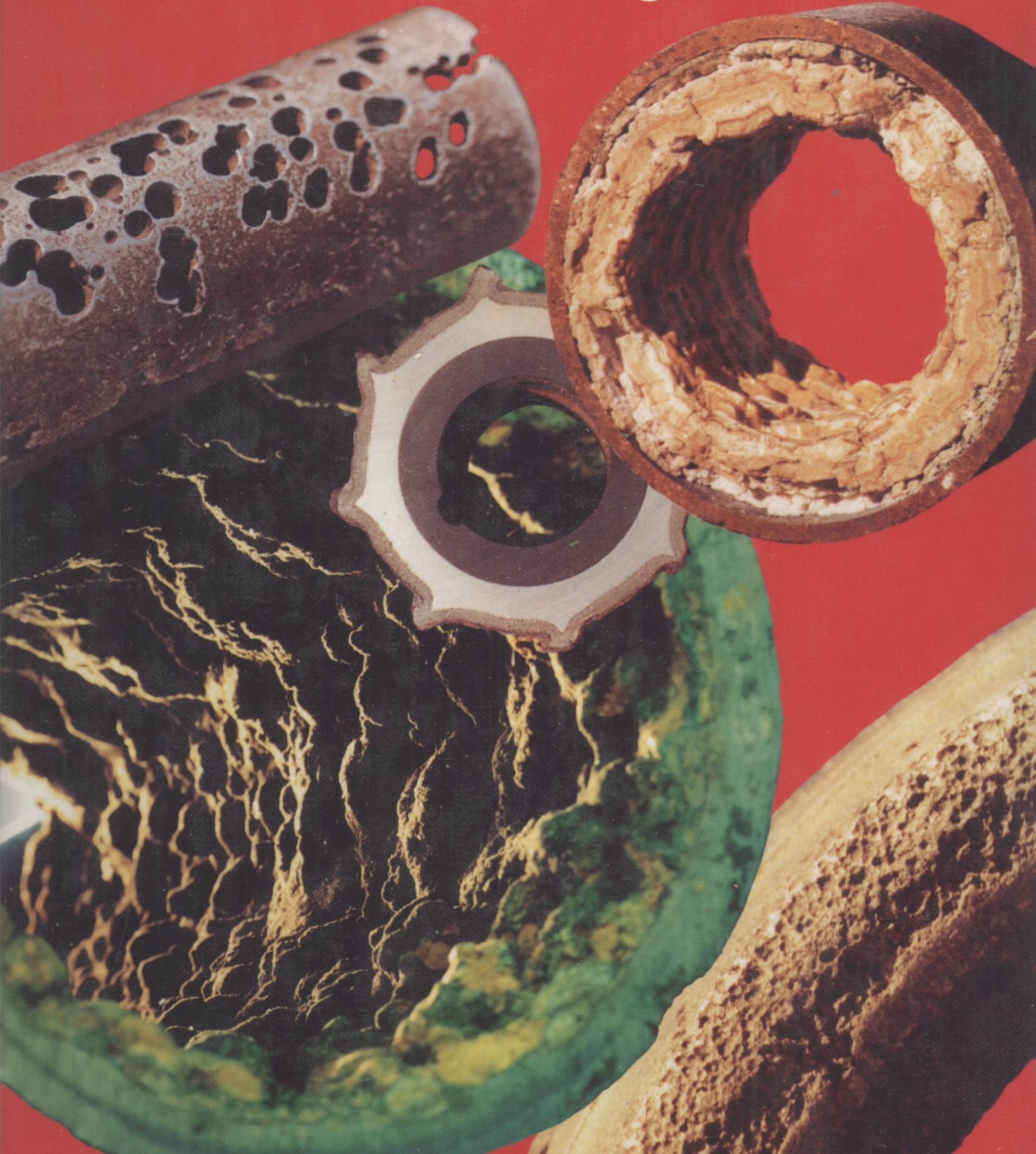
The NALCO Guide to Cooling Water Systems Failure Analysis



The Nalco Guide to Cooling Water System Failure Analysis

Nalco Chemical Company

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The Nalco Guide to Cooling Water System Failure Analysis

To our families for their patience, understanding, and support.

