Water Treatment for HVAC and Potable Water Systems

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To my wife, Conny

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Preface

It is the object of this book to present the current technology of water treatment for corrosion and deposit control in commercial and industrial heat-transfer equipment, with specific emphasis on heating, ventilating, and air conditioning (HVAC) systems. These include air-conditioning chillers, cooling towers, evaporative condensers, closed-circuit coolers, chilled-water systems, hot-water heating systems, steam boilers, and service-water-supply systems. The aim is to inform design engineers, operating engineers, and building managers and operators of the "why," "what," and "how" of water treatment.

The first section outlines the reasons why water treatment is necessary for efficient and energy-saving operation as well as for prevention of equipment failure and costly maintenance, repair, and replacement. It delves into why and how water is the root cause of these costly problems.

The next portion of the book covers corrosion and deposits in detail and their causes and mechanisms; this information aids in understanding the solutions to the problems.

The final chapters describe the solutions—the current cures and preventive maintenance procedures—available for avoiding these problems and maintaining the equipment at peak energy efficiency

I sincerely thank the staff and officials of Metropolitan Refining Co., Inc , for their encouragement in this work and permission to use Company photographs, drawings, and facilities. I am especially grateful to Benedict S. Seidman, President, for his editorial assistance; to Bernard E. Zolit, Vice President, Technical Director, to my predecessor, William J Covney (deceased), and to all my associates who, over the years, have provided the education, guidance and inspiration which made this work possible, to my wife, Conny, and various friends for typing the manuscript, and to Richard J Reilly of Jaros, Baum & Bolles, Consulting Engineers, for his very careful review of the manuscript which provided valuable suggestions.

Richard T. Blake

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Chapter One

Why Water Treatment?

Water treatment for corrosion and deposit control is a specialized technology. To understand it thoroughly requires some knowledge of the sciences of chemistry, physics, biology, and engineering. Essentially, it can be understood when one first recognizes why treatment is necessary to prevent serious failures and malfunction of equipment which uses water as a heat-transfer medium. This is more easily seen when one observes (1) the problems water can cause, (2) the mechanism by which water causes these problems, and (3) the actual solutions or cures available to prevent the problems.

Water is a "universal solvent." Whenever it comes into contact with a foreign substance, there will be some dissolution of that substance. Some substances will dissolve at faster rates than others, but in all cases a definite interaction occurs between water and whatever it contacts. Because of this interaction, problems occur in equipment such as boilers or cooling-water systems in which water is used as a heat-transfer medium. In systems open to the atmosphere, corrosion problems are made worse by additional impurities picked up by the water from the atmosphere.

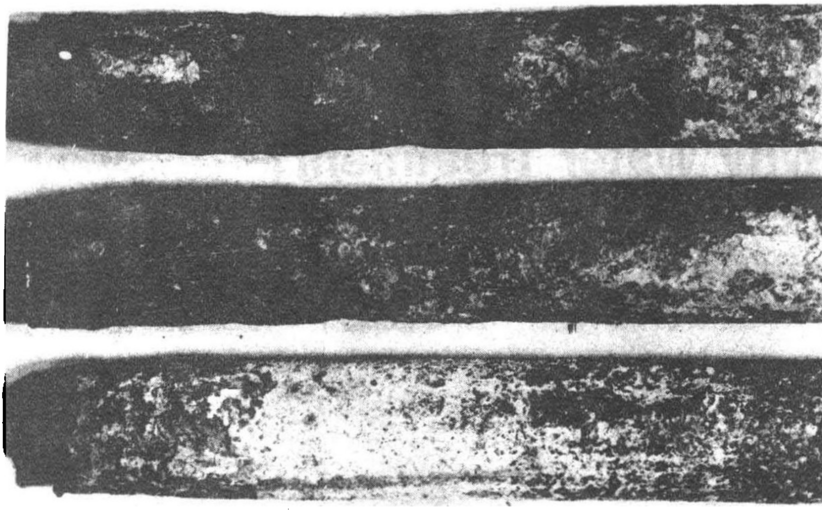

FIG. 1-1 Corrosion on boiler tubes. (*Babcock & Wilcox Co.*)

