CONDENSER AND BOP EXCHANGER LAYUP- Do's and Don't's

39th Annual Electric Utility Chemistry Workshop
June 4-6, 2019
Champaign Suites
Champaign, Ill

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Abstract

Many condensers and BOP exchangers have experienced rapid tube failures when stagnant service water remained in the exchanger tubes during outages. Tube penetrations in as little as three weeks of stagnant layup are common, even in waters not known to be particularly aggressive. Although high performance alloys like titanium grade 2, and austenitic and ferritic high performance stainlesses like N08367 and S44660 respectively are more resistant to layup problems, deposits may build during outages significantly impacting thermal performance once back on-line. This presentation identifies the common failure mechanisms, which alloys are particular sensitive, and changes that have occurred that increase the sensitivity today. It will also provide recommendations of what to do, and more importantly, what to ensure that your condenser/exchanger comes back into service problem free.

Introduction

One of the more devastating things to experience is to return from an outage and learn that your condenser or key BOP exchangers has numerous leaks preventing an on-time start-up. Most tube materials have been selected for clean flowing-water service. However without special preparations during shut down, conditions on the service water side of the tubing can be quite different than what the material was selected. These surprise failures are not uncommon. Some examples include:

- 300 MW plant using once through Iowa river water, 304 SS after a 3 week planned outage,
- 600 MW plant using once through lake cooling water in Northern Illinois, 304 SS after a 70 day forced outage,

- 300 MW plant using once through lake cooling cooling water , 316 SS after a 30 day planned outage,
- 400 MW Lake Michigan water – TP439 BOP exchanger – 6 weeks from start of service
- 680 MW in Nebraska, once through cooling lake – 1 week outage

Some of these plants listed above exhibited leaks in 30% of the tubing in the bundle, a very significant number that affected thermal performance and load capability after plugging of the tubes. Numerous additional examples with a lesser number of tubes plugged have been reported. The majority of these tube problems could have been prevented using proper lay-up practice at the start of the outage. Once the damage has been initiated,

With the increase in cycling starts and stops for traditionally operated base loaded units, the potential for damage increases significantly. Numerous references (1,2,3,4,5) approach the subject on how to plan and lay-up the cooling water tubing side but since these papers mostly take a broad look of overall plant lay-up, the descriptions specific to protecting tube interior are not detailed enough to assemble a written practice for this area. Additionally, the guidelines tend to conflict with each other in some areas as consensus has not been obtained between the various organizations. For example, the definition for short lay-up period can range from a few hours, to several days. This definition may be impacted by margin of risk that is developed between the corrosion resistance of the alloy, and the perceived aggressiveness of the water. Higher corrosion resistant alloys and/or lower aggressive water will lower the risk. In most general areas, the referenced guides tend to agree. For example, the VGB guidelines (1) clearly identify that the stainless steels need to be treated much more carefully than the copper alloys. Although is not stated in any of the North American guides, general experience here supports the difference.

Risks from Improper Layup

The majority of the failures could be from one or more of several mechanisms such as but not limited to:

1. Concentration of solids due to evaporation developing crevices,
2. Reduction of pH causing depassivation,
3. Exhaustion of biocides,
4. Creation of chloride salts that exceed the alloy's threshold limit,
5. Failure to turn off chemical treatment during CW shutdown.

A combination of more than one of these mechanisms may be needed to cause the attack.

Concentration of Solids

If a cooling water with relatively high total dissolved solids (TDS) is left in the tube, contaminates can concentrate to a point where they can be aggressive to the tube surface (Figure 1). Even though the condenser may be drained, the slope of the condenser is rarely sufficient to completely drain all of the water in the tubing. Construction variations along the length of the condenser allow low spots and, in older condensers with long spans, the sagging between the supports will also allow pooling. With time, the water evaporates concentrating the TDS. Higher chlorides are the most aggressive substance. However, with copper alloys, sulfides may also cause damage. Admiralty brass has been known to pit with as little as 3000 to 5000 ppm chlorides, while aluminum brass and copper-nickels may start being attacked at something exceeding 25,000 ppm chlorides (see Figure 2). However, when sulfides are present, a sulfide layer may replace the traditional copper oxide or oxy-hydroxide protective patina. If the CW pH is above 8, the damage may be minimal. Below that pH the copper sulfide surface can become water soluble and the tube wall will quickly dissolve as the tube attempts to repassivate. (Reference 6).

