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An Introduction to Chemical Cleaning of Industrial Water Systems

Course No: H03-003
Credit: 3 PDH

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1. GENERAL GUIDANCE. Chemical cleaning of water systems can be divided into two classifications: pre-operational and remedial. Pre-operational cleaning is performed to prepare the water-contacted metal surfaces to receive chemical treatment, which provides protection from scale, corrosion, and microbiological growth. Remedial cleaning is performed to restore water systems that have been fouled with scale, corrosion products, and microbiological growth due to inadequate or ineffective water treatment. Cleaning, particularly remedial-type cleaning, is often performed by outside contractors familiar with cleaning procedures, techniques, and safety. It should be noted that if the water system is significantly scaled, the chemical treatment program was obviously inadequate and was not properly designed, set-up, controlled, or applied. After cleaning has been completed, the chemical treatment program and quality control (QC) program must be improved so the same problem does not recur. Use of a well-designed quality assurance (QA) program would have produced identification and notification of potential and developing problems before they became serious. Pre-operational cleaning is often performed by contractors responsible for the fabrication of the water system before turning it over to the owner. Water system operations personnel must assess the effectiveness of any cleaning process that has been performed.

1.1 PRE-OPERATIONAL CLEANING. Pre-operational cleaning can be performed on all new systems or pieces of equipment installed in any existing system, including new boiler tubes or new chiller copper tube bundles. New piping and coils will usually be contaminated with materials such as mill scale, rust, oil, and grease resulting from the fabrication, storage, and installation of the equipment. Pre-operational cleaning is performed to remove these materials and prepare metal surfaces to receive corrosion protection from chemical treatment. Pre-operational cleaning agents that are used include detergents, wetting agents, rust removers, and dispersants. These cleaning agents have a pH in the range of 9 to 11. Water systems containing piping or

components constructed of galvanized steel and aluminum should not be subjected to procedures that require high pH (greater than 8.5) because this would contribute to initiating corrosion of these surfaces.

The requirement for performing a pre-operational cleaning process is usually written into the specification for new construction of a water system that must be performed by a mechanical contractor. The mechanical contractor is required to perform the work as directed in the specifications; however, if the specifications are not appropriate for the specific system, including consideration of all system metallurgy, the cleaning process may contribute to corrosion to mild steel, galvanized steel, copper, or aluminum, or it may result in incomplete cleaning of dirty and corroded metal surfaces. The specifications should be reviewed by a qualified base inspector or qualified independent consultant to ensure that cleaning agents and procedures have been specified appropriately. A contracting officer or other individual responsible for QA should inspect the equipment after cleaning and document the effectiveness of the cleaning process.

1.2 REMEDIAL CLEANING. Remedial cleaning is performed to restore a water system that is fouled with scale, corrosion products, or microbiological biomass due to inadequate or ineffective water treatment. The problem could have resulted from using improper chemical technology, failure to maintain treatment levels within control parameters, or the failure of pre-treatment equipment. The cleaning agents used for remedial cleaning usually include acids, chelants, neutralizing agents, and specialty cleaning chemicals.

1.2.1 SAFETY AND ENVIRONMENTAL ISSUES. Remedial cleaning may pose safety issues for personnel handling acids, caustics, and various chemicals. There could also be environmental concerns associated with chemical disposal. Inexperienced personnel should not perform the chemical cleaning of an industrial water system.

1.2.2 CONTRACTING CLEANING SERVICES. For some cleaning jobs, such as large boilers and cooling towers, it may be advisable to engage a service company

specializing in chemical cleaning. If the cleaning service is contracted, it is vital that adequate lines of communication be established, and that safety procedures employed by the service company comply with appropriate regulations. An orientation meeting should be scheduled between appropriate personnel and the service company representatives. At that time, the scope of the work can be defined, proper procedures initiated, and the nature of the hazards described thoroughly. The use of proprietary cleaning chemicals or chemical formulations may be involved; disclosure of the use and nature of these chemicals should be made at the orientation meeting. Appropriate policies and restrictions can also be explained. The inspection of equipment after cleaning is usually the final step in the overall cleaning process.

1.3 REASONS FOR CLEANING. Maintenance of an effective water treatment program is essential to minimize scale and corrosion problems in industrial water systems; however, scale and deposits that form will require remedial cleaning (descaling). If not removed, these scale and water-caused deposits may impact the safety of operations personnel, interfere with heat transfer, and cause excessive damage to (or destruction of) the water-using equipment. Cleaning is not appropriate for the removal of deposits when corrosion of the system has advanced to the point where a large number of leaks may result from the removal of the deposits.

1.4 TYPES OF DEPOSITS. The deposits that occur in water systems can be inorganic mineral salts and corrosion products or organic (oily) or biological in nature. Deposits range in composition from very dense crystalline structures, to very porous and loosely bound materials, to gelatinous slimes. Most of the deposits formed from water constituents consist of corrosion products such as iron and copper oxides, mineral scales, or mixtures of these materials.

1.4.1 WATERSIDE DEPOSITS LOCATED IN HEAT EXCHANGERS. Water deposits located in heat exchangers are usually carbonate-based scales, while steamside deposits may be a mixture of metallic oxides and organic residuals from lubricating oil, particularly where reciprocating-type engines are used. In steam systems, the oxides are usually iron and copper, resulting from aggressive condensate. Microbiological

deposits may form in cooling systems from bacterial or algae growths, or from decomposition products of various microorganisms.