Most people have seen the obvious examples of corrosion of metals in contact with water and the devastating effect corrosion can have. Corrosion is the sole cause of failure and costly replacement of equipment and is itself a good reason why water treatment is necessary. In a report by the National Bureau of Standards, it has been estimated that in the United States alone the loss caused by corrosion of metals is $70 billion annually.[1] In November 1977, R. H. Hausler reported to the National Association of Corrosion Engineers that the annual cost of corrosion is $50 billion. The direct losses for replacement and protection are reported to be $10 to $15 billion annually; and over $5 billion is spent for corrosion-resistant metallic and plastic equipment, almost $3 billion for protective coatings, and over $340 million for corrosion inhibitors.[2]

Typical examples of these losses resulting from failures of piping, boiler equipment, and heat-exchanger materials because of corrosion and deposits are depicted in Figs. 1-1 to 1-3. These examples clearly demonstrate the cost of corrosion and deposits. Without careful attention to water treatment, losses due to equipment failure can be substantial. Only with correct application of corrosion inhibitors

[1] R. W. Staehle, Editorial, *Corrosion (Houston)*, June 1978, p. i.

[2] R. H. Hausler, "Economics of Corrosion Control," *Mater. Perform.*, June 1978, p. 9.

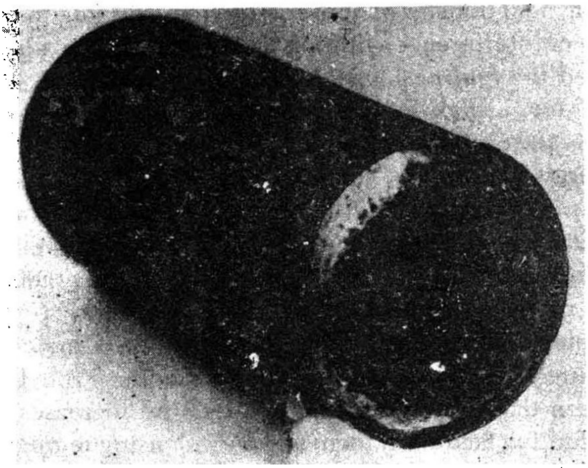

FIG. 1-2 Corrosion product accumulation in pipeline. *(Metropolitan Refining Co., Inc.)*

and water treatment will HVAC equipment such as heating boilers and air-conditioning chillers and condensers provide maximum economical service life. Even more costly than failures and replacement costs, however, and less obvious, is the more insidious loss in energy and operating efficiency caused by corrosion and deposits.

In heat-transfer equipment, corrosion and deposits will interfere

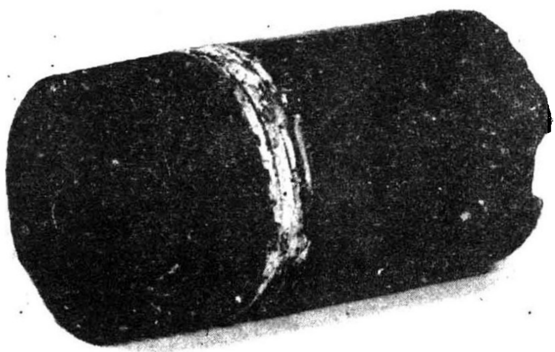

FIG. 1-3 Pipeline corrosion failure at threaded joint. *(Metropolitan Refining Co., Inc.)*

with the normal efficient transfer of heat energy from one side to the other. The degree of interference with this transfer of heat in a heat exchanger is called the *fouling factor*. In the condenser of an air-conditioning machine, a high fouling factor causes an increase in condensing temperature of the refrigerant gas and in turn an increase in the energy required to compress the refrigerant at that higher temperature. The design fouling factor for air-conditioning chillers and condensers is 0.0005. This means that the equipment cannot tolerate deposits with a fouling factor greater than 0.0005 without seriously reducing the efficiency of the machine.

Figure 1-4 graphically illustrates the effect of scale on the condensing temperature of a typical water-cooled condenser. From this chart it can be seen that the condensing temperature increases in proportion to the fouling factor. An increase in condensing temperature requires a proportionate increase in energy or compressor horsepower to compress the refrigerant gas. Thus the fouling factor affects the compressor horsepower and energy consumption, as shown in Fig. 1-5.

Condenser tubes are quickly fouled by a hard-water supply, which deposits calcium carbonate on the heat-transfer surface. This type of fouling and its mechanism will be explained in a later chapter.