The initiation of attack in stainless steels is more complicated. Kovach and Redmond (Reference 7) and Janikowski (Reference 8) have identified that the chloride resistance of stainless steels is not only a function of the alloy content (with Cr, Mo, and N being the principal alloy additions providing chloride resistance), the alloy crystal structure is also important (Figure 3).

Also factoring into this attack is the water pH (lower is more aggressive), water temperature, and the availability of oxygen. In most cases, and provided the pH and temperature remain the same, an oxygen free environment provides more corrosion resistance.

Once the TDS concentration reaches the saturation limit, compounds start to precipitate out on the tube surface, changing the potential mechanism from pitting corrosion to crevice corrosion. Crevice corrosion may initiate at temperatures 35 C lower than the temperature that pitting may start. The crevice can concentrate chlorides and impact pH. An alloy that normally would be resistant from pitting corrosion at the same temperature may be aggressively attacked once the crevice is formed.

Stagnation's Impact on pH & Exhaustion of Biocides

In stagnant conditions, a drop in pH is quite common. Carbon dioxide can form carbonic acid. Many aerobic bacteria can produce carbon dioxide. However, once the oxygen is used up, anerobic bacteria can thrive. These can be particularly aggressive. Copper alloys and the lower performance stainless steels (300 series) are particularly sensitive to depassivation as a result of the drop in pH.

Two groups of bacteria have been implicated in the failures of numerous tubing applications, the sulfate reducing bacteria and manganese and iron fixing bacteria. The sulfate reducing bacteria are anerobic bacteria that convert sulfates in the water into sulfuric acid and/or hydrogen sulfide. The two most common are Thiobacillus and Desulfovibrio. Their presence can be particular disasterous to copper based alloys as the protective patina is converted to copper sulfide which is soluble is water with a pH of less than 8. Figure 4 shows sulfate reducing bacteria tubercle on Admiralty brass opened to see the actively corroding copper colored surface under the deposit. This tubing was in a BOP exchanger in a plant on Lake Erie that was used in cyclic operation. The exchanger was not drained during shutdown and tubing was failing in less than 2 years of service. Attack of stainless steels as a result of the presence of the sulfate reducing bacteria is more rare than with copper alloys, but not unknown. The unexpected TP439 tubing in the BOP exchanger that failed in just 6 weeks on Lake Michigan water was the result of sulfate reducing bacteria exposure and stagnant condition. Note that these two waters are often considered to be some of the cleanest waters in North America, so when stagnant conditions exist, tubes are at risk in almost any water.

Probably the most common 300 series, 439, or lower performance duplex stainless steel, condenser and BOP exchanger corrosion failures are related to the manganese and iron fixing bacteria. Although less common, several Eastern US copper-nickel tubed condensers have also needed retubing for this reason. Variations of the mechanism have been described by Tverberg, Pinnow, and Redmerski (ref. 9) and Dickenson and Pick (ref. 10). As little as 0.5 ppm iron ion or 20 ppb of water soluble Mn^{+2} ion can be captured by the bacteria and oxidized to insoluble Fe_2O_3 or MnO_2 and deposited as a fairly dense brown to black layer. The layer reduces heat transfer in addition to forming a crevice. In many cases, the attack is initiated on the introduction of shock chlorination which reacts with the layer forming localized HCl. This HCl is sufficient concentrated under the layer to initiate chloride pitting. The pitting is often spherical or multi-spherical shaped with a very small opening on the surface (Figure 5). Alloy 439 has also exhibited closely spaced more open pitting (Figure 6). However, this tubing may have had an initial heat treat related Cr depletion layer on the ID surface.

In certain situations, the attack may occur without the presence of the bacteria or the oxidizing chloride. These chloride ions may not be the only source for the oxidation required to initiate the pitting. One multi-unit plant exhibited extensive Mn related BOP and condenser tubing failures without using chlorine based biocides (ref. 11). Licina has confirmed this by examining a number of test combinations using reversed potentiodynamic corrosion test scans to find the threshold levels of chloride and manganese. In his testing, without the addition of an oxidizing biocide, that very low levels of non-oxidizable chloride (70 ppm) and Mn (100 ppb) can cause pitting attack of 304L (ref. 12).

Risks for High Performance Alloys?

