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# Power Division feature section

Heat Exchanger Committee

# Challenges, considerations, and options to effectively refurbish lube oil and hydrogen coolers

By James W. Smith, Jr.

*Power plants today are plagued with aging balance-of-plant heat exchangers, particularly lube oil coolers and hydrogen coolers that have reached the end of their useful lives. Refurbishment of these coolers requires that plant engineers and maintenance personnel carefully evaluate the extent of the damage and research available solutions.*

## Introduction

"The eddy current results have been evaluated and the decision is unanimous. We cannot plug that many tubes and keep the cooler in service. The cooler must be refurbished or replaced." This decision is one reached every day in our country's aging power plants regarding their turbine/generator systems' two very important heat exchangers—lube oil coolers and hydrogen coolers. A system engineer is assigned to see this task through to completion and often has no experience. There are many factors to consider.

*Refurbish* means to "To make clean, bright, or fresh again; renovate." Refurbishment of lube oil and hydrogen coolers is usually less expensive than replacement because most major components of these heat exchangers, other than the tubes, can be cleaned and made functionally "as good as new." The heat exchanger tubes, upon failure, no longer function as designed and effectively cripple the heat exchanger's performance. Tube replacement can effectively be accomplished through a process commonly known as "retubing." When compared to replacement or rebundling, retubing (or refurbishment) can be more challenging because many more components must be evaluated, resulting in more decisions. Much can be learned and used in future heat exchanger evaluations through the challenges of the refurbishment process. Lube oil and hydrogen coolers are essential to plant performance and their refurbishment requires careful consideration.

## Challenges

Examples of existing lube oil and hydrogen cooler bundles prior to refurbishment are shown in Figures 1 and 2. The figures visually demonstrate the challenges of refurbishment.

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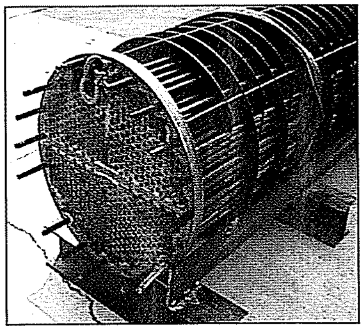

*Figure 1. Lube oil cooler prior to refurbishment*

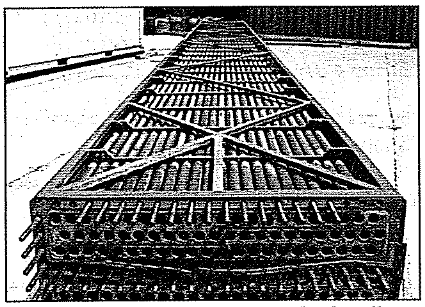

*Figure 2. Large hydrogen cooler bundle prior to refurbishment*

Other challenges of immediate concern are less obvious:
- gathering the details related to the cooler's original construction and present condition
- defining the scope of the necessary repairs
- researching the options for cooler component replacement (primarily the tubes)
- determining lead times for materials and how long the refurbishment process will take
- identifying qualified refurbishment contractors.

In most cases, the engineer responsible for the task of refurbishing either of these cooler bundles must also worry about
- developing and working within a budgeted cost for the repairs
- creating a specification for the refurbishment
- coordinating with the purchasing department on the release of a RFQ (Request for Quote) or solicitation
- coordinating with plant maintenance on the removal of the coolers from the generator (hydrogen cooler) or oil reservoir (lube oil cooler)
- assuring operations that all refurbishment work can be accomplished within the allotted time period built into the planned outage schedule.

An experienced, qualified refurbishment contractor can be a valuable resource to assist in overcoming most of these challenges. Assistance in establishing what should be considered and what options are available to effectively refurbish lube oil and hydrogen coolers is paramount.

## CONSIDERATIONS/OPTIONS

Most considerations are generally common to both lube oil or hydrogen cooler bundles. These are related to the primary components: tubes, tubesheets, sealing surfaces, covers, and frame/tube supports. Lube oil and hydrogen cooler bundles both use plant cooling water for cooling, both usually include copper alloy tubes and tubesheets, both usually have floating return-end tubesheets and both are designed so that the tube bundle is inserted/immersed in an open reservoir instead of a shell. The actual design details are very different.