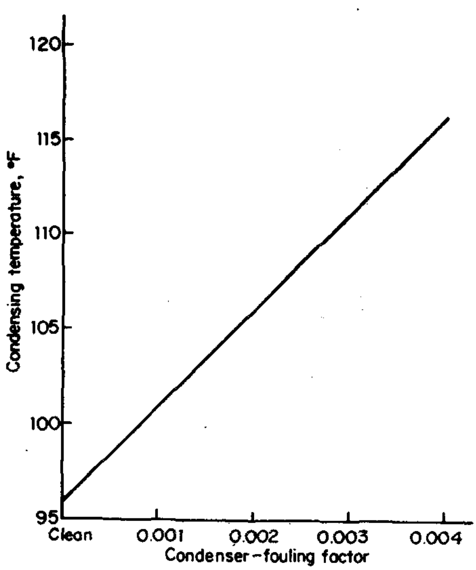

FIG. 1-4 Effect of scale on condensing temperature. *(Carrier System Design Manual, Part 5: Water Conditioning, Carrier Corporation, 1968, p. 5-2. Used by permission.)*

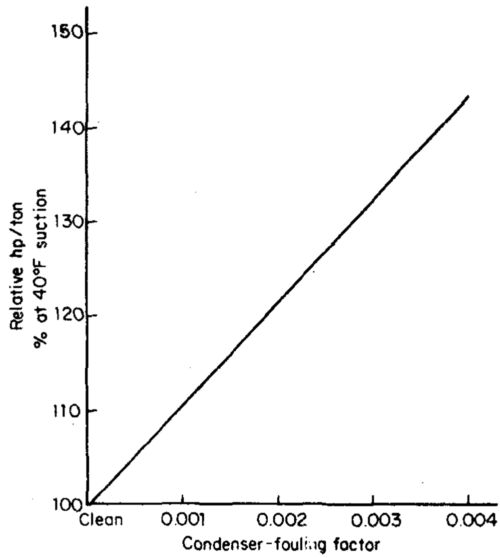

FIG. 1-5 Effect of scale on compressor horsepower. *(Carrier System Design Manual, Part 5: Water Conditioning, Carrier Corporation, 1968, p. 5-2. Used by permission.)*

Table 1-1 lists the fouling factors of various thicknesses of a calcium carbonate type of scale deposit most frequently found on condenser water tube surfaces when no water treatment (or incorrect treatment) is applied. The additional energy consumption required to compensate for a calcium carbonate type of scale on condenser tube surfaces of a refrigeration machine is illustrated in Fig. 1-6. The graph shows that a scale thickness of only 0.025 in (fouling factor of 0.002) will result in a 22 percent increase in energy consumption, which is indeed wasteful.

TABLE 1-1 Fouling Factor of Calcium Carbonate-Type Scale

Approximate thickness of calcium carbonate–type scale (in)	Fouling factor
0.000	Clean
0.006	0.0005
0.012	0.0010
0.024	0.0020
0.036	0.0030

SOURCE: *Carrier System Design Manual,* Part 5: *Water Conditioning,* Carrier Corporation, 1968, Syracuse, N.Y., p. 5-3. Used with permission.

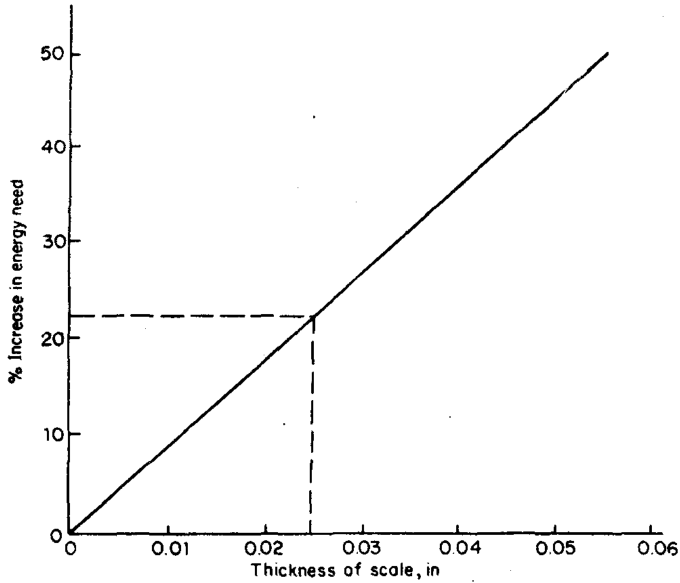

FIG. 1-6 Effect of condenser-tube scale on energy consumption. $K = 1.0$ Btu/(h · ft²)(°F · ft). Example: Scale that is 0.025 in thick requires 22 percent increase in energy.