Earlier, we have discussed the risks of not preparing for tubing lay-ups when the tubing is not a high performance alloy. The list of proven alloys include grades that have been developed for seawater as they can tolerate more aggressive chemicals and a much wider pH range. They include:

- Titanium grade 2
- High-performance stainless steels
    - Super-ferritics such as SEA-CURE® and AL29-4C®
    - 6% Mo containing austenitics such as AL6XN® (N08365)
    - Super-duplex stainless steels such as 2507 or Zeron 100®

Copper alloys are not included in this list as the patina is sensitive to H_2S and low pH common during lay-up.

High performance alloys have little risk of pitting during shorter term unprepared lay-up in fresh or lower chloride waters. However, in longer term situations, deposits may build that could have a significant impact on thermal performance. The cost of the performance loss and subsequent cleaning should be evaluated and compared to the cost of an effective lay-up. In many cases, the cost of the lay-up is justified many times over. In Figure 7, a seawater tubesheet exhibits two issues for high performance alloys that are a concern. On the top half of the bundle, salt crystals are evident in each tube as seawater slowly dried in each tube. This action raises chloride levels above the pitting threshold for the high-performance alloys in the paragraph above. Essentially, the condenser tubing is used for a crystallizer! Below this section was a level that shows the potential for macrofouling that can impact thermal performance upon start-up.

In seawater or brackish water, lay-ups should be a standard practice even for relatively short times. The deposits that form in this environment can be quite difficult to remove and could have a greater financial impact.

Suggested Short-Term Lay-up Considerations

How long is a short term lay-up vs. long term lay-up time? Is it one hour, one day, three days, or a week? When the referenced guidelines are used, the suggestions between them may be quite different. Each plant operation is unique and the length of time is very specific to the plant. A number of factors need to be considered for making that decision:

1. Is the water fresh, mildly brackish (many tower waters may be considered this), seawater?
2. If the CW pumps continue operating, how well is the chemistry monitored and controlled?
3. What is the pump operating cost?
4. How corrosion resistant is your alloy?

The goal is fouling prevention at for the lowest cost and ease of maintenance. In preparation for this paper, a survey was made to members of the EPRI Power Plant Environmental Chemistry group. Of those who responded, many stated that leaving the CW pumps during short term plant shut downs. Follow are a summary of the suggestions from the review papers and that group.

Don’ts – Both Long Term and Short Term

Here’s the section where we get to the title namesake. As preventing a problem from happening is probably most important, I’ve reversed the do’s and don’ts priority for their importance.

1. Don’t shut down the CW pumps and leave the tubes full of water! Even a few hours of stagnant water can damage some of the more sensitive tube alloys. This may be difficult in plants designed with the condenser lower than the cooling tower basin. If building a new plant, or considering adding a tower do to 316B concerns, it will make life much easier if the tower basin is lower than the condenser.
2. Don’t assume that the biocides will provide long term protection without flow! A shock biocide charge will rarely remain after a few hours.
3. Do not expect positive tubing cleanliness by continuing flow with low flow pumps! This question has come up numerous times in new construction.
    a. The condenser design relies on head loss to ensure relatively even flow through all of the tubing. With low flow the head loss is minimal and the flow will take the easiest route through the bundle which is usually the shortest. Tubing nearer the top will very likely remain stagnant. In some bundles, lower head may not completely the entire condenser creating alternating wet/dry conditions. Typical head loss across a bundle with 6 to 9 ft/s can be 12 to 22 ft. In Figure 8, a

   schematic of a condenser shows an example of dropping flow from 8 ft/s to 4 ft/s can result in head drop across bundle from 21.75 ft to 6.48 ft. Incomplete fill is likely.

b. The low flow will allow sediments to settle and with microbial growth will be cemented to the bottom of the tube. Many bacteria produce polysaccharides which act as the glue for the silt and sand particles.
c. Unless certain provisions are maintained in the condenser system to keep the entire condenser full, many of the tubes may be only partially full producing more aggressive wet/dry conditions in those tubes.

Do's – Short-Term Practices

Depending on your tube material and financial review, this time frame may be a few hours to a few days. Most responders to the survey continue to run the CW system. Below are suggestions that may be considered and added to your checklist.

1. Keep the circulation water pumps operational. At a minimum, keep velocity at 5 ft/second minimum. This velocity needs to be sufficient to prevent settling of suspended solids and should create enough head loss to help balance the waterbox flow.
2. Institute a standard practice that ensures that the water boxes are full.
3. If using a biocide practice, continue to do so. Make sure monitoring of your standard parameters is continued and notifications to proper personnel are in place.
4. If your system is has a ball cleaning system, continue to run it. Make sure that the proper sized balls are used and they are replaced as they wear.
5. Continue the use of your anti-scalant. Alternatively, drop the pH to prevent scaling. However, continue pH monitoring as one respondent to the survey cautioned that acid valves may not be 100% reliable and the results can be catastrophic.
6. On the shift after the shut-down, have someone double check the chemistry and shutdown lineup.
7. Formalize the procedure and train to ensure it is followed in case of emergency.