### Tubes

The tubes should be of primary consideration when refurbishing lube oil or hydrogen cooler bundles. The performance of either of these coolers revolves around the bundle design, simply comprised of a "bundle of tubes."

With regard to the tubes, the following issues should be considered:
- Determine the existing tube details. Be thorough with this and get the details right. Do the research to locate or obtain the OEM data sheets, specifications, and drawings and all maintenance and inspection documents, i.e., eddy current reports, tube sample validation of eddy current findings, tube maps pertinent to the cooler's history. It is not unusual to find that the OEM specification/drawings for the tubes do not match existing tubes due to past undocumented tube replacement.
- Clearly identify the reasons behind the failure mechanism of the tube to be replaced. The most logical source should be the eddy current reports. The most definitive source would be the laboratory analysis of the removed sample.
- Is the replacement tube to be the same ("replace in-kind") tube as that removed? If so, investigate how the old tube failure mechanism might apply to the new tube? Was it a one-time event caused by improper lay-up? Was it a long-term failure due to

wall thinning (old age)? In most cases, knowledgeable plant personnel in the water chemistry and metallurgical departments enjoy discussing this subject.

- Is it advantageous to replace the failed tubes with a different material? Again, investigate and determine the advantages and disadvantages. Will the new tube material be affected by the old tube failure mechanism? What are the consequences/ effects regarding cooler performance? What are the consequences/ effects regarding cooler mechanical design? How do the price and lead times compare?
- If the tube is to be fabricated—i.e., bent, finned, etc.—there are experienced, knowledgeable tube fabricators available in the U. S. Research them and be careful to verify their qualifications and references. If they are providing the base tube, assure that their source meets your approval. Lube oil cooler bundles often have u-bend tubes or tubes with low fin (integral fins) machined on the tube OD surface to enhance surface area. All hydrogen cooler bundles, except for plate fin designs, have applied copper alloy fins (application of spiral fin stock to tube OD) and the fins are secured with a solder coating (to applied fin and tube OD). Make sure to request a solder coating that is free of lead such as 95-5 solder (tin/antimony).

Most lube oil or hydrogen coolers in service today were originally designed to have non-ferrous, seamless copper alloy tubes manufactured to ASTM B111. The primary copper alloys used then were (and still are):

- C443 Admiralty Brass—Arsenic inhibited
- C706 90-10 Cupro-Nickel
- C687 Aluminum Brass

### Lube oil cooler bundle tubes

Primarily the tubes found in lube oil cooler bundles are straight and have a bare (smooth) OD. Some designs include enhancement of the OD surface specified as low fin (integral fins). This enhancement is best described as small machined/formed fins on the tube OD, much like threads on a bolt, and the result is an increase in the tube OD surface area that makes the tube more effective in transferring heat to the cooling water. Also some designs have u-bend tubes to return the cooling water flow (2 pass)

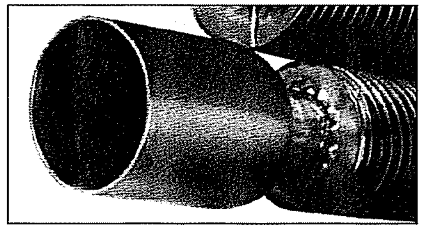

*Figure 3. Hydrogen cooler with belled end*

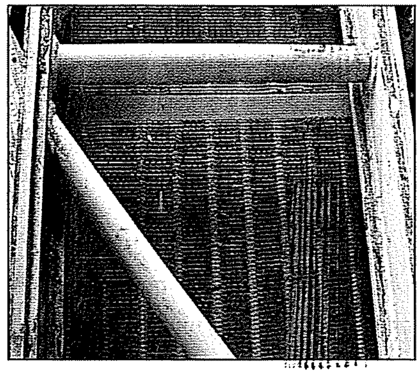

*Figure 4. Hydrogen cooler with plate fin core*

instead of the conventional return chamber comprised of a tubesheet and cover.

### Hydrogen cooler bundle tubes

The tubes found in hydrogen cooler bundles are straight, bare tubes that have a thin fin applied to the tube OD. Some designs include one end of the base tube to be belled or swaged to a diameter equal to the applied fin OD as shown in Figure 3 to allow removal of individual tubes from the bundle (through one of the tubesheets).