1.4.2 BOILER DEPOSITS. Boiler deposits may take various forms. In low-pressure boilers using a relatively hard feedwater, deposits are essentially calcium and magnesium, silicates, sulfates, carbonates, phosphates and hydroxides, plus some organics. Deposits may also contain considerable amounts of silica, iron, and copper. These deposits can be spongy or porous or relatively hard and glass-like. Deposits of the latter characteristic occur where silica is present in appreciable quantities in the boiler water. Deposits in medium-pressure to high-pressure boiler systems usually are mixtures of iron and copper oxides and phosphates. Dense deposits may tend to form in high-heat transfer areas. Considerable quantities of sludge-type accumulations may be found in downcomers, mud drums, waterwall headers, crossover tubes, and areas of low water circulation in the boiler.

2. REMEDIAL CLEANING PROCEDURES. Cleaning procedures presented herein are general in nature and must be modified to fit specific applications. Because contractors perform most cleanings, these procedures are provided only for general information purposes only.

2.1 CLEANING METHODS

2.1.1 MECHANICAL METHODS. Mechanical methods are the oldest techniques used for removing deposits. To perform an adequate mechanical-type cleaning, the equipment to be cleaned may need to be partially or entirely dismantled. Even when equipment is dismantled, some areas may be extremely difficult to reach and clean. Chemical cleaning has largely replaced mechanical process equipment cleaning as the most satisfactory method of removing deposits; however, mechanical methods such as wire brushing, tumbling, scraping, and abrasive blasting with sand and grit are still employed in special applications.

2.1.2 CLEANING AGENTS. Cleaning agents may be broadly classified as being acid, alkaline, organic, or solvent cleaners. There is no general or universal cleaner that removes all deposits. The selection of a solvent or cleaning agent is based on the material's ability to remove or dissolve the deposit, as well as on cost considerations, safety hazards, and the effect of the cleaning material on the metals involved.

2.1.3 GENERAL GUIDANCE AND PROCEDURES FOR PREPARING CLEANING SOLUTIONS. General guidance and procedures for preparing cleaning solutions of inhibited hydrochloric (muriatic) acid and inhibited sulfamic acid are provided elsewhere. Inhibited acid contains special chemical inhibitors that prevent the acid cleaner from attacking the base metal while allowing the acid to remove the unwanted corrosion product or scale deposit.

2.2 HYDROCHLORIC (MURIATIC) ACID. Inhibited hydrochloric (muriatic) acid in strengths of 5 to 20% is very effective for removing calcium scale and iron oxide; however, for most applications, a 10% solution is adequate. The following formulation is for a 10% hydrochloric acid solution. It can be used for removing scale consisting primarily of carbonates with lesser amounts of phosphates, sulfates, and silicates. This type of scale is typically found in a steam boiler system containing copper alloys that has been treated with a phosphate-based program. Depending on the specific descaling application, some of these ingredients can be omitted from the formulation. For example, diethylthiourea is not needed if there is no copper in the system. It should be noted that if diethylthiourea is used, the waste material should be treated as a hazardous waste. Where there is only carbonate scale to be removed, ammonium bifluoride, which is used to remove silica-based scales, may be omitted. The addition of a wetting agent is preferable but not absolutely necessary.

2.2.1 EXAMPLE PROCEDURE FOR 10% SOLUTION. The following is an example procedure that can be used to make 3785 liters (1000 gallons) of a 10% solution:

1. Add 1079 liters (285 gallons) concentrated (36% strength) hydrochloric acid, American Society for Testing and Materials (ASTM) E 1146,

Specification for Muriatic Acid (Technical Grade Hydrochloric Acid), to approximately 2271 liters (600 gallons) of water.

2. Add the proper amount of a corrosion inhibitor, *Specification MIL-I-17433, Inhibitor, Hydrochloric Acid, Descaling and Pickling*, recommended by the manufacturer to the diluted acid solution. The inhibitor must be compatible with hydrochloric acid and must not precipitate under any condition during the cleaning operation.
3. In a separate tank containing about 284 liters (75 gallons) of water:
 - a) Add 39 kilograms (85 pounds) of the chemical (1,3) diethylthiourea to complex any copper and keep it from depositing. Do not use the diethylthiourea as the corrosion inhibitor required in paragraph 9-2.2.1(step 2) above.
 - b) Add 55 kilograms (120 pounds) of ammonium bifluoride, technical grade, to help dissolve certain iron and silica scales.
 - c) Add 3.79 liters (1 gallon) of wetting agent, *Specification MIL-D-16791, Detergents, General Purpose (Liquid, Nonionic)*.
 - d) Add the dissolved diethylthiourea, ammonium bifluoride, and wetting agent to the diluted acid solution. Add sufficient water to obtain 3785 liters (1000 gallons).

2.2.2 CARBONATE DEPOSITS. Carbonate deposits dissolve rapidly in hydrochloric acid, with evolution of free carbon dioxide. The escaping carbon dioxide tends to create some circulation or agitation of the acid, which ensures the continual contact of fresh acid with the scale. Once the carbonate has been dissolved from a mixed deposit, a loose, porous structure may be left behind. This residual material can be effectively removed from the equipment either mechanically or by washing with high-pressure water.