Do's – Long-Term Lay-up

After your team agrees on what time frame "long term" starts, prepare a practice based on the following suggestions:

1. Drain the tubing. If the condenser is lower than the cooling tower basin, the system will need a capable pumping system and reliable valving to prevent water re-entry.
2. If the tubing has some scaling or fouling, consider cleaning tubes while they are still wet.
3. With higher performance alloys, particularly with mildly brackish and seawater CW systems, rinse the tubing with potable water to remove high TDS water.
4. With the low performance stainless steels and copper alloys, rinse the tube ID with condensate.
5. After rinsing, blow dry or dehumidified air through the man ways. Faster drying reduces the time for tube corrosion to occur. Some plants have fabricated portable manifolds to fit the openings and to increase air flow. If the condenser is drained and rinsed while hot, drying may be minimized.
6. Formalize the procedure and train to ensure it is followed in case of emergency.

If Careful Layup Is Not an Option

Most plants today consider themselves having limited resources to perform all of the tasks. In such a case, the most cost effective long-term solution may be to invest in a high performance tubing alloy. Although the cost may be twice that of the low cost alloys, that difference can be easily made up from the cost of a couple of forced outages to plug leaking tubes. The most popular alloys include titanium grade 2, super-ferritic stainless steels like SEA-CURE® (UNS S44660), and 6% molybdenum- containing austenitic stainless steels like AL6XN® (UNS N08367).
Consider running pumps continuously while maintaining biocides when lower performance tubing is used. The biocide impact needs monitored to ensure a residual of 0.3 to 0.5% free chloride or equivalent at the outlet.

When the higher performance alloys are installed but you are unable to drain the condenser, you may want to still consider running the pumps for a few hours daily to keep the tube surfaces cleaner. This should be paid back by preventing the loss of thermal performance when this is not done.

Corrosion Performance of Commodity Condenser Tubing

When discussing the need to prevent corrosion the tubing in "critical" applications in power plants, it is very important to understand that today's commodity (300 series, 439, and lean duplex stainless steels, and copper based) alloys are quite different than what was delivered 25 years ago. The market today is now globally competitive and a significant amount of tubing for both condenser and BOP exchangers is being imported into the US. All manufacturers need to reduce cost to remain in business. As ASTM tubular product specifications rarely specify a corrosion test, the manufacturers have focused on cost and productivity over corrosion resistance. This has resulted in an over "decay" in corrosion performance.

Copper Alloys

Most of the copper alloy tubing that is used power applications today is sourced from outside of the U.S. In the drive to become competitive, three changes have gradually evolved. The chemistry has been adjusted to provide a lowest cost product, regardless of the corrosion resistance. Detrimental impurities, which were once carefully controlled, may be in greater concentration than before. One addition that was added improve corrosion resistance, arsenic, has been restricted because of its toxicity during the manufacturing process. The major difference, which has had significant impact on reliability, is ID surface cleanliness control during the cold drawing process. Buecker (ref 5) identified major pitting of relatively new tubing which was found to have high sulfur drawing lubrication drawing residual which prevent proper passivation of the tubing surface. The author has been involved with several exchangers that premature failure (as short as three months of service) was found to be related to the presence of graphitic char on the surface. This char is galvanically 0.5 V cathodic to the surrounding copper alloy causing galvanic corrosion. The char is from two possible sources: degradation of the drawing lubricant during the subsequent heat treating operation or the use of carbon monoxide reducing gases during heat treatment.

Stainless Steels

Almost all stainless steel tubing is welded from strip. Blessman (ref. 13) has identified changes in production of current condenser tubing. In the goal to remain competitive the following tube manufacturing changes have resulted in reduction of corrosion resistance:

- With improvements in melt practice, alloy additions are now controlled at the ASTM minimum levels instead of the mid-range as in the past.
- Welds are rarely cold worked using both OD and ID tooling limiting homogenization of the weld during heat treatment times.
- Most stainless steel tubing is now heat-treated using induction methods which only last a few seconds instead of the traditional furnace heat treat process. This also limits homogenization of the weld structure.