The majority of hydrogen cooler bundles are designed to use individually finned tubes as shown in Figure 4.

Thin strips of copper are spirally wound on the edge of the tube OD and solder coated to permanently adhere them. The fin density (FPI—fins per inch) and fin height (from the tube OD) of the fins dictate the amount of surface area necessary for cooler heat exchange performance. The FPI can be modified to increase surface area (improve performance) but the fin height cannot be changed without modifying the frame support plate mechanical design. When the fins are wound on the tube OD, the ends of the fins are tacked to the tube OD at each end to prevent them from unwinding. Protective collars are strategically placed along the length of the finned area at the cooler frame support plate locations, as

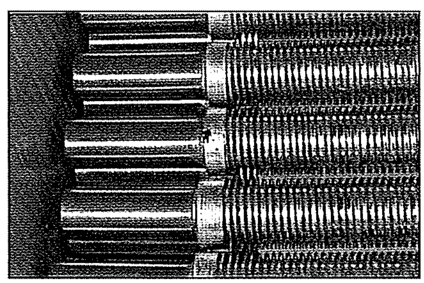

*Figure 5. Hydrogen cooler tubes with applied spiral wound fins*

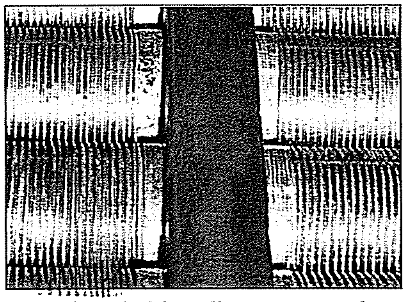

*Figure 6. Packed fin collar in support plate*

shown in Figure 5 and 6, to prevent damage to the delicate fins. These collars differ depending upon the manufacturer. They are made from carbon steel, rubber or comprised of closely packed fins to mock a solid mass. How these collars are spaced and secured in the cooler frame also varies from manufacturer to manufacturer. The common goal being to reduce tube vibration, some designs utilize standard tube support plates with holes to capture the collars and some designs use mechanical means to compress the collars together in one mass from the perimeter without using support plates. The hydrogen cooler bundle mechanical design may vary from manufacturer to manufacturer, but the tube details are similar.

**Tubesheets**

The tubesheets are an integral part of the bundle design as they not only support the seal of each individual tube end but also the seal at the ends of the cooler bundle separating the cooling water and media to be cooled. In most lube oil and hydrogen cooler bundle designs the tubesheet material is a copper alloy and the ASTM Standard is B171—Copper Alloy Plate and Sheet for Pressure Vessels. Refer to this specification for individual alloy composition, tensile and yield strengths. Also, be aware that tensile and yield strengths vary in these alloys with regard to thickness. The primary tubesheet alloys used are:

- C365 Leaded Muntz Metal
- C464 Naval Brass, Uninhibited
- C613/C614 Aluminum-Bronze

With regard to the tubesheets, the following issues should be considered:

- Do what is necessary to determine the existing tubesheet material. If not specified in any of the OEM information, clean a portion of the tubesheet face, making sure to remove all layers of surface corrosion. Note the color of the metal and use a magnet to verify that it is not carbon steel and in fact a copper alloy. Carbon steel is used in some designs and over time and in the presence of copper alloy tubes, the tubesheet surface can appear to be a copper alloy. Some QC or Metallurgy Departments have hand held alloy analyzers that can assist in the identification of the tubesheet alloy. Aged copper alloy tubesheets can be difficult to identify using even the most technologically advanced material due to elemental leaching or de-alloying, so do not make assumptions.
- Inspect the tubesheets for damage, focusing primarily on the surfaces in contact with the cooling water. The opposing tubesheet surface (seeing oil in lube oil coolers and hydrogen in hydrogen coolers) is usually found in excellent condition. Damage can generally be categorized as either corrosion or flow induced erosion around the inlet end tube holes and under partition/divider plates. Corrosion damage is more difficult to quantify but can be identified as non-uniform pits or areas of material loss, areas that are discolored (usually exhibiting a pink or white tint) and areas that are brittle and cracked. Copper alloy tubesheets are known to de-alloy or leach away some elements in their composition over many years of service, especially when proper cleaning is not performed. The result is a discolored, brittle area that is permanently damaged. Pay particular attention to damage found in the ligaments (thin sections of tubesheet between tubesheet holes). Once cleaned, carefully chip away at ligament areas that appear to be damaged and see if the material crumbles. If so, this can be a serious problem as the depth of the damage cannot be determined until the tubes are removed.
- Tubesheets, especially copper alloys, can be inspected using a simple dye-penetrant process (preferably after tubes are removed) like that used for checking welds. Once cleaned, perform the dye check on the entire tubesheet surface. Then ligament cracking, micro-cracking and other sub-surface defects will easily be identifiable.
- Unfortunately, options are limited when correcting damage found in copper alloy tubesheets. Unless the damage is minor and only found on the immediate surface, it is suggested that the damaged tubesheet be replaced if possible during refurbishment. In the case where this is not possible, protective

