THE PRACTICAL APPLICATION AND INNOVATION OF CLEANING TECHNOLOGY FOR CONDENSERS

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ABSTRACT

Maintaining clean condenser tubes is of vital importance for reliable, efficient power generation. Two major problems result from substances on the interior of tube surfaces: (1) Loss of heat transfer, and (2) Under-deposit corrosion. Internal tube fouling is nearly always detrimental to heat transfer, thus reducing the efficiency of steam condensing, resulting in a lower vacuum (higher pressure) and less efficient steam turbine operation. Under-deposit corrosion of tube material can result in through-wall leaks, permitting ingress of cooling water into high purity steam condensate. Because poor vacuum conditions in the condenser can reduce electric generating capacity, and contaminants in steam condensate can cause significant damage to boiler tubing and steam turbine materials, measures to prevent fouling or remove foulants must be applied. Early identification of fouling characteristics and a fundamental knowledge of cleaning system capabilities are essential in determining the most effective cleaning technology. Unique circumstances may require innovative solutions. The common causes of condenser tube fouling and the practical application and innovation of cleaning technology are discussed. *State-of-the-Art* methods for off-line mechanical tube cleaning are presented, and their effects on tube condition examined.

INTRODUCTION

Maintaining clean condenser tubes is of vital importance to reliable, efficient power plant operation. Ideally, fouling would be avoided entirely; however, this is rarely the case. Condensers may become lightly fouled with soft organic deposits, or can be severely scaled with hardened minerals. The probability of success in cleaning the condenser is dependent on the selection of the appropriate cleaning technology under the specific fouling conditions. Early identification of fouling characteristics and a fundamental knowledge of cleaning system capabilities are essential in determining the most effective cleaning technology, as well as the frequency of cleaning required.

Two major problems result from substances on the interior tube surfaces: (1) Loss of heat transfer, and (2) Under-deposit corrosion. Internal tube fouling is nearly always detrimental to heat transfer, thus reducing the efficiency of steam condensing, resulting in a lower vacuum (higher pressure) and less efficient steam turbine operation. In severe cases, poor vacuum conditions in the condenser can reduce electric-generating capacity by more than fifty percent. Under-deposit corrosion of tube metal can result in through-wall leaks, permitting ingress of cooling water into high-purity steam condensate. Contaminants in cooling water (which may be concentrated significantly in a recirculating cooling tower) can cause major damage to boiler tubing and steam turbine materials, potentially resulting in huge economic penalties in unit outages and equipment repair and/or replacement. Measures to remove foulants from condenser tubes can be a very minor price to pay in terms of the overall picture.

Options for cleaning foulants off-line include chemical (acid or chelate dissolution) and mechanical means (metal or plastic scrapers, brushes, high pressure water, etc.). On-line preventive measures also exist, including chemical treatments (scale and corrosion inhibition, dispersants, biocides) and continuous recirculation of mechanical cleaners of a variety of types. A close look will be taken at the use of metal scrapers for off-line cleaning, as this has been a reliable and effective technology for several decades, with scraper designs continually evolving to meet the needs of various fouling situations. Metal scrapers have distinct advantages over other tube cleaning methods in certain scenarios. The most effectively designed scrapers are sized to closely match tube interior dimensions in order to clean near to the base metal. Scrapers are propelled through the tubing at high velocity (20 ft/sec) by pressurized water. Occasionally, when difficult deposits and corrosion products are encountered, repeated passes of the scrapers may be used to insure optimal cleaning. Innovation of new tube cleaner designs may also be required to enable effective cleaning of unique deposit scenarios, or when existing technology is inadequate. Since condenser fouling can have such a dramatic impact on cost-effective power plant operation, deposition and corrosion should be carefully monitored, and the condenser cleaned at optimal intervals.

CONDENSER TUBE FOULING

The principal modes and types of fouling on the interior of condenser tubes are:

- Deposition or particulate
- Scaling or crystallization
- Microbiological
- Debris or macrofouling
- Corrosion and corrosion products

In most cases, fouling is not due to a single mechanism; however, in many situations one mechanism will be dominant. Fouling tends to increase over time, with the rate of increase being very site-specific. Recognizing this, the Tubular Exchanger Manufacturers Association [1] has recommended that designers of heat exchangers include an allowable fouling resistance in their calculations, in order that some fouling can be tolerated before cleaning becomes necessary. Heat Exchange Institute standards [2] also include some fouling in their requirements for steam surface condensers. Although these allowances tend to mask losses of efficiency, fouling still may have an impact on under-deposit corrosion; most corrosion problems on the interior of condenser tubes result from tube fouling. Thus, determining when to clean often requires striking a balance between tolerable efficiency loss and providing protection from corrosion. A model of under-deposit corrosion [3] is shown in Fig. 1.