For suggestions for specifying corrosion testing of various grades for new tubing procurement details are included in reference 14.

Summary

With the significant increase in cycling operations, tube lay-up practice has become important. For long tube life and predictable thermal performance, short term shutdown practices and long term lay-up procedures need to be carefully developed and followed. Tubes should not be left filled with stagnant water more than a few hours. Practices may vary based on tube material and water source and each location procedures should be specifically developed for itself. A typical lay-up flow chart is presented in Figure 9. If new tubes are being sourced, one should consider both the materials based on the anticipated operations and including corrosion testing requirements in the procurement specification.

Acknowledgments

This paper would have not been nearly as complete and useful if it were not for the responses to the ASME PPEC sub-committee request for suggestions from Brad Buecker, Jeffrey Demattos, Scott Glover, Arne Lindberg, John Rudisaile, Bill Stroman, and Bernie Wieck.

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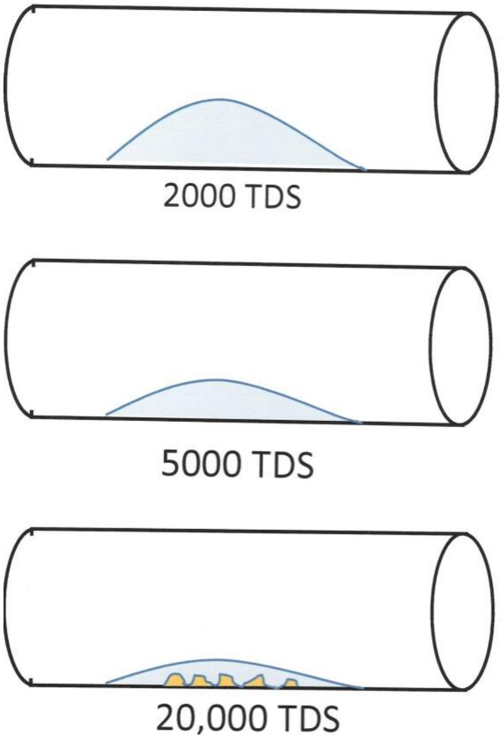


Figure 1. Impact of water evaporation when high TDS water is allowed to remain in tube