2.2.3 PHOSPHATE DEPOSITS. The removal of phosphate deposits can usually be accomplished by using hydrochloric acid; however, phosphate deposits have a tendency to dissolve rather slowly. To minimize the total cleaning time, a temperature of 49 to 60 °C (120 to 140 °F) is usually necessary to remove a predominantly phosphate scale.

2.2.4 METALLIC OXIDES. Most metallic oxides found in deposits can be removed with hydrochloric acid. The rate of dissolution is a function of temperature and solution velocity. If copper oxides are present on steel surfaces, special precautions are needed to prevent copper metal plate-out on the steel.

2.2.5 SILICA AND SULFATE SCALE. Heavy silica and sulfate scale is almost impossible to remove with hydrochloric acid. Special chemicals and procedures are required to remove this scale.

2.2.6 HYDROCHLORIC ACID LIMITATIONS. Hydrochloric acid is not used to clean stainless steel because the chloride ion in the acid solution may cause pitting or stress corrosion cracking. Hydrochloric acid is not used for removing scale from galvanized steel surfaces since the galvanizing will corrode. Aluminum is not cleaned using hydrochloric acid.

2.3 SULFAMIC ACID. Sulfamic acid is an odorless, white, crystalline solid organic acid that is readily soluble in water. An inhibited sulfamic acid compound, in a dry powder form, is available under Specification MIL-B-24155, *Boiler Scale Removing Compound*. A 5 to 20% solution (2 to 9 kilograms to approximately 38 liters of water [5 to 20 pounds to approximately 10 gallons of water]) is used for removing scale from metal surfaces. The following information pertaining to sulfamic acid should be considered:

- Carbonate deposits are dissolved in sulfamic acid in a similar manner as in hydrochloric acid. All the common sulfamate salts (including calcium) are very soluble in water.

- The dry powder form of sulfamic acid is safer to handle than a liquid solution of hydrochloric acid; however, aqueous solutions of sulfamic acid are much slower in action and require heating to remove scale. The sulfamic acid solution is heated to a temperature in the range of 54 to 71 °C (130 to 160 °F) to obtain the same fast cleaning time that is achieved by using hydrochloric acid at room temperature. Sulfamic acid is more effective on sulfate scale than hydrochloric acid.
- Inhibited sulfamic acid, used at temperatures up to 43 °C (110 °F), will not corrode galvanized steel. Its use is recommended for removing scale in cooling towers, evaporative condensers, and other equipment containing galvanized steel. In general, sulfamic acid can be applied to equipment while it is operating but should be drained from the system after a few hours, and the concentration of the normally used corrosion inhibitor should be increased several-fold to protect the metal surfaces.
- Commercially prepared descaling compounds consisting of concentrated or diluted inhibited acid (containing 7 to 28% of the acid and inhibitor) may be purchased under various trade names at prices 4 to 30 times the cost of the ingredients themselves if purchased as generic chemicals.
- Advertisements of some of these products may contain claims that cotton clothing and skin are not attacked by the acid. These claims are usually based on a very dilute solution of the acid that causes a minimal attack on clothes and skin; however, the cost of the cleaning process may be increased because a higher quantity of dilute product may be needed. Be aware that handling acid in any strength must be performed with considerable care, caution, and adherence to safety procedures.
- The cost of diluted acid is expensive; therefore, concentrated acid of government specifications should be purchased and diluted to usable strengths.

The necessary corrosion inhibitors can be added to the dilute acid solution. Users of small quantities of acid cleaners (possibly less than 38 liters [10 gallons] of diluted acid per year) may not be able to justify purchasing undiluted acid and spending the time, cost, and effort to prepare the cleaning solution; therefore, consider the specific requirements before ordering.

2.4 CLEANING PREPARATION. The unit to be cleaned must be isolated from other parts of the system. For systems that cannot be isolated by the closing of valves, isolation may be accomplished using rubber blankets, wooden bulkheads with seals, inflatable nylon or rubber bags, rubber sponge-covered plugs, or blind flanges and steel plates with rubber seals. Long lines may require auxiliary connections for chemical cleaning. The following information should be considered before the cleaning process is started:

- Decide whether to clean using a soaking process or by circulating the cleaning. In either case, temporary piping or hose lines will be required to connect the cleaning solution mixing tanks or trucks to the unit, with return lines to tanks or drains. Proper precautions and adequate provisions must be made to protect equipment, isolate control lines, replace liquid level sight glasses with expendable materials, and provide suitable points for checking temperatures. It may be necessary to remove selected system components if the cleaning process might damage them.
- The entire cleaning procedure/process must be developed in detail before starting chemical cleaning operations. Factors to be considered include: the methods for controlling temperatures; the means of mixing, heating, and circulating the chemical solution; proper venting of dangerous gases from equipment to a safe area; and means for draining, filling, and flushing under inert atmospheres. Sampling points, test procedures, and control limits should also be established.

2.5 METHODS FOR REMOVING SCALE. Removing scale may be accomplished by circulating the inhibited acid solution through the equipment or by soaking the equipment in a tank of inhibited acid. Before starting any descaling process, check the acid to make sure it is properly inhibited. You may check the acid by placing a mild steel coupon into a beaker containing the prepared, diluted acid. You should notice no reaction around the coupon. If you observe a reaction generating hydrogen gas bubbles around the coupon, add more inhibitor.