Deposition or Particulate Fouling

Deposited material is fine-particulate debris that settles on the tube surface due to gravity under low-flow conditions. This debris may be natural sediment (e.g. river silt), biogrowth (e.g. algae), coal dust from plant operations transported to source water, or crystalline solids precipitated as particulates in a cooling tower basin (e.g. calcium carbonate, silicates, phosphates, sulfates, etc.). Deposits may form inconsistently over a tube surface, primarily occurring at the bottom of the tube due to gravity settling.

Normal recommended flows through condenser tubes (minimum seven feet per second) should be adequate to prevent the settling of particulates; however, a condenser with an average flow representing 7 fps may have areas or specific tubes with much lower flow rates. For example, inadequate circulating water pumping may not entirely fill an inlet waterbox, so that intermittent and partial flow can occur in upper tubing. Partial blockage will also cause reduced flow through tubes, which can result in considerably increased particulate settling and accumulation downstream of the blockage.

The most serious problem resulting from deposition in condenser tubes is under-deposit corrosion. This can be a serious problem even when heat transfer efficiency is only a minor concern, because the amount of tube surface containing deposits that stimulate under-deposit corrosion can be relatively small. Corrosion occurs primarily because of the electrochemical potential differential between the tube surface beneath the deposit and the adjacent general (clean) tube surface. Additionally, corrosion is often enhanced by the action of bacteria within the deposit, which can produce corrosive metabolic constituents. Because of this phenomenon it is necessary to keep tubes as clean as is practical.

Scaling or Crystallization Fouling

Scale occurs when the saturation point of dissolved constituents in the cooling water is exceeded, and precipitation occurs directly on tube surfaces. Some common cooling water constituents form scales that precipitate preferentially under higher temperature conditions (calcium carbonate, calcium phosphate); therefore, formation of scale on warm tube surfaces is promoted. Such scaling is also more likely to occur on hotter tube surfaces (towards the condenser outlet).

When condenser tubes are scaled it is usually a widespread occurrence, and very detrimental to heat transfer. Even a thin layer of scale can cause a major reduction in heat transfer; for instance, manganese, silica and calcium carbonate scales have been reported to cause losses in output capacity of 20 to 25 megawatts [4]. Scale can also provide sites for local under-scale corrosion (Fig. 2). Inconsistently-present scale, with areas of scale-free surface due to either loss of existing scale or inconsistent formation, is particularly detrimental; erosion-corrosion can result in brass tubes due to local flow turbulence [5] (Fig. 3), and the likelihood of damage from differential concentration corrosion cells may also be enhanced. The most comprehensive removal of scale is generally required.

Microbiological Fouling

Bacteria present in natural waters will commonly form a thin biofilm on condenser tube surfaces. Recirculating cooling water (cooling towers) is typically treated with biocidal chemicals, such as bleach, chlorine gas or organic biocides. These may be fed continuously or intermittently (e.g., two hours daily), and are very effective in limiting the growth of microorganism populations. However, once a biofilm gains a foothold, biocides may not be effective for film removal. Biofilm development is inversely related to flow velocity; attachment of bacteria to the substrate is more difficult at higher velocities. Conversely, low velocities (similar to those that may support fine particulate deposition) are conducive to bio-growth. Biofilms contain a considerable amount of entrapped water, and when dry, may appear to be of minimal significance; however, water is a relatively good insulator of heat, so even thin biofilms can have a major impact on heat transfer. In one incident, a station lost over 50% of generating capacity due to backpressure problems resulting solely from a biofilm [6]. In many cases, biofilms will entrap fine particulates, which may further reduce heat transfer.