Preface

Cooling water system corrosion causes immediate and delayed problems. Difficulties spread from a failure like ripples from a pebble thrown into a pool. A single failure may force an unscheduled outage, redirect worker efforts, contaminate product, compromise safety, increase equipment expense, violate pollution regulations, and decrease productivity.

The closer one is to the failure, the more its direct effects are apparent. The cumulative effects of failure are often overlooked in the rush to "fix" the immediate problem. Too often, the cause of failure is ignored or forgotten because of time constraints or indifference. The failure or corrosion is considered "just a cost of doing business." Inevitably, such problems become chronic; associated costs, tribulations, and delays become ingrained. Problems persist until cost or concern overwhelm corporate inertia. A temporary solution is no longer acceptable; the correct solution is to identify and eliminate the failure. Preventative costs are almost always a small fraction of those associated with neglect.

The solution to any cooling water system failure begins with a thorough understanding of the cause. Careful, meticulous investigation will almost always reveal the failure source and any attendant accelerating factors. Ideally, potential problems will be identified before failure. The identification of cooling water system potential problems begins with a knowledge of how to recognize such problems. Knowing where particular forms of damage might occur, what damage looks like, how critical factors influence damage, and, most importantly, how such problems can be eliminated are the objectives of this book.

This book follows the format used in *The Nalco Guide to Boiler Failure Analysis,* also authored by Robert D. Port and Harvey M. Herro, copyright 1991 by McGraw-Hill, Inc. Each chapter is divided into eight sections, giving specific information on damage:

General Description

Locations

Critical Factors

Identification

Elimination

Cautions

Related Problems

Case Histories

All areas of the cooling water system where a specific form of damage is likely to be found are described. The corrosion or failure causes and mechanisms are also described. Especially important factors influencing the corrosion process are listed. Detailed descriptions of each failure mode are given, along with many common, and some not-so-common, case histories. Descriptions of closely related and similarly appearing damage mechanisms allow discrimination between failure modes and avoidance of common mistakes and misconceptions.

Many sources contain scattered information concerning cooling water system corrosion and defects, and many literature studies describe corrosion processes and mechanisms from a predominantly theoretical viewpoint. Until now, however, no source discusses cooling water system corrosion with emphasis on identification and elimination of specific problems. Much of the information in this book is unique; every significant form of attack is thoroughly detailed. Color photos illustrate each failure mechanism, and case histories further describe industrial problems.

Visual inspection techniques are stressed as the most important tools used to study failures. This text is not a substitute for rigorous failure analysis conducted by experts, but it will help the reader identify and eliminate many cooling water system problems. Still, on occasion, the experienced, skilled, failure analyst using sophisticated analytical techniques and specialized equipment may be required to solve complex or unusual problems. Common sense, appropriate experience, and systematic investigation are, however, often superior to the more elaborate, but less effective, techniques used by some.

Acknowledgments

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Harvey M. Herro
Robert D. Port

ABOUT THE AUTHORS

HARVEY M. HERRO obtained a B.S. in Physics from Marquette University and a Ph.D. in metallurgical engineering from Iowa State University. Dr. Herro, who has been with Nalco since 1982, holds patents for corrosion monitoring using chemical techniques, is the author of numerous papers on corrosion and failure analysis, and is a frequent lecturer. He is an active member in the National Association of Corrosion Engineers (NACE) and the American Society for Metals (ASM). Dr. Herro currently chairs Task Group T-3A-12 Underdeposit Corrosion at NACE and is an active member of many of its committees. At Nalco, he leads the Nalco Corrosion Detection Group and conducts training on recognizing forms of industrial corrosion.

ROBERT D. PORT is a metallurgical engineer with more than twenty years' experience in failure analysis, at both Nalco Chemical Company and at independent metallurgical laboratories. Mr. Port is the author of numerous papers on failure analysis, and frequently speaks to technical societies and industrial groups. He is a member of NACE and is active on its committee for Failure Analysis in Steam Generating Systems and its committee on Corrosion in Steam Generating Systems. Mr. Port attended the University of Illinois where he received his B.S. in Metallurgical Engineering.