2.5.1 RECIRCULATING CLEANING PROCESS FOR BOILERS. The following example is an appropriate procedure for cleaning small boilers or other systems using a hot recirculating inhibited acid solution:

1. Fill the boiler or system with preheated (71 to 77 °C [160 to 170 °F]) dilute inhibited acid solution.
2. Allow the dilute inhibited acid solution to remain in place for 8 hours. Circulate the acid solution for approximately 15 minutes each hour at a rate of about 3.15 liters per second (50 gallons per minute) to ensure good mixing.
3. Keep the temperature of the acid solution preheated at 71 to 77 °C (160 to 170 °F). Measure and record the temperature at least once every 30 minutes.
4. Check and record the acid strength at least every hour (see paragraph 9-2.6).
5. Drain the system by forcing the acid solution out using 276 to 345 kilopascals (40 to 50 pounds per square inch gauge) nitrogen; follow Federal Specification A-A-59503, *Nitrogen, Technical, Class 1*. If leaks develop when the system is under nitrogen pressure, you must use an alternate method for removing the acid, such as pumping.
6. Fill the boiler with preheated (65 to 71 °C [150 to 160 °F]) water and soak at this temperature for 15 minutes.
7. Drain under nitrogen pressure of 276 to 345 kilopascals (40 to 50 pounds per square inch gauge).

8. Prepare this mild, acid-rinse solution: Add 7.57 liters (2 gallons) of hydrochloric acid (ASTM E 1146) for each 3785 liters (1000 gallons) of water. Also add corrosion inhibitor, Specification MIL-1-17433, in the amount recommended by the manufacturer.
9. Fill the boiler with the preheated (71 to 77 °C [160 to 170 °F]) mild acid-rinse solution and soak for 30 minutes.
10. Drain the mild acid-rinse solution under nitrogen pressure at 276 to 345 kilopascals (40 to 50 pounds per square inch gauge). Maintain a positive pressure of nitrogen in the boiler to prevent outside air from leaking inside.
11. Prepare this passivating solution: To each 3785 liters (1000 gallons) of distilled water (or other water with less than 50 ppm total hardness [as CaCO₃]), add 36 kilograms (80 pounds) of passivation compound 0.5% by weight sodium nitrite and 0.25% by weight monosodium phosphate.
12. Fill the boiler with the passivating solution preheated to 65 to 71 °C (150 to 160 °F), circulate for 10 minutes, and hold in the boiler at 65 to 71 °C for an additional 30 minutes.
13. Drain and rinse boiler until the pH of the rinse water is pH 8 to 10.

2.5.2 CIRCULATING METHOD WITHOUT HEAT. The steps below describe a typical process for descaling smaller equipment, such as enclosed vessels or hot water heater coils, without heating the inhibited acid solution:

1. Note that an acid cleaning assembly may consist of a small cart on which is mounted a pump and an 18.9- to 189-liter (5- to 50-gallon) steel or polyethylene tank with a bottom outlet to the pump.
2. Install sill cocks at the bottom of the water inlet of the heat exchanger and the top of the water outlet so that a return line can be connected directly from the acid pump and from the heat exchanger to the acid tank.
3. Prepare an inhibited acid cleaning solution.

4. Pump the acid solution into the heat exchanger through the hose connection. Continue circulation until the reaction is complete, as indicated by foam subsidence or acid depletion.
5. If the scale is not completely removed, check the acid strength in the system. If the acid strength is less than 3%, add fresh acid solution and continue circulation until the remaining scale is removed. Usually an hour of circulation is adequate.
6. Drain the heat exchanger.
7. Neutralize remaining acid by circulating a 1% sodium carbonate (soda ash) solution (about 3.6 kilograms per 38 liters [8 pounds per 100 gallons]) for about 10 minutes.
8. Rinse thoroughly with water until the pH of the rinse water is pH 8 to 10.

2.5.3 FILL AND SOAK METHOD

1. Prepare an inhibited dilute acid solution (see paragraphs 9-2.2 and 9-2.3) in a container of suitable size.
2. Depending on the item to be cleaned and the types of scale involved, you may want to place an agitator (mixer) in the tank or install a pump outside the tank to circulate the acid solution. A method to heat the acid may be required, such as a steam coil. All equipment must be explosion-proof and acid-resistant.
3. Immerse the item to be cleaned in the dilute acid solution. Continue soaking until the reaction is complete as indicated by foam subsidence or acid depletion.
4. If the scale is not completely removed, check the acid strength (see paragraph 9-2.6). If it is less than 3%, add additional acid and continue soaking the items until the remaining scale is dissolved. Usually 1 to 2 hours of soaking is adequate.
5. Remove item from tank.

6. To neutralize remaining acid, immerse the item in a 1% sodium carbonate (soda ash) solution (about 3.6 kilograms per 38 liters [8 pounds per 100 gallons]) for 2 to 3 minutes.
7. Rinse the item thoroughly with water.