coatings can be applied (like those applied to the condenser).

• Evaluate the "designed" sealing surfaces of the tubesheets. Most lube oil and hydrogen coolers have a stationary or fixed tubesheet on the inlet end using a "static" gasketed joint and a floating tubesheet on the outlet/return end using a "dynamic" packed joint on the perimeter or outside surface of the tubesheet. In service, the floating tubesheet is allowed to move (or the bundle lengthen) as the tubes change in length due to temperature fluctuations. This movement prevents unwanted ompressive forces on the tube and tube-to-tubesheet joints. Figures 7 and 8 show two common packed joint configurations.

• During refurbishment, the tubesheet holes, must be carefully evaluated. Damage to the tubesheet hole(s) caused by improper plugging is usually found in all "used" tubesheets. The primary reason is that simple tapered/one piece plugs are normally employed by plants to plug tubes. The plug taper is induced/formed into the tubesheet hole when the plug is driven in the hole using excessive force. Slightly tapered tubesheet holes or holes that are out-of-round can be roller-burnished to correct them as long as the resulting diameter is not excessive. If excessive, and limited to a small number of tubesheet holes, the enlarged holes can be repaired by reaming and installing a copper alloy bushing between the tubesheet and tube. Care must be taken to minimize damage (thinning) of the ligament, as this thin portion of the tubesheet materials between holes plays a large role in sealing the tube-to-tubesheet joint. It is not unusual to find serrations or grooves in the tubesheet hole surface. These serrations are added to increase the tube-to-tubesheet joint strength and years of testing show that they can easily double the joint strength. These serrations are not normally damaged during cooler retubing.

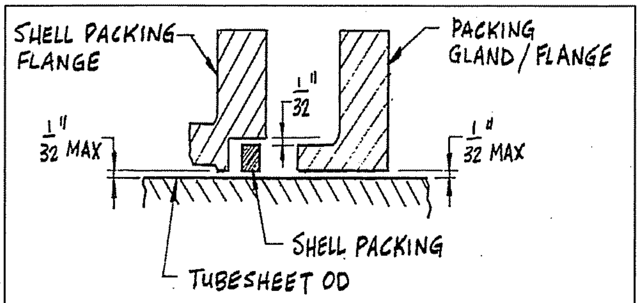

*Figure 7. Common packed floating tubesheet joint*

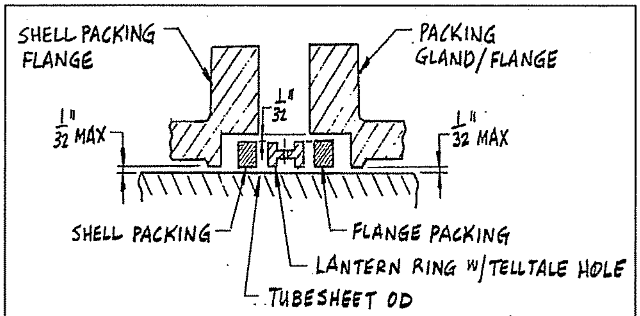

*Figure 8. Common packed floating tubesheet joint with lantern ring*

• Some lube oil cooler designs have only one tubesheet by design as shown in Figure 9. The tubes are fabricated as u-bends (sometimes called "hairpin tubes") that allow the cooling water to pass through the lube oil twice. Also, because each u-bend tube is only attached to the tubesheet at each end of the "hair pin," it is allowed to lengthen uninhibited as the temperature increases.