Mr. Port and Dr. Herro have made presentations at professional societies such as the Electric Power Research Institute (EPRI), NACE, ASM, the American Boiler Manufacturer's Association (ABMA), and the American Chemical Society (ACS). Together, the authors have completed more than 4700 failure analyses.

Nalco Chemical Company, headquartered in Naperville, Illinois, has worldwide sales of over one billion dollars.

Contents

Chapter

1

Cooling Water System Design and Operation

Cooling systems suffer many forms of corrosion and failure. The diversity of attack is caused by differences in cooling water system design, temperature, flow, water chemistry, alloy composition, and operation. An almost endless variation of process stream chemistries may be involved in cooling water systems. Refinery and chemical process industries can employ hundreds of heat exchangers at a single plant, each with a different process stream chemistry. Hence, portions of the system contacting water (and sometimes steam) will mostly be discussed in this text. As the reader will note, the variety of problems encountered on waterside surfaces are formidable enough.

Types of Systems

Cooling water systems are either open or closed, and water flow is either once-through or recirculating. The three basic types of cooling water systems are once-through, closed recirculating (nonevaporative), and open recirculating (evaporative). Each is shown schematically in Figs. 1.1 through 1.3.

True closed systems neither lose nor gain water during service. Open systems, however, must have water added to make up for losses.

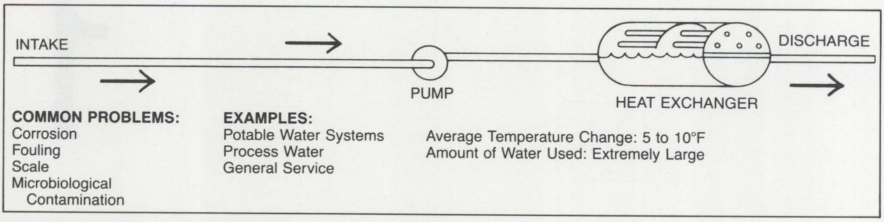

Figure 1.1 Schematic of once-through cooling system.

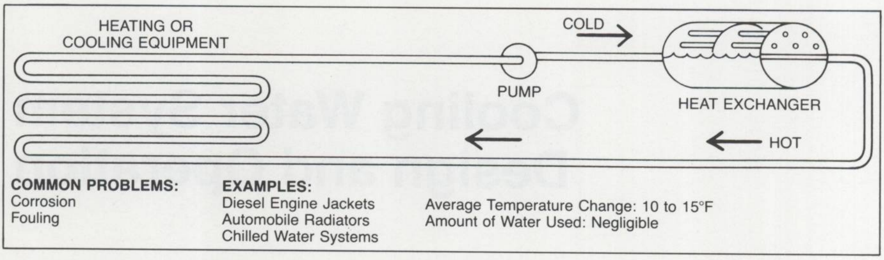

Figure 1.2 Schematic of closed recirculating cooling system.

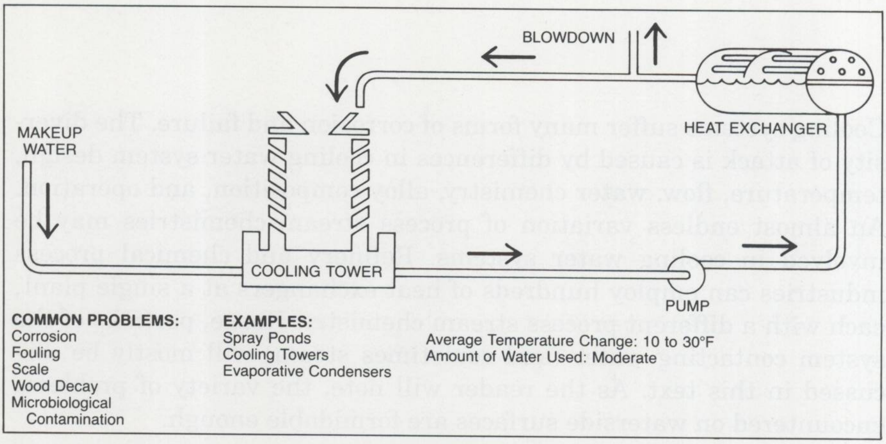

Figure 1.3 Schematic of open recirculating cooling system.