2.6 CHECKING ACID SOLUTION STRENGTH. The initial strength of the dilute inhibited acid will vary from 5 to 20%, although 10% is typical. As the acid is consumed by dissolving the scale, the strength of the acid decreases. The strength of the acid solution should be measured periodically during a cleaning operation. When the acid strength falls below 3%, the solution may be discarded since most of its scale-dissolving capability will have been used. Use the following procedure to check the acid strength:

Apparatus:

Burette, 25 milliliters (0.8 ounce) automatic (for sodium hydroxide solution)

Stirring rod

Bottle, with dropper, 50 milliliters (2 ounces) (for phenolphthalein indicator solution)

Graduated cylinder, 10 milliliters (0.3 ounce)

Casserole, porcelain, heavy duty, 210-milliliter (7.1-ounce) capacity

Reagents:

Sodium hydroxide solution, 1.0 normality (N)

Phenolphthalein indicator solution, 0.5%

Method:

1. Measure 10 milliliters of acid solution accurately in the graduated cylinder.
2. Pour into the casserole.
3. Add 2 to 4 drops of phenolphthalein indicator solution to the casserole and stir.
4. Fill the automatic burette with the 1.0 N sodium hydroxide solution; allow the excess to drain back into the bottle.

5. While stirring the acid solution constantly, add sodium hydroxide solution from the burette to the casserole until color changes to a permanent faint pink. This is the endpoint. Read the burette to the nearest 0.1 milliliter (0.003 ounce).

Results:

1. For hydrochloric acid:

Percent hydrochloric acid = milliliter of 1.0 N sodium hydroxide x 0.36

2. For sulfamic acid:

Percent sulfamic acid = milliliter of 1.0 N sodium hydroxide x 0.97

3. DEVELOPING A WATER TREATMENT PROGRAM

3.1 GENERAL INFORMATION. Although each water treatment program may contain unique aspects, the strategic goals of every program are regulatory compliance and safety, protection of water-contacted equipment, and acceptable costs. Achieving these goals requires the cooperative efforts of personnel from several areas, including environmental protection, engineering, contracting, operations, and outside resources. Outside resources include water treatment services companies, equipment suppliers, and mechanical contractors. In some cases, facilities may use outsourcing for procurement of all industrial water treatment chemicals and associated services. This section addresses some of the options for developing both a water treatment program and performance standards that apply to implementation of the program.

Problems can occur when water treatment programs are not developed properly. Each water treatment program is designed to address regulatory compliance and safety requirements as well as water quality and equipment protection. A potential consequence of inadequate planning and design of a water treatment program is preparing inadequate scopes of work for use in procuring (contracting) for services. If equipment protection is not adequate, the cost attributed to this failure often far outweighs the cost of the water treatment chemical program. The most obvious problem is damage to, or the need for premature replacement of, the water-contacted equipment. Loss of operational efficiency is also a problem but is not always as

apparent because it is rarely measured accurately. However, the additional operational costs due to operational inefficiency can be substantial. Specific types of equipment and system failures are described in Chapters 3, 4, and 5. When developing a water treatment program, you must give adequate effort and consideration to defining goals, devoting adequate resources to accomplish goals, and assessing performance.

3.2 OPTIONS FOR SETTING UP A WATER TREATMENT PROGRAM. There are four methods for developing and implementing a water treatment program:

- a) **Generic Programs:** In a generic water treatment program, facility operations personnel identify and use generic or commodity chemicals as part of the water treatment program that has been developed by facility personnel. Facility operations provide all services for chemical feed and control as well as monitoring and performance assessment. Facility personnel may be required to handle and mix generic chemicals. Alternatively, a contractor can develop the program for using generic chemicals, with services being provided by facility personnel.
- b) **Outsourcing of Proprietary Chemicals Only:** Procurement of proprietary water treatment chemicals is outsourced from a qualified water treatment contractor. Facility operations provide all services for chemical feed and control, as well as monitoring and performance assessment.
- c) **Outsourcing of Proprietary Chemicals and Some Basic Periodic Services:** Proprietary water treatment chemicals, control and feed equipment, and periodic services are outsourced from a qualified water treatment contractor. Facility operations provide daily services for chemical feed and control, and monitoring and performance assessment.

- d) Complete Outsourcing: All chemicals and services are outsourced to a contractor. The facility provides only maintenance of operating equipment (no water-treatment-related services).

3.3 DEVELOPING A SCOPE OF WORK (SOW) FOR INDUSTRIAL WATER

TREATMENT. A SOW (sometimes called a “statement of work” or a “statement of services to be provided”) is developed for inclusion in the required procurement documents (i.e., request for proposal/bid [RFP/RFB] and contract). The SOW will identify the specific services, chemicals, and equipment that a contractor is to provide under the terms of the contract. The SOW will, at a minimum, specify or identify the following: SOW to be performed; qualifications of supplier; water characteristics of each system to be treated; description of industrial water systems and their operation; performance specification (results required); service requirements; equipment requirements for control, feed, monitoring, and sampling; requirements for chemicals and test equipment; and quotation for total chemical cost and usage. These issues are described below.

3.1 QUALIFICATIONS. The SOW specifies the minimum qualification requirements for contractors and contractor representatives. These requirements are developed to allow the participation of qualified contractors (water treatment chemical companies) having national, regional, and local operations. The SOW can specify the minimum number of years that the company has been in business and the minimum number of years and type of experience of contractor representatives, as well as required technical service capabilities.