As mentioned previously and as shown in Fig. 4, certain types of bacteria produce corrosive metabolic by-products (sulfate-reducing bacteria, SRBs); others (iron-oxidizing) may actually consume base metal. Corrosion by bacteria is usually not a serious problem except in cases where stagnant conditions exist (under deposits or scale, or off-line during unit outages). One exception is manganese pitting of stainless steel, which occurs on-line with a thin manganese oxide scale that is believed to be deposited by micro-organisms (Fig. 5).

Debris and/or Macrofouling

Macrofouling of the condenser inlet tubesheet and tubes can occur by any substance whose size is close to, or greater than, tube internal diameter. Rocks, concrete pipe debris, cooling tower materials (plastic fill, wood), chunks of ash, large pieces of rusted steel, coal, windblown debris (paper trash, leaves or other vegetation), aquatic animals (crayfish, fish, clams), and any other substance that enters the circulating water can obstruct cooling water flow.

Partial flow blockage of condenser tubes can occur when a tube inlet is partially covered by debris (e.g., a piece of plastic), or when an object lodges within a tube (e.g., a rock or piece of wood). Two damaging effects can result: (1) Slower flow through the tube will permit fine particulates to accumulate and settle, and (2) Local flow around the lodged item may be high, causing erosion-corrosion (primarily a problem for copper alloys). Screens are employed prior to the condenser, with mesh size selected to prevent debris larger than tube internal diameter from traveling to the waterbox. However, clogged screens may overflow, corrosion may create wider openings in the screens, elongated objects may pass through screens and lodge sideways on tubesheets, and sometimes open circulating water systems can permit entry of debris after the screens, or debris may originate downstream of the screens (e.g. deteriorating concrete tunnels or waterbox epoxy coatings, rust chunks).

Corrosion Fouling

Saxon [7] reported that properly cleaned copper alloy tubes in waters of low corrosivity are not normally susceptible to pitting. Copper alloys passivate by forming a protective cuprous oxide (Cu_2O) film on the surface. This basic protective film is non-porous, very thin, and transfers heat efficiently. Undisturbed, this film keeps the tube from pitting. Unfortunately, normal operating conditions can be damaging to this film. Copper oxides will continue to grow in oxygenated water of high conductivity, and a very thick outer layer of porous cupric oxide (CuO) can develop. This porous, non-protective oxide disturbs the cuprous oxide film and concentrates corrodents that can attack and pit the base metal. Thus, cupric oxide not only reduces heat transfer, but can also accelerate corrosion. Where thick cupric oxide films develop, they must be removed regularly to prevent pitting and extend tube life. Under normal circumstances, stainless steels and titanium form very thin passive oxide films that neither inhibit heat transfer, nor promote corrosion.

PREVENTION OF TUBE INTERIOR FOULING

Suitable approaches exist for addressing routine condenser tube fouling problems. However, applying preventive measures for all possible fouling scenarios would be cost-prohibitive, particularly for those issues a station considers itself unlikely to encounter. Chemical and mechanical preventive approaches are commonly utilized.

Chemical Treatment

Several chemicals, often in combination, are used to control condenser tube fouling. Chemicals are primarily utilized with recirculating cooling towers, because (1) The concentration of dissolved constituents is significant, increasing the threat of scaling and corrosion, and (2) Once-through cooling systems often discharge directly into a river or lake, with chemicals restricted in the effluent. Table I identifies some chemical treatment methods commonly used.

Treatment Method	Description
pH control	Most scales formed from natural waters have greater tendency to occur at elevated pH. Sulfuric acid is the most common chemical used for pH reduction, because of its comparatively low cost and widespread availability.
scale inhibitors	Phosphonates, such as HEDP (1-hydroxyethylidene-1,1-diphosphonic acid), and polymers such as polyacrylate are commonly used to inhibit scale formation, along with a variety of related specialty molecules.
dispersants	Dispersants act much like soap, keeping fine particulates in suspension, or causing settled particulates to go into suspension.
biocides	Oxidizing biocides are added primarily to kill bacteria and algae, thus preventing them from gaining a foothold. Non-oxidizing biocides are also frequently used.
corrosion inhibitors	Zinc and phosphate inhibit corrosion of carbon steel, and triazoles inhibit copper-alloy corrosion.

TABLE I
Common Chemical Treatment Methods

Another common means of minimizing chemically-influenced problems is to minimize the concentration of dissolved solids in the system, particularly in cooling towers. A balance must be determined between minimizing water use, and avoiding excessive buildup of scaling and corrosive constituents in recirculated water.