Open recirculating systems employing cooling towers and spray ponds allow the dissipation of enormous heat loads while limiting the amount of water consumed. An open recirculating water loop joined to a closed loop used in an air-conditioning system is diagrammed in Fig. 1.4. Typical hyperbolic cooling towers in a utility are shown in Fig. 1.5. Once-through cooling takes water from a plant supply, passes it

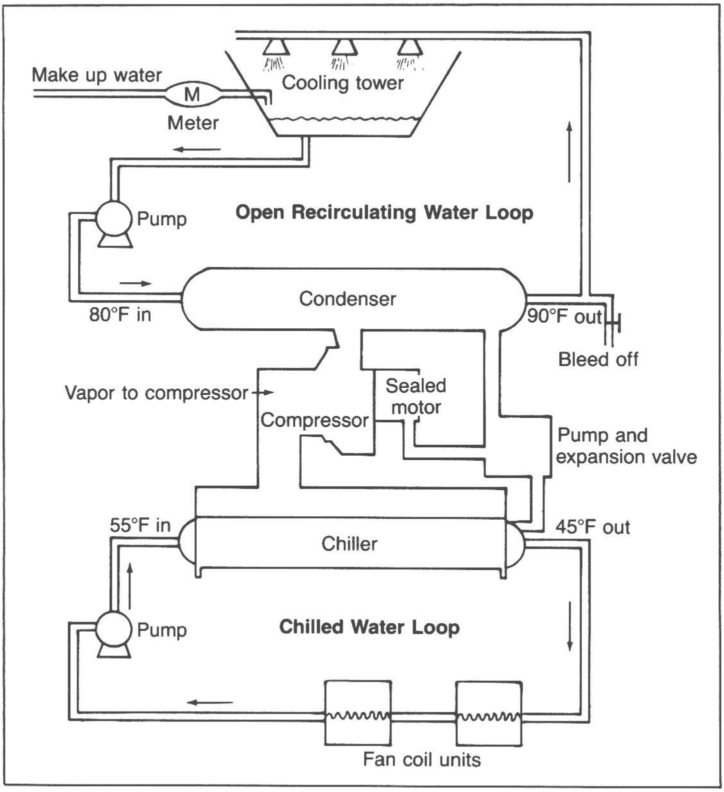

Figure 1.4 Schematic of all components of a complete air-conditioning system. [*Fig. 37.8, The Nalco Water Handbook, 1st ed. (1979), reprinted with permission from McGraw-Hill, Inc.*]

through a cooling system, and finally sends it to a receiving body of water. Closed recirculating system operation is obvious, since no water is added or lost.

Closed and open systems experience forms of attack related to the amount of water added to the system. In closed systems (nonevaporative) where water loss is low, the total waterborne material entering the system is limited. Thus, deposited minerals accumulate at a much slower rate than in systems in which large amounts of makeup water are added. Open recirculating (evaporative) and once-through systems are exposed to large quantities of solutes, suspended solids, and biological materials. As a consequence, fouling and associated corrosion are generally more significant in open systems than in true closed systems. The amount of deposit is not always proportional to the damage

Figure 1.5 Hyperbolic towers cooling condenser water in a utility station. [*Fig. 38.10, The Nalco Water Handbook, 1st ed. (1979), reprinted with permission from McGraw-Hill, Inc., Courtesy of The Marley Company.*]

produced, however. Often, closed systems are used in critical cooling operations where even a small amount of deposit cannot be tolerated (Fig. 1.6).

Cooling System Equipment

Cooling water system designs and equipment vary widely depending upon application. Included are heat exchangers, transfer piping, pumps, cooling tower components, and valves. By far, the greatest variety of designs involves heat exchangers.

Heat exchangers have two common designs: shell-and-tube and plate-and-frame designs. Shell-and-tube heat exchangers are very common. A typical shell-and-tube design is shown in Fig. 1.7. The most frequently affected component in the shell-and-tube exchanger is the tubes. Corrosion fatigue, stress-corrosion cracking, erosion-corrosion, underdeposit attack, dealloying, oxygen corrosion, and many other forms of wastage frequently occur. Tube sheets, baffles, and water boxes also may be damaged by any of the aforementioned mechanisms.