3.2 SUBMITTAL REQUIREMENTS AND FORMAT. The SOW clearly specifies the type of response (submittal) that is required from an RFP or RFB. This is necessary to avoid receiving bid responses that are so different in their presentation that they cannot be easily or objectively compared. The evaluation process can be simplified by requiring bidders to provide a comprehensive acknowledgement that they understand and accept all requirements for compliance, qualifications, service requirements, and performance

standards. The RFP/RFB should require a simple, generic, technical summary that lists the proposed chemical technology and treatment ranges for each type of system to be serviced under the procurement.

3.3 WATER QUALITY. The water supplied as makeup to industrial water systems is characterized in terms of its source, treatment, and quality, including seasonal and temporal variances. If external treatment is used on individual systems such as a steam boiler, this treatment is identified.

3.4 DESCRIPTION OF SYSTEMS AND OPERATIONS. A description of the number, capacity, and types of systems to be serviced under the contract is a critically important element of a SOW. The metallurgy of all water-contacted surfaces is identified. Without this information, performance standards cannot be adequately defined. The condition of equipment is documented. Operational parameters, such as the equipment duty, load, and usage, are described so that water usage (preferably total water usage for each system) and chemical restrictions can be considered in developing the proposal.

3.5 PERFORMANCE SPECIFICATION. Performance criteria are specified for protecting equipment against deposition, corrosion, and biological growths. Certain minimally acceptable standards for performance must be met. Allowances are made for problems that cannot be totally controlled by chemical treatment alone. One example is SS accumulation in a cooling tower system. Chemical dispersants can aid in keeping SS from settling on metal surfaces, but it may require adequate flow and physical removal to maintain good control.

3.6 SERVICE REQUIREMENTS. The SOW accurately describes the services to be provided by the contractor. Service includes the frequency of on-site visits, the duties to be performed, and the methods of reporting. The duties to be performed can include these activities: water testing; making log entries; training; maintaining automated chemical control and feed equipment; manual addition of chemicals to industrial water systems; inventory control; corrosion coupon studies; microbiological population

determination; equipment inspections; laboratory support; quarterly reviews; and annual reviews.

3.7 CONTROL, FEED, MONITORING AND SAMPLING EQUIPMENT REQUIREMENTS. The SOW specifies what equipment, if any, is required to achieve consistent control of the makeup water treatment chemical program. Automated control and feed equipment is required on most medium and large cooling towers and on most steam boilers. Automated control and feed equipment helps limit the demand for service maintenance. To provide for the preparation of an appropriate SOW, engineering and facility maintenance personnel carefully evaluate their capabilities in the area of water treatment and water systems. Inadequate water treatment equipment can result in higher service requirements or inconsistent control of the chemical program.

3.8 CHEMICALS AND TEST EQUIPMENT. The SOW specifies any restrictions on the use or discharge of chemicals. Examples of restrictions can include limitations on the use of acid, shipping container size limits, microbiocide selection criteria, and limitation on use of dry chemicals.

3.9 QUOTATION FOR COST AND USAGE. The SOW specifies how the cost of chemicals and services is being calculated and quoted. For example, quotations for chemical treatment can be based on the cost to treat 3.785 cubic meters of water. Cost for services in the SOW can be required to be included in the cost of chemical treatment or quoted separately as line items, time, and materials. Contracts that require a "not-to-exceed" quotation supply bidders with a not-to-exceed water usage estimate.

4. REPORTS AND AUDITS. Reports and audits are tools for documenting performance and cost effectiveness of any industrial water treatment program. Audits serve to verify results from the water treatment service company. Audits also serve to verify the cost-effectiveness of product being supplied by the water treatment service company. Audits are performed by appropriate agencies or by independent consultants contracted to perform such duties.

5. GLOSSARY

Acid — A compound, usually having a sour taste, which can neutralize an alkali or base; a substance that dissolves in water with a formation of hydrogen ions.

Aeration — Intimate contact between air and liquid by one of the following methods: spraying the liquid in the air; bubbling air through the liquid; or agitating the liquid to promote surface absorption of air.

Algae — Tiny plant life, usually microscopic, existing in water. They are mostly green, blue-green, or yellow-green, and are the cause of most tastes and odors in water. They create suspended solids (SS) when they grow in an industrial water system.

Alkalinity — (a) A term used to represent the content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates in water. (b) The capacity of water to react with hydrogen ions.

Alkalinity, total or mixed indicator (M) — A measure of the total alkalinity of water. Measured by the quantity of 0.02 normality (N) sulfuric acid required to bring water to pH of 4.4, as indicated by the change in color of methyl orange or a mixed indicator. Results are expressed in parts per million (ppm) as calcium carbonate.

Alkalinity, Phenolphthalein (P) — A measure of hydroxide ions (OH) plus one-half of the normal carbonates in water. Measured by the quantity of 0.02 normality (N) sulfuric acid required to bring the water to pH 8.2, as indicated by the de-colorization of phenolphthalein indicator. Results are expressed in parts per million (ppm) as calcium carbonate.

Alkalinity, Hydroxyl — A measure of hydroxyl ion (OH) contribution to the alkalinity. This is related to the system pH and also may be referred to as “causticity.”

Bacteria — Simple single-cell microscopic organisms generally free of pigment. They do not require light for their life processes.

Backwash — The reversal of flow through a filter or an ion exchanger to wash clogging material out of the filtering medium and reduce conditions causing loss of head.

Backflow preventer — A device for a water supply pipe to prevent the backflow of water into the water supply system from the system which it supplies.

