlorination. Adsorption by activated carbon.
HARDNESS	Calcium and magnesium salts expressed as $CaCO_3$.	Chief source of scale in heat exchange equipment, boilers, pipe lines, etc. Forms curds with soap. Interferes with dyeing, etc.	Softening. Demineralization. Internal boiler water treatment. Surface-active agents.
ALKALINITY	Bicarbonate (HCO_3), carbonate (CO_3), and hydrate (OH), expressed as $CaCO_3$.	Foaming and carryover of solids with steam. Embrittlement of boiler steel. Bicarbonate and carbonate produce CO_2 in steam, a source of corrosion in condensate lines.	Lime and lime-soda softening. Acid treatment. Hydrogen zeolite softening. Demineralization. Dealkalization by anion exchange.
FREE MINERAL ACID	H_2SO_4, HCl, etc. expressed as $CaCO_3$.	Corrosion.	Neutralization with alkalies.
CARBON DIOXIDE	CO_2	Corrosion in water lines and particularly steam and condensate liens.	Aeration. Deaeration. Neutralization with alkalies.
pH	Hydrogen ion concentration defined as $pH = \mathrm{Log}\frac{1}{(H+)}$	pH varies according to acidic or alkaline solids in water. Most natural waters have a pH of 6.0-8.0.	pH can be increased by alkalies and decreased by acids.