Plate-and-frame exchangers transfer heat by passing cooling fluids and process fluids between large corrugated panels. Crevices exist between closely spaced panels that stimulate localized attack. Plates

Figure 1.6 Dark oxide and deposit lobes on a copper continuous caster mold from a steel-making operation. Since heat transfer is high, even small amounts of deposit are unacceptable.

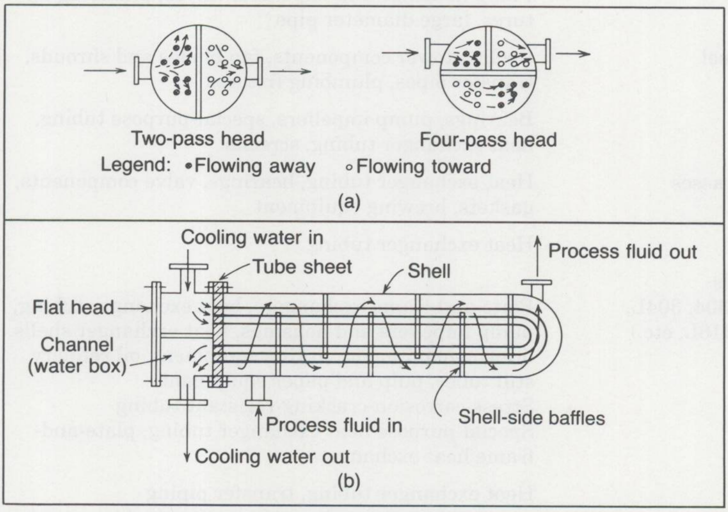

Figure 1.7 Simple detail of shell-and-tube heat exchanger. The water box may be designed for as many as eight passes, and a variety of configurations of shell-side baffles may be used to improve heat transfer. (a) Several water box arrangements for tube-side cooling. (b) Assembly of simple two-pass exchanger with U-tubes. [*Fig. 38.2, The Nalco Water Handbook, 1st ed. (1979), reprinted with permission from McGraw-Hill, Inc.*]

are often exposed to a highly oxygenated environment and, consequently, are fabricated of stainless steel. Stress-corrosion cracking—caused by the combined actions of high residual forming stresses, high operating temperatures, and evaporative concentration of chlorides—frequently occurs.

Alloy Choice

Virtually all commercially available alloys have been used in cooling water systems. A partial listing of the more common alloys and uses is given in Table 1.1. Often, materials used for heat exchanger and other cooling applications are either innately noble or show a strong tendency to passivate in a particular cooling water environment. (Corrosion spontaneously decreases when exposed to a given environment.) Of course, process streams must also be tolerated by the chosen alloy.

TABLE 1.1 Common Alloys Used in Cooling Water Systems

Alloy	Common uses
Carbon steel, low-alloy steels	Transfer lines, heat exchanger shells, baffles, pump components, heat exchanger tubing, fan blades and shrouds, valves, screens, fasteners
Cast iron	Pump housings and impellers, valves, plumbing fixtures, large diameter pipe
Galvanized steel	Cooling tower components, fan blades and shrouds, transfer pipes, plumbing fixtures
Bronzes	Bearings, pump impellers, special-purpose tubing, heat exchanger tubing, screens
Copper and brasses	Heat exchanger tubing, bearings, valve components, gaskets, brewing equipment
Cupronickel	Heat exchanger tubing
Stainless steels	
300 series (304, 304L, 310, 316, 316L, etc.)	Plate-and-frame exchangers, heat exchanger tubing, pump impellers and housings, heat exchanger shells, brewing equipment, drying equipment, oil refinery still tubes, pulp and paper equipment
Duplex	Stress-corrosion-cracking-resistant tubing
400 series	Special-purpose heat exchanger tubing, plate-and-frame heat exchangers
Aluminum	Heat exchanger tubing, transfer piping
Molybdenum	Furnace electrodes used to melt siliceous compounds
Nickel	Special-purpose heat exchangers, caustic handling
Titanium	Fresh and sea water condenser tubing, severe corrosion condition equipment