Base — An alkali or hydroxide of alkali metals and ammonia. They can neutralize acids to form salts and water. A base will ionize to form hydroxyl ions (OH⁻).

Biocides — Material typically used to destroy microorganisms (also called “microbiocides”).

Biological Deposits — Water-formed deposits of organisms or the product of their life processes. Biological deposits may be composed of microscopic organisms, as in slimes, or of macroscopic organisms such as barnacles or mussels.

Blowdown — Draining a portion of water from a system to reduce the concentration of dissolved solids or to discharge accumulations of materials carried by the water.

British Thermal Unit (BTU) — The amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit (°F).

Brine — A saturated solution for ion exchange regeneration, refrigeration, or cooling processes. It is usually a sodium chloride water solution for ion exchange regeneration. It may be sodium chloride water solution or calcium chloride water solution for refrigeration.

Causticity — A common term that describes hydroxyl alkalinity or the alkalinity resulting from the presence of the hydroxyl ion (OH⁻).

Concentration — A measure of the amount of dissolved substances contained per unit volume of solution. This may be expressed as grains per gallon, pounds per million gallons, milligrams per liter, ppm, or percent.

Condensate — The material formed when vapor returns to the liquid state. In steam heating systems, the water condensed from steam. In air conditioning, water extracted from air by condensation on the cooling coil of a refrigeration machine.

Conductivity, Specific Conductance — The reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specified temperature. Electrical conductivity is expressed in micromhos (μmhos), the reciprocal of megohms. This is used as a measure of total dissolved solids (TDS).

Corrosion — The destruction of a substance, usually a metal, or its properties because of a reaction with its (environmental) surroundings.

Disinfection — The process of killing most (but not necessarily all) of the harmful and objectionable microorganisms in a fluid by various agents such as chemicals, heat, ultraviolet light, ultrasonic waves, or radiation.

Cycles of Concentration (COC) — In a system in which water lost through evaporation and blowdown is replaced with makeup water, COC is the ratio of the makeup quantity to the blowdown quantity ($COC = M/B$). It is the number of times the makeup water is concentrated in the system. The COC can also be calculated by dividing either the conductivity or the chloride content of the blowdown by the conductivity or chloride content of the makeup ($COC = \text{Cond}_{bd}/\text{Cond}_{mw}$).

Deaerator — Device for removing non-condensable gases from the boiler. It may operate on the principle of either heat or vacuum.

Dealkalization — Exchange of bicarbonate for chlorides in an ion exchange process.

Deionization — Complete removal of ions from water.

Demineralization — Reduction of the mineral content of water by a physical or chemical process; removal of salts.

Dissolved solids — (a) Solids, usually minerals, which are present in solution. (b) The dried residue from evaporation of the filtrate after separation of suspended solids (SS).

Distribution Ratio (D.R.) — This is a measure of the vapor/liquid ratio for a given material. Extremely high and low values are generally inadvisable. A high D.R. results in either high amine losses at any vents or little availability of amine at points of initial condensation, or both. A low D.R. results in high amine losses in the blowdown.

Evaporation — The process by which water passes from a liquid state to a vapor. It is the main process by which heat is removed from a cooling tower and steam is produced in a boiler.

Feedwater — Water being applied to the feedwater heater or to the boiler, consisting of both makeup and condensate return.

Filming Amines — Chemicals that form an impervious barrier between metal and the steam condensate to prevent corrosion.

Foulants — Deposition of materials normally in suspension. This includes silt, air-scrubbed dust, microbiological residuals, reaction products from treatment, and corrosion products.

Generic Chemicals — A chemical identified and purchased by the recognized chemical name, such as the International Union of Pure and Applied Chemistry (IUPAC) designation. These generic chemicals may be blended or used separately. They are usually much less expensive than special chemical blends developed by manufacturers under a trade name.

Hardness — (a) A characteristic of water, chiefly due to the existence of carbonate and sulfate (and occasionally the nitrite and chloride) salts of calcium, iron, and magnesium. (b) Commonly computed from the amount of calcium and magnesium in the water and expressed as equivalent calcium carbonate. (c) Causes "curding" of water when soap is used, increased consumption of soap, deposition of scale in boilers, injurious effects in some industrial processes, and sometimes objectionable taste in the water.

Hardness, Carbonate — Hardness caused by the presence of carbonates and bicarbonates of calcium and magnesium in water. Such hardness may be removed to the limit of solubility by boiling the water. This is also called temporary hardness.

Hardness, Non-Carbonate — Hardness caused by calcium and magnesium sulfates and chlorides and compounds other than carbonates which cannot be reduced materially by boiling the water. (Also called "permanent hardness".)

Hardness, Total — The sum of carbonate and non-carbonate hardness.

Hydrogen Ion Concentration — Commonly expressed as the pH value that represents the logarithm of the reciprocal of the hydrogen ion concentration.

Inhibitor (applied to corrosion) — A chemical substance or mixture that effectively decreases corrosion when added to a liquid (usually in small concentrations).

Ion — A particle, atom, or group of atoms, carrying either a positive or negative electrical charge, formed when an electrolyte is dissolved in water.

Ion Exchange — A process where water is passed through a granular material wherein ions on the granular material are replaced by ions contained in the water. For example, in the zeolite softening process, the sodium ions (Na^+) of the granular zeolite are replaced by the calcium ions (Ca^{++}) in the water to leave the water free of calcium (the cause of hardness), but with an increased amount of sodium.