Cost of Scale

The actual cost of scale is even more surprising. For example, it can be demonstrated that a 500-ton air-conditioning plant operating with a scale deposit of 0.025 in of a calcium carbonate–type scale will cost $2376 in additional energy consumption for only 1 month of operation, or 720 hours (h). The most efficient electric drive air-conditioning machine will require 0.75 kilowatts (kW) per hour per ton of refrigeration for compressor operation. The average cost for this energy in early 1979 was 4¢ per kilowatthour (kWh). (In New York City the cost was 7.5¢/kWh.) Therefore the cost of the electrical energy required to drive a compressor for a 500-ton air-conditioning machine can be calculated as follows:

500 tons × 0.75 kW/ton = 375 kW

375 kW × 720 h = 270 000kWh

270 000 kWh × 4¢/kWh = $10,800

The graph in Fig. 1-6 shows that a deposit of 0.025 in of scale increases energy requirements by 22 percent if the same refrigeration load is maintained. The increased energy cost is then:

$10,800 × 0.22 = $2376/month

This example illustrates what can result when water treatment is neglected. Energy costs to the consumer can be substantial, and unfortunately they are not always obvious. With proper care and attention to water treatment, wasteful use of energy can be avoided. In a boiler operation for heating or other purposes, an insulating scale deposit on the heat-transfer surfaces can substantially increase energy requirements.

Boiler scale or deposits can consist of various substances, including iron, silica, calcium, magnesium, carbonates, sulfate and phosphates. Each of these, when deposited on a boiler tube, contributes in some degree to the insulation of the tube; that is, the deposits reduce the rate of heat transfer from the hot gases or fire through the boiler metal to the boiling water. When this occurs, there is an elevation in the temperature of the boiler-tube metal. The scale coating offers a resistance to the rate of heat transfer from the furnace gases to the boiler water. This heat resistance results in a rapid rise in metal temperature to the point at which the metal bulges and eventual failure results. This is the most serious effect of boiler deposits, since failure of such tubes causes boiler explosions.

Figure 1-7 shows a boiler tube blister caused by a scale deposit. In addition to tube blisters and failures, deposits cause a loss of

FIG. 1-7 Boiler-tube blister. *(Metropolitan Refining Co., Inc.)*

energy as a result of their insulating capability. The actual loss of energy caused by scale is not of enormous significance; it has been reported to be "less than 2 percent for scale of ordinary thickness and heat transfer."[3] For the most efficient and energy-saving operation, however, it is important that even the smallest losses due to deposits be prevented. For example, a loss of only 2 percent in energy as a result of a scale deposit can mean that 432 gallons (gal) more of #6 fuel oil than is normally used would be required per month for the operation of a steam boiler at 100 boiler horsepower (bhp). At 100-bhp, the consumption of #6 fuel oil at 150 000 Btu/gal at 80 percent efficiency is 30 gal/h. At this boiler load, consumption would be 21 000 gal #6 fuel oil per month (720 h). If the boiler operated with scale reducing the efficiency by 2 percent, an additional 432 gal per month would be required. At the beginning of 1979, the cost for #6 fuel oil averaged 40¢/gal, thus the cost resulting from the scale deposit would be $172.80 more per month. Treatment to prevent such deposits, therefore, is not only necessary to prevent failures but can result in more efficient operation with lower fuel consumption.

[3] Eskel Nordell, *Water Treatment for Industrial and Other Uses*, Reinhold Publishing Corporation, New York, 1951, p. 190.

Chapter Two

Water Chemistry

Water and its impurities are responsible for the corrosion of metals and the formation of deposits on heat-transfer surfaces, which in turn reduce efficiency and waste energy. Having seen the effect of corrosion and deposits, let us see how they can be prevented. The path to their prevention can best be approached through understanding their basic causes why and how they occur.

Water, the common ingredient present in heat-transfer equipment such as boilers, cooling towers, and heat exchangers, contains many impurities. These impurities render the water supply more or less corrosive and/or scale-forming.

Thales of Miletus, the Greek natural philosopher (ca.624–550 B.C.) who is considered the founder and father of Greek geometry, astronomy, and philosophy, taught that water was the original substance of all things, that is, the primeval or first principle of matter. To Thales, all things were a modification of water; all came from water, existed as a form of water, and returned to water.

This philosophy of matter and existence lasted in various forms for many centuries but has long since been abandoned. It is true,