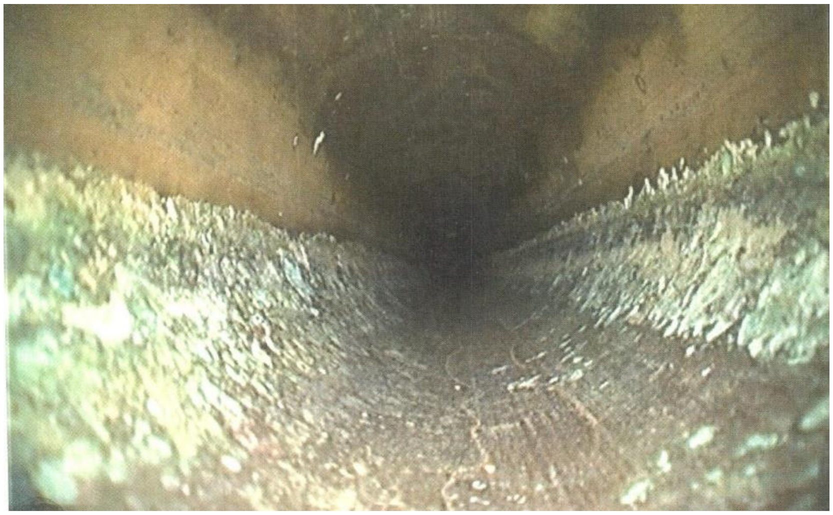


Figure 2. Deposits on Admiralty Brass in Great Lakes water due to evaporation

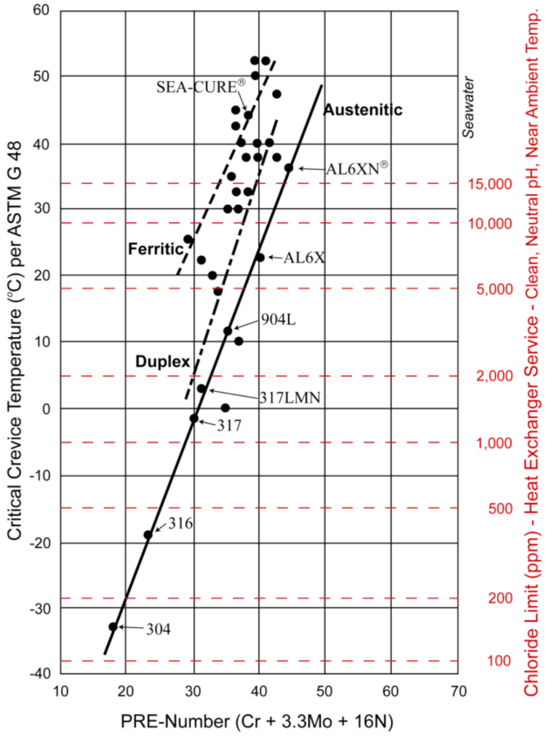


Figure 3. Relationship between chloride resistance, alloy content, and crystal structure of stainless steels.

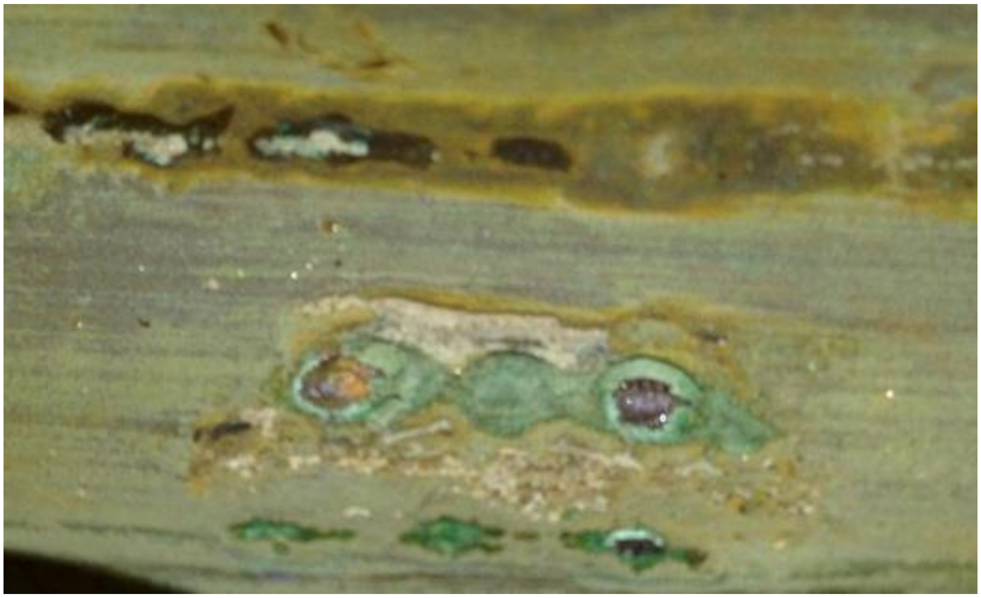


Figure 4. Tubercles on Admiralty brass with active pit as a result of sulfate reducing bacteria. This was found in a BOP exchanger in a plant on Lake Erie which was used alternating service and was full with stagnant water when not in use.

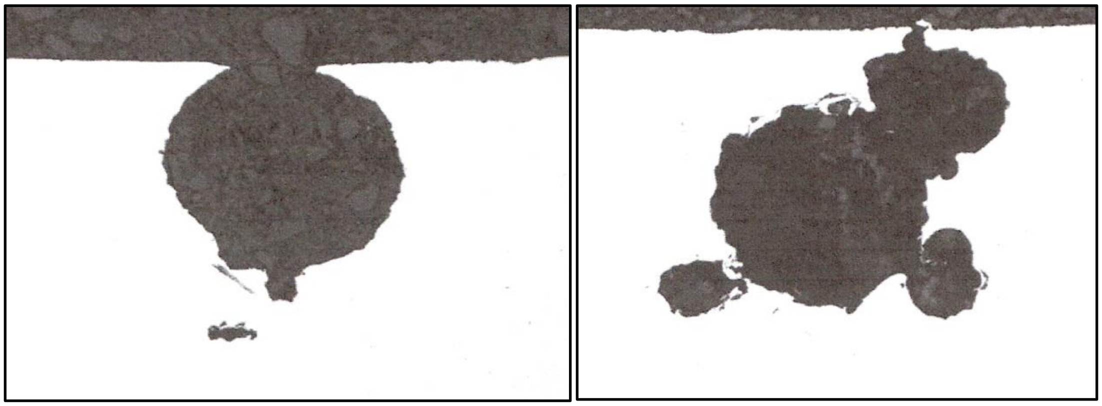


Figure 5. Spherical or multi-spherical pits in stainless steels with small openings common with Mn attack.