Langelier Index (saturation index) — An index based on the calcium hardness, total alkalinity, total dissolved solids (TDS), temperature, and pH. It is used to classify waters

by their ability to either dissolve or deposit calcium carbonate. It is the algebraic difference between the actual pH and the calculated pH of saturation. It was one of the first indices developed for this purpose and was designed specifically for municipal water flowing in distribution lines.

Makeup Water — Water supplied to replace the loss in a system due to leaks, evaporation, wind drift, bleed-off, blowdown, or withdrawal.

Microbiocide — A material added to cooling tower water and chilled water to control the growth of microorganisms such as algae, bacteria, and fungi.

Micromho — An electrical unit of conductance (one-millionth of a mho), which is the reciprocal of electrical resistance.

Microorganism — A minute plant or animal in water or earth that is visible only through a microscope.

Milligrams Per Liter (mg/l) — A unit of the concentration of water or wastewater constituent. It is 0.001 gram of the constituent in 1000 milliliters (ml) of water.

Neutralizing Amines — Chemicals used to neutralize carbon dioxide in steam condensate to prevent corrosion.

Normality (N) — The concentration of a solution in relation to a normal solution. Normality is a measure of the “strength” of a given solution. The normal solution contains a specific weight of a substance per liter based on the characteristics of the substance. Thus, a half-normal solution would be expressed as 0.5N or N/2.

Oxygen Scavenger — A chemical used to remove final traces (trace amounts) of oxygen from boiler feedwater.

pH — Logarithmic measure of hydrogen ion concentration indicating degree of acidity or alkalinity of a solution. The pH range varies from 1 to 14. Values below 7.0 indicate acidity and above 7.0 indicate alkalinity (basicity).

pH_{eq} — The pH of equilibrium. The adjusted pH value of a water-based on the empirical relationship between total alkalinity and pH developed from studies of hundreds of cooling systems. Development of an empirical relationship was necessary because pH in cooling waters is often buffered, a factor which affects the relationship between pH and bicarbonate alkalinity.

pH_s — The pH of saturation. It is the pH value below which a material will go into solution (dissolve) and above which it will precipitate. It is applied to calcium carbonate in the Langelier, Ryznar, and Practical Scaling Indices. It is a function of the calcium hardness, the total alkalinity, the total dissolved solids (TDS) and the temperature. It is determined with graphs, tables, or special slide rules. This equation is useful:

$$\text{pH}_s = 12.27 - 0.00915T - \log \text{CaH} - \log \text{TA} + (\log \text{TDS})/10.$$

Phosphates — Chemicals used for corrosion control in cooling towers and deposit control in boilers. Commonly, these occur as orthophosphates or polyphosphates. The level of the active phosphate chemical is reported either as percent P₂O₅ (phosphorus pentoxide) or as PO₄ (phosphate), with these two oxides of phosphate being related by factor as follows: PO₄ = 1.34 x P₂O₅.

ppm — Parts per million; one pound of material dissolved in one million pounds of water.

Precipitate — (a) To separate a dissolved substance in the solid form by its removal from a solution. (b) The substance in solid form that has been separated from solution.

Practical Scaling Index (PSI) — A modified scaling index developed by P.R. Puckorius and J.M. Brooke to provide a better and more consistent indication of scaling conditions of cooling water. It is based on using the pH of equilibrium (pH_{eq}) rather than the actual pH, and is calculated as follows:

$$\text{PSI} = 2 \text{pH}_s - \text{pH}_{\text{eq}}.$$

As with the RSI, a value less than 6.0 in natural water indicates a scale-forming tendency. A value greater than 6.0 in natural water indicates a scale-dissolving tendency.

Regeneration — That part of the operating cycle of an ion exchange process in which a specific chemical solution is passed through the ion exchange bed to prepare it for a service run (i.e., return the ion exchange bed to its original composition).

Ryznar Index (stability index) — An index classifying water as to its ability to dissolve or deposit calcium carbonate scale. It is calculated as twice the pH of saturation minus the actual pH (RI = 2 pH_s - pH). Although in theory an RI of 7.0 should be neutral, experiments indicate that 6.0 is a better value. A value less than 6.0 in natural water

indicates a scale-forming tendency. A value greater than 6.0 in natural water indicates a scale-dissolving tendency.

Scale — Deposition on a heat transfer surface of normally soluble salts. Scale is usually crystalline and dense, frequently laminated, and occasionally columnar in structure.

Shock Feed — The process of adding one or more water treatment chemicals in one application rather than gradually.

Slime — Biological growths that may accumulate to the extent that they foul equipment.

Sludge — A water-formed deposit that will settle, and may include all suspended solids (SS) carried by water. Sludge is commonly formed in boilers where it may be baked into place and become hard and adherent.

Softening Water — The process of removing from water the mineral substances that produce a condition called hardness. There are two softening processes in general use: chemical precipitation (lime and lime/soda softening) and the zeolite ion exchange process.

Solids, Suspended (SS) — All matter in water that is not dissolved and can be removed with filtration.

Solids, Dissolved — The total concentration of all substances in a filtered solution which exist as solids after the liquid is completely evaporated from the solution.

Solids, Total — The sum of the suspended and dissolved matter (solids).

Zeolite — Natural minerals as well as synthetic resins used for ion exchange.