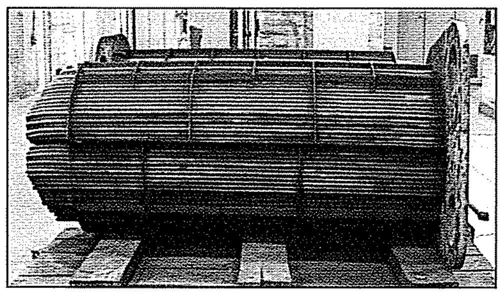
*Figure 9. Example of a u-tube main turbine lube oil cooler bundle*

• Some lube oil cooler designs utilize a sealed chamber in lieu of u-bend tubes. This chamber design has two parts: a return tubesheet and a cover. These two parts, semi-permanently sealed together using packing and both a threaded and a soldered/brazed joint, create a chamber allowing the cooling water to flow down one half of the tubes in the bundle and return back through the other half. Unfortunately, this design allows unwanted fouling media (such as mud and sand) to collect inside the chamber resulting in the creation of corrosion cells and tubesheet damage. A cleanout plug is usually designed into the cover but it is small and proper cleaning is difficult. The issues surrounding this design will be discussed later.

### Covers

The covers on the ends of both lube oil and hydrogen coolers are primarily either cast iron or fabricated from carbon steel plate materials. The cover design, or manner in which the ends of the cooler bundles are covered varies from manufacturer to manufacturer. Unlike the tube bundle, they can usually be easily repaired or replaced without disturbing the secured tube bundle.

With regard to the covers, the following issues should be considered:

- Covers, especially ones made from cast iron, should always be removed carefully using the push-off bolts on the cover flange to break the seal. Use wedges with caution, as localized forces can easily break the casting. Repairs are difficult if not impossible. Also, use care when "securing cast iron covers to prevent breakage caused by excessive forces when tightening the bolts or studs/nuts.

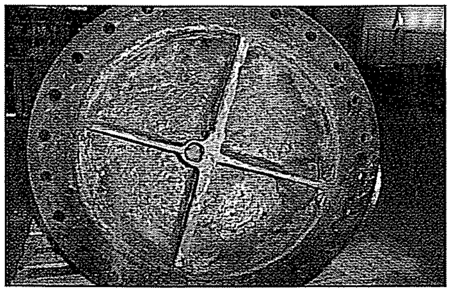

*Figure 10. Example of epoxy repair to damaged partition/divider plate*

- Aged covers that have partition or divider plates always exhibit some damage to the sealing surface or edge of the divider/partition. In addition, effects of corrosion/erosion usually reduce the thickness and strength of the divider/partition, making it fragile. Depending upon the material, design, age and condition, repairing damage to the divider/partition can be difficult. If the cover is made from cast materials and/or is very old, it is suggested that a metal epoxy coating be used to buildup or strengthen the divider/partition as shown in Figure 10. It is risky to repair the damage using welding or brazing methods.
- Some of the lube oil and hydrogen cooler covers were made years ago and the manufacturer's and/or casting molds are no longer available. As shown in Figure 11,

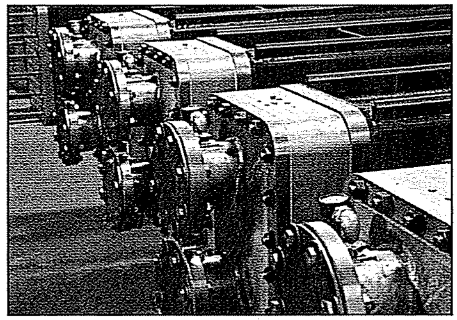

*Figure 11. Replacement inlet/outlet cover installed on hydrogen cooler*

dimensionally similar replacement covers, can be manufactured using modern 3D machining methods and machine tools. Welded construction is also available even for copper alloys. A copper alloy replacement cover will not corrode like its iron based predecessor, will be more forgiving if not cleaned properly and will not require protective coatings.