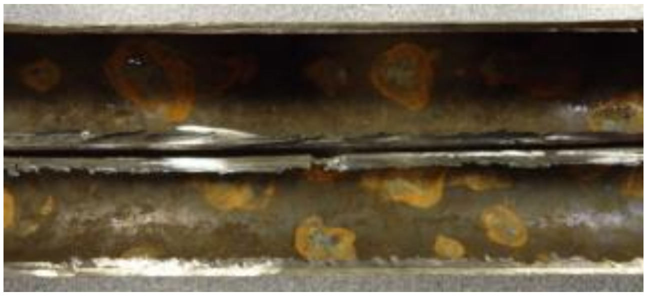


Figure 6. Attack on TP439 can be closely spaced multiple sites.

Figure 7. A combination of sea-salt crystals of tubes left to dry at the top and macrofouling at the water level on an improperly laid up seawater condenser bundle.

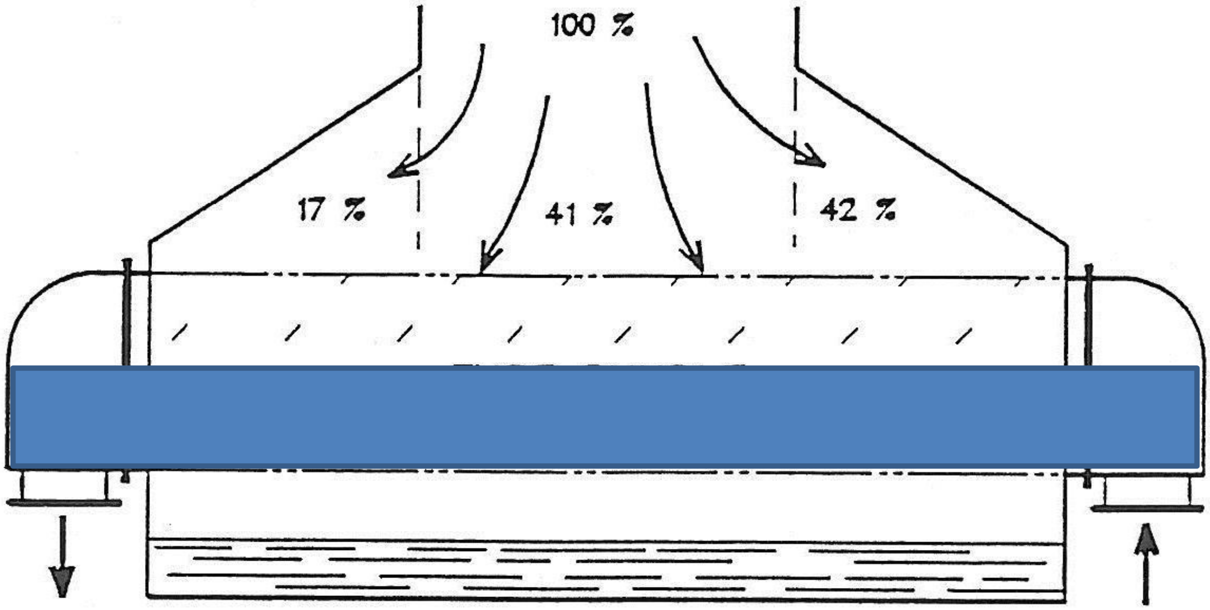
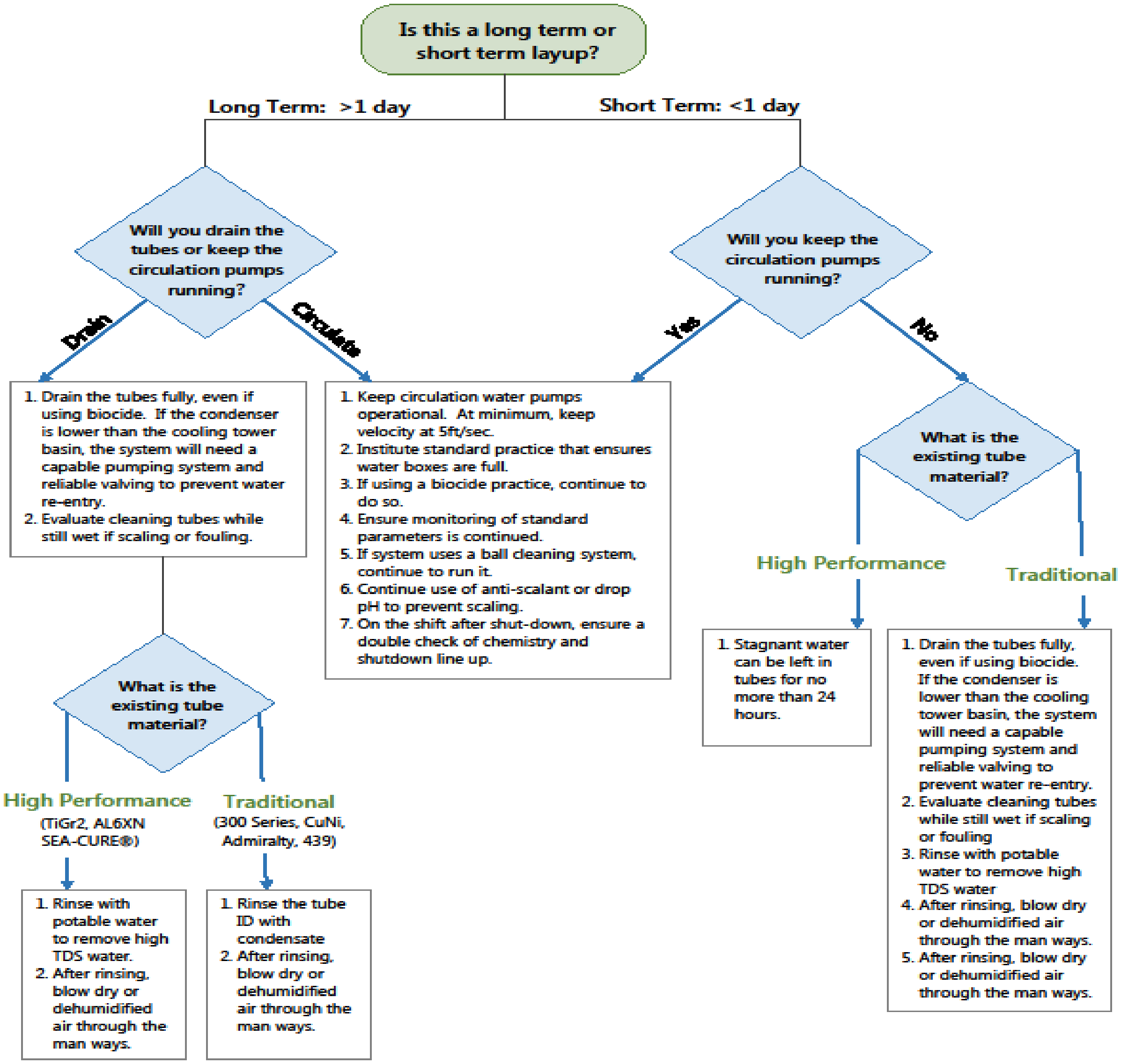