Some scales can be removed on-line (or off-line) by lowering circulating water pH to the point of scale dissolution by increasing the sulfuric acid feed (pH of 5.8 or less for calcium carbonate, 4.0 for calcium phosphate); however, potential risks to base metal and carbon steel piping must be carefully considered. In the case of an on-line chemical cleaning by pH reduction, one major disadvantage is uncertainty regarding the composition of the foulant.

Mechanical Fouling Prevention

A number of approaches have been developed to prevent condenser tube fouling by mechanical means. As previously mentioned, screens are installed to block large debris from reaching the condenser. Settling ponds and/or clarifiers remove particulate and some dissolved constituents. Filtration systems, such as sand filters, can also be employed to remove fine particulates, on either a full-flow or sidestream partial flow basis. A number of systems have been developed which send cleaning objects such as sponge balls, brushes or plastic scrapers through tubes with cooling water flow, theoretically wiping tubes clean; some of these cleaners are retrieved at the condenser outlet and returned automatically to the inlet, others are returned to the inlet via backwashing. Because of the random distribution of some of the cleaning devices not all tubes receive consistent cleaning action. Increasing cooling water flow through the condenser can be effective in limiting microbiological growth; this will also keep temperatures lower, possibly to a point at which scale formation is less likely. However, higher flow rates can cause increased rates of erosion-corrosion in copper alloys.

OFF-LINE OPTIONS FOR CLEANING FOULED TUBES

Chemical Dissolution

Mineral scale can generally be removed by a chemical solvent (e.g. hydrochloric acid for calcium carbonate, hydrofluoric acid for silicon-based scales). Major risks include incomplete scale removal, in which case pitting may occur under the remaining scale where the cleaning solution was entrapped and not adequately rinsed, and corrosion of the base metal. Additionally, the work can be expensive, job duration may increase outage time, safety concerns exist, and the subsequent disposal of the waste chemical solution may be costly. It has been frequently found that some residual material must be removed by mechanical cleaning methods following the chemical clean.

Mechanical Removal

Several viable options are used for removing condenser tube foulants mechanically. High pressure water (8,000 – 40,000 psi) may be effective, although some potential exists for cutting softer copper alloys. Sponge balls may be sent through tubes to remove existing foulants; abrasive balls are available for harder foulants such as scale, although effectiveness may be limited. Brushes of various types may be propelled through tubes; mechanically-powered rotating brushes can also be used. Metal or plastic scrapers powered by pressurized water are commonly used and are effective for general purpose foulant removal, plastic being used for only the lightest deposits.

Large debris blocking tubes may be removed by backflushing or any of the mechanical methods listed above; however, if debris is firmly lodged in the tube, it must be rodded out with steel bar stock or a flexible fiberglass rod. It is generally necessary to open the waterbox and physically remove large debris that has accumulated and blocked flow at the inlet tubesheet, or it will simply return to the tubesheet when flow is resumed.

OFF-LINE MECHANICAL CLEANING OPTIONS

While cleaning and preventive measures for condenser tube fouling can be performed *on-line*, the remainder of this paper focuses on cleaning technology innovations and procedures that are performed *off-line*; specifically, mechanical cleaning options, which are the most frequently chosen, most generally applicable and effective, and fastest cleaning methods available.

Saxon and Putman [8] addressed the benefits of mechanical cleaning for improving plant performance and, consequently, reducing CO_2 emissions. Their conclusions are straightforward: Off-line mechanical cleaning is especially useful where fouling problems exist that are too severe to be handled by any of the other methods. Obviously, the tool selected must be the most appropriate for removing a particular type of deposit.

Although the use of high-pressure water can be effective with certain foulants, the jet nozzle must be moved along the tube slowly, and the time required to clean a heat exchanger can be excessive. Great care must be taken to avoid damaging the tubesheet, tube coatings, or inlet-end inserts which may be present. Otherwise, the successful removal of fouling deposits may be accomplished at the cost of new tube leaks or increased tubesheet corrosion, only recognized after the unit has been brought back on-line. Molded plastic cleaners (pigs) are quite popular for some light silt or microbiological film applications. Brushes can also be used to remove these soft deposits. Brushes are also useful for cleaning tubes with enhanced surfaces (e.g. spirally indented or finned), or those tubes with thin wall metal inserts or epoxy type inlet coatings.

Metal Scrapers

With harder types of deposits, calcium carbonate (calcite) being a notable example, metal cleaners of various designs have been developed for effective removal. The spring-loaded blades of the metal cleaner are an essential element in the success of the technology. The use of spring-loaded tube cleaners was identified as a best maintenance practice by Putman and Walker [9]. The blades are mounted on a spindle (Fig. 6). At one end of the spindle has a serrated plastic disk that allows a jet of water to propel the cleaners through a tube with greater hydraulic efficiency. The water is directed to the tube being cleaned by a water gun, and is delivered by a portable pump. Water pressure of 300 psig is most effective for propelling the cleaning tools through the tubes at their design travel speed of ten to twenty feet per second. The use of water pressure also prevents the cleaner’s exit velocity from rising above a safe level. Some other cleaning systems use air or a mixture of air and water to propel the cleaner, but air pressure is compressible and dangerous to use. Since the pump is usually mounted on a wheeled base plate, the system can be conveniently moved from unit to unit within a plant, or even moved to another plant.

Another advantage of using water for tube cleaner propulsion is that the material removed is rinsed out, and can be collected in a plastic container for later drying and weighing to establish the deposit density (g/m^2), followed in many cases by laboratory analysis of the deposit.

Most metal cleaners are designed to have a controlled spring-loaded cutting edge; however, if effective deposit removal is to be the result, the dimensions of the cutting surfaces have to be closely matched to the internal diameter of the tube being cleaned. This not only improves the peripheral surface contact, but also ensures that the appropriate spring tension will be applied as the cleaner moves through the tube (Fig. 6). The effective life of cleaners with this design can be as high as 12 tube passes.

In practical experience, Kim [10] found that annual off-line mechanical tube cleanings using metal scrapers was effective in reducing the corrosion rate, retarding pitting and increasing unit availability, reversing a trend of increasing tube leaks and plugging.

Innovations in Cleaning Technology

As a result of an innovative research program organized to resolve problems encountered in the field and to develop new products where existing equipment was found to be inadequate, new tube cleaners have been developed. For example, in order to provide the blades with more circumferential coverage of the tube surface, a new scraper design was introduced (Fig. 7). The increased contact surface provided by the greater number of blades was found to be more efficient in removing tenacious deposits such as those consisting of various forms of manganese.

Another development involved a tool for removing hard calcite deposits, which were sometimes found to be difficult to remove in a timely manner, even by acid cleaning. This cleaner is shown in Fig. 8, and consists of a teflon body on which are mounted a number of rotary cutters. These are placed at different angles around the body, which is fitted with a plastic disk similar to those used to propel other cleaners through tubes. Used on condenser tubes that had accumulated a large quantity of very hard deposits, Stiemsma, et al [11] described how cleaners of this type removed 80 tons of calcite material from a large surface condenser. It has now become a standard tool whenever hard and brittle deposits are encountered. Hansen and Saxon [12] demonstrated the practical use of this tool for removing scale from stainless steel condenser tubes. Boroscopic photography shows the effectiveness of this cleaning tool in Fig. 9 and Fig. 10.

Additional developments for the removal of manganese dioxide, iron oxide, and silica deposits include the stainless steel brush, which has over 1,000 contact points per brush (Fig. 11). Actual aluminum brass tube samples with iron and manganese deposits were examined in the "as found" and "as cleaned" condition (Fig. 12). After one pass of the stainless steel brush the cleanliness factor for the tube from waterbox A went from 83.3 percent to 91.5 percent, and from 73.6% to 94.1% in the tube from waterbox B.

The experience gained from using these techniques has allowed the cleaning duration to be forecast with confidence and cleaning to be performed on schedule. For instance, a normal crew of four technicians can clean 5,000 tubes during a 12-hour shift. Clearly, the number of tubes cleaned in a day could rise with an increase in crew size, limited only by the availability of adequate space for the crew to work effectively.

All off-line cleaning methods may sometimes require additional deposit removal assistance, especially where the deposits have been allowed to build up excessively, and sometimes become harder. In such cases, for example, it may be necessary to acid clean, followed by cleaning with mechanical cleaners or high-pressure water to remove any remaining debris. Tube cleanliness can then be maintained by regularly scheduled off-line cleaning.

Effect of Metal Scrapers on Tube Surface

One perceived drawback of using metal scrapers to clean condenser tubing is their effect on tube metal, including concerns over incompatibility of the carbon steel scrapers with various tube metal alloys, and the possibility that base metal might be removed by the scraper digging into the tube wall. Additionally, many plant operators are concerned that metal scrapers will remove protective oxide coatings from tube surfaces, thus exposing base metal to accelerated local corrosion.

With cleaners that have been properly designed and carefully manufactured, loss of base metal is very minor. Indeed, Hovland, et al [13] tested such carbon steel cleaners, manufactured by Conco Systems, Inc., by repeatedly passing them through 30 feet long 90-10 CuNi tubes. It was found that after 100 passes of these cleaners, wall thickness reduction was only between 0.0005 and 0.0009 inches (12.5 and 23 μm). At this rate, extrapolating the worst-case removal from this series of tests for a 0.049" wall thickness, it would take about 2700 passes of a cleaner per tube, or roughly 1000 years of annual condenser cleanings to result in a critical reduction in tube wall loss.

Regarding exposure of base metal to accelerated corrosion due to removal of a protective oxide layer, no evidence of this scenario has been produced. In fact, where protective oxide is removed, it is rapidly re-formed upon exposure to oxygenated water, with no detrimental effects.

Galvanic Corrosion of Stainless Steel

According to electrochemical theory, metals and alloys can be ordered according to relative reactivity, with magnesium, zinc and aluminum towards the active end of the series, and titanium, passive stainless steel and copper alloys towards the passive or noble end. When a galvanic couple exists (two different metals or alloys in physical contact), the less noble partner acts as an anode and will corrode (oxidize). The relative surface areas of anode and cathode are also important in determining the corrosion rate; if a large cathodic area is associated with a small anodic area, the corrosion rate is increased, since all of the electrochemical oxidation current is focused on a small region. In general, the corrosion rate is also increased with increasing water salinity (dissolved solids) and / or increasing temperature.

Note that stainless steel can be in either an active or passive state. In air, stainless steel is passive. Immersed in water, passive stainless steel is more noble than copper alloys, and much more noble than carbon steel. Its normal state in oxygenated fresh water is passive, provided the tube surfaces are clean. In saline water, anodic protection may be required to maintain the more noble (passive) state, in order to reduce the rate of corrosion. Note that a variety of stainless steel alloys exist, including the austenitic (300-series) and ferritic types

(400-series). Specialized stainless steels can be very corrosion resistant, including the austenitic alloy AL6XN (high Cr, Ni, Mo, and N), and the ferritic alloy SeaCure (high Cr and Mo). Stainless steel alloys are susceptible to pitting by under-deposit corrosion, as they depend on a thin surface chromium oxide layer for passivation, and this layer is best maintained by continuous exposure to oxygen.

Most stainless steel condenser tube installations have been composed of the 304 or 316 alloys. They were first installed for surface condenser applications over 45 years ago, and have seen many routine cleanings with both carbon steel and stainless steel scrapers. As described by Saxon [14] and later Putman [15], it is clear that these tubes, as with other alloys, frequently require cleaning.

While concerns over material incompatibility have been expressed, in practice there has been no evidence of carbon steel particles from properly designed mechanical scrapers embedding into stainless steel tubes. Tests were conducted by Anderson [16] on stainless steel tubes that had been cleaned with carbon steel mechanical scrapers. No transfer of carbon steel onto the stainless steel tube surfaces was observed, and this has been the common experience. There is no possibility of galvanic corrosion of the stainless steel; embedded carbon steel particles would corrode preferentially. After such particulates are oxidized to iron oxide they should be removed, similar to any other particulate fouling. It is well known from the literature and in practice that if 300-series stainless steel tubes are not kept clean, deposits such as naturally occurring iron oxide, manganese oxide, calcium carbonate and bacterial accumulations are prone to cause pitting and crevice corrosion. Stainless steel condenser tubes must be kept clean, and properly-designed metal scrapers, either carbon steel or stainless steel, are an effective option.

While this section has focused on 300-series stainless steel tubes, similar considerations would apply to the possible embedding of carbon steel scraper material in other common tube alloys, such as titanium and copper alloys – the carbon steel debris would oxidize preferentially to the base metal.

SELECTING A CLEANING PROCEDURE

Regardless of the tube material, the most effective way to ensure that tubes achieve their full life expectancy and maximum heat transfer efficiency is to keep them clean. Each time the tube deposits, sedimentation, biofouling and obstructions are properly removed, the cleaned surfaces should be returned as nearly to bare metal as possible. This restores optimal heat transfer and essentially supplies the tube itself with a new life cycle, as protective oxide coatings quickly rebuild themselves to re-passivate the cleaned tube.

While most existing foulants can be removed by either chemical or mechanical means, selection of an optimal method is generally based on the type of foulant and the cost of the technique. Putman [17] described the important criteria in selecting an appropriate cleaning procedure: the selected cleaning procedure should remove the particular deposits that are present as effectively as possible, and render the unit *out of service for the minimum amount of time*. Some other major considerations in the selection process are discussed briefly in the following paragraphs.

Removal of Obstructions

Many tube-cleaning methods are ineffective when there are obstructions within tubes, or when various forms of macrofouling are present. When such obstructions are found it is inadvisable to proceed with the cleaning regimen as planned. Attention should be given to shellfish which constitute macrofouling, and can include Asiatic clams and zebra mussels in cooling water. Other obstructions generated directly from the process medium must be considered as well. The selected tube cleaner must have the body and strength to remove such obstructions. The cleaning method may be required to remove the byssal material that shellfish use to attach themselves to tube walls, as well as hard, aged deposits.

Certain types of other debris and process impurities can become obstructions, including cooling tower fill, waste construction material, sponge rubber balls, rocks, sticks, seaweed and fresh water trash, any or all of which can become lodged in the tubes or on the tubesheet, and will require removal. Cleaning objects can themselves become obstructions, although experience has shown that if appropriate procedures are followed, properly designed cleaners will not become stuck inside tubes, unless the tube is deformed.

Removal of Corrosion Products

When heat exchangers are equipped with copper alloy tubing, corrosion product growth under deposits is a particular concern. Copper oxide corrosion products can grow to the point at which they will seriously impede heat transfer. Not only will the performance of the condenser be degraded, but such deposits will also increase the potential for tube failure. Under deposits, a protective inner cuprous oxide film cannot be maintained; thus, the base metal is exposed to attack. When destructive copper oxide accumulations occur, they must be removed, together with overlying deposits and scale.

Surface Roughness

Rough tube surfaces, often the result of accumulated fouling deposits, are associated with increased friction coefficients, while the reduced cooling water flow rates allow deposits to accumulate faster. It has been found that rough tube surfaces pit more readily than smooth surfaces, and are also responsible for inducing erosion-corrosion damage in copper-alloy tubes [18]. A tube surface rendered smooth from effective cleaning can improve condenser performance in several respects:

- Lower water temperature rise across the heat exchanger, reducing the heat loss to the environment (improved heat transfer capacity)
- Increase in both flow volume and water velocity, often resulting in reduced pumping power requirements
- Increased time required between cleanings, by reducing rate of re-deposition of fouling material on the tube surfaces.
- Reduced pitting from turbulence and gas bubble implosion
- Longer tube life

CONCLUSION

Amidst a marketplace replete with numerous cleaning and service options for removing fouling from the interior of condenser tubes, site engineers and staff must choose maintenance practices which will help to improve performance while protecting from corrosion, ensuring that the integrity of their equipment will not be compromised. Innovative techniques or procedures may be required. Interim gains in performance can be achieved while maintaining the long-term efficacy of a given unit, so long as the cleaning technology applied is sound and site-specific.

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[16] Anderson, Susan et. al., "Mechanical Manganese Dioxide Removal in Stainless Steel Condenser Tubes," *EPRI Service Water Systems Cleaning Technology Seminar*, Palo Alto, CA, February 21-22, 1990.

[17] Ibid, Putman, R.E., 2001.

[18] Ibid, Howell, A.G. and Schwarz, R.C., 1993.

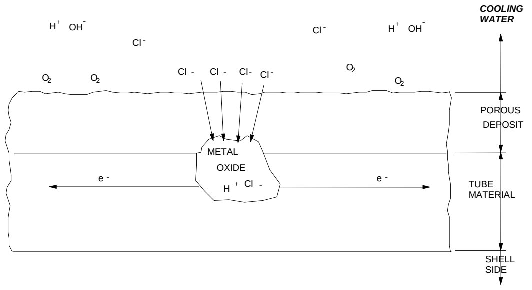


Figure 1
Model of Under-deposit Corrosion

Figure 2
Pitting Under Scale in Stainless Steel Tube
(Photo Courtesy of Howell Image Sciences)

Figure 3
Erosion-corrosion Around Deposits
(Photo Courtesy of Howell Image Sciences)

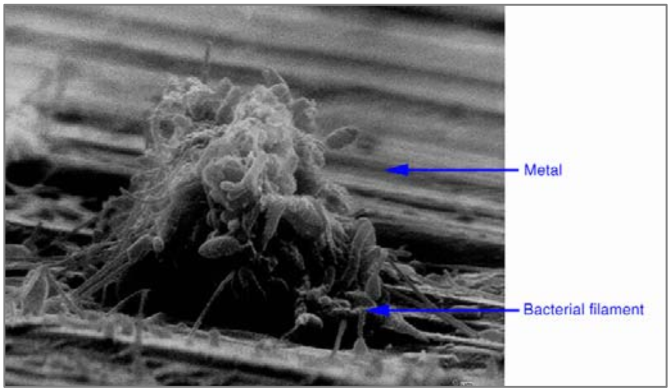


Figure 4
Bacteria Consuming Base Tube Metal

Figure 5
Pitting Due to Manganese Deposits
(Photo Courtesy of Howell Image Sciences)

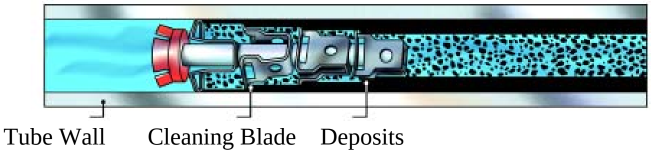


Figure 6
Tube Cleaner in Action
(Figure Courtesy of Conco Systems, Inc.)

Figure 7
Hex Cleaner
Patent No. 0698423
(Photo Courtesy of Conco Systems, Inc.)

Figure 8
Cal Buster
Patent No. 5153963
(Photo Courtesy of Conco Systems, Inc.)

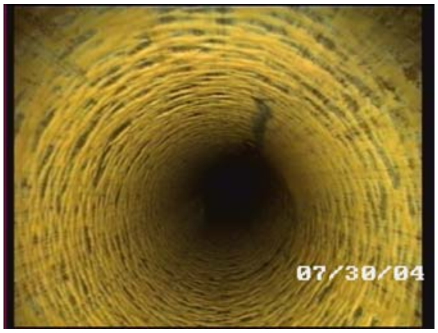


Figure 9
Stainless Steel Condenser Tube with Calcium Carbonate Scale

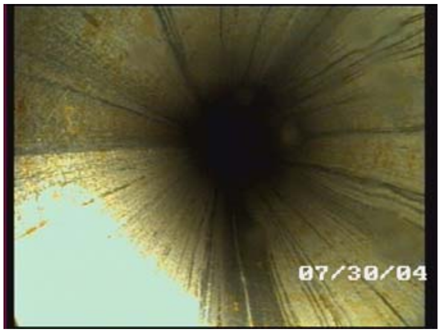


Figure 10
Stainless Steel Condenser Tube with Calcium Carbonate Scale Removed

Figure 11
Stainless Steel Tube Cleaning Brush
Patent No. D450035
(Photo Courtesy of Conco Systems, Inc.)

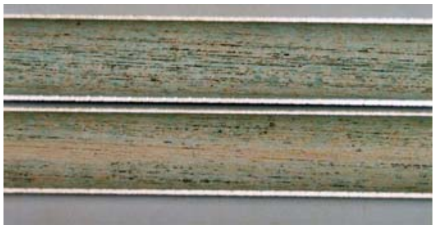
A Water Box	As Found Tube CF 83.3%	
	Cleaned Tube SSTB 1 Pass CF 91.5%	
B Water Box	As Found Tube CF 73.6%	
	Cleaned Tube SSTB 1 Pass CF 94.1%	

Figure 12
Aluminum Brass Tubes Tested for Manganese and Iron Deposit Removal