### Frames

The bundle frames for lube oil and hydrogen coolers are very different. Hydrogen cooler frames are rigid frames with aligning rails matching grooves in the generator housing. They are manufactured using carbon steel welded construction and are painted/coated with di-electric coatings due to their installation into the hydrogen rich environment. As shown in Figure 12, lube oil coolers do not use rigidly constructed frames, but instead use segmented tube supports/baffles made from copper or carbon steel materials. The baffles are aligned and secured using tie-rods and spaced using tubular spacers on the tie-rods between the baffles. The tie-rods are traditionally attached only to the rear face of the stationary/fixed tubesheet. For both cooler types, the floating tubesheet is attached only to the tubes.

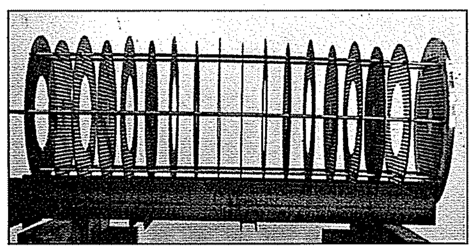

*Figure 12. Example of main turbine lube oil cooler bundle frame design*

With regard to the frames, the following issues should be considered:

- Because most hydrogen cooler frames were manufactured and painted/coated many years ago, it is possible that the paint was lead based. The refurbishment plan should account for new industry standards for lead paint abatement that will apply when removing the old paint prior to application of new coatings.

• Most hydrogen cooler bundle designs include centering/alignment components that are attached to the rear face of the floating tubesheet. When refurbishing the cooler bundle, care must be taken not to disturb or destroy these parts. When the refurbished cooler bundle is installed into the generator housing, these components are used to align the floating tubesheet in the generator housing packing gland.
• The segmented baffles used in the lube oil cooler tube support assembly should be thoroughly inspected when refurbishing the cooler bundle. Steam clean to remove oil residue. Visually inspect each plate thoroughly to identify broken or missing sections or cracked ligaments (between holes). Replace the part if this damage is found. Distorted or bent baffles can usually be straightened.
• The tie-rods used to secure/align the lube oil cooler baffles in the tube support structure are usually replaced due to distortion resulting from years of handling and damage caused during tube removal. Using new, straight tie-rods when reassembling the cooler tube support structure will improve baffle alignment and thus make new tube insertion more efficient.
• The tubular spacers used to space the baffles in lube oil cooler tube support structure should be replaced if damaged. When manufacturing replacement spacers, the length should be held to a tolerance of +/- 1/32" and the ends cut square. Properly manufactured spacers will improve baffle alignment.

## RECOMMENDED REFURBISHMENT TECHNIQUES

Many considerations and options have been discussed earlier in this paper, but there are specific, recommended techniques to utilize when refurbishing lube oil and hydrogen coolers. The tooling and techniques used for the tube removal and installation are well known and understood as they are also used for most shell and tube heat exchanger and condenser retubing projects. Not well known are techniques specific to retubing and testing of lube oil and hydrogen cooler bundles.

### Specific lube oil cooler techniques

Several techniques specific to the refurbishment of lube oil cooler bundles are offered as follows:

• Replacement of the tie-rods is recommended.
• Due to the large number of tubes in some main turbine lube oil coolers (MTLOC), the use of a "tube cluster removal method" is practical. This method utilizes several clusters of tubes (5-10 tubes per cluster) in strategically placed locations in each of the four approximate quadrants of the MTLOC tube pattern. Leave these tube clusters undisturbed while all the other tubes are removed and replaced. The rigid clusters will help maintain original bundle dimensions during the main portion of the tube removal work. Once the majority of the tubes, except for the clusters, are replaced and expanded, replace the tubes in the clusters.
• Due to forces exerted upon the tubesheet during tube rolling, it is suggested that all tubes in one end be rolled before rolling the opposite end. Roll the tubes working from the inside (center) outwards to minimize distortion. Monitor tubesheet flatness during tube rolling for evidence of distortion. If evidence of distortion is found, immediately stop, evaluate and modify the process or attach rigid fixturing. Temporary threaded tie-rods can be inserted through the new bundle tubes in locations needed to hold