Figure 8. Schematic of a condenser. Dropping flow from 8 ft/s to 4 ft/s can result in head drop across bundle from 21.75 ft to 6.48 ft.



1. Drain the tubes fully, even if using biocide. If the condenser is lower than the cooling tower basin, the system will need a capable pumping system and reliable valving to prevent water re-entry.
2. Evaluate cleaning tubes while still wet if scaling or fouling.

1. Keep circulation water pumps operational. At minimum, keep velocity at 5ft/sec.
2. Institute standard practice that ensures water boxes are full.
3. If using a biocide practice, continue to do so.
4. Ensure monitoring of standard parameters is continued.
5. If system uses a ball cleaning system, continue to run it.
6. Continue use of anti-scalant or drop pH to prevent scaling.
7. On the shift after shut-down, ensure a double check of chemistry and shutdown line up.

1. Stagnant water can be left in tubes for no more than 24 hours.

1. Drain the tubes fully, even if using biocide. If the condenser is lower than the cooling tower basin, the system will need a capable pumping system and reliable valving to prevent water re-entry.
2. Evaluate cleaning tubes while still wet if scaling or fouling
3. Rinse with potable water to remove high TDS water
4. After rinsing, blow dry or dehumidified air through the man ways.
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1. Rinse with potable water to remove high TDS water.
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1. Rinse the tube ID with condensate
2. After rinsing, blow dry or dehumidified air through the man ways.

Figure 9 Lay-up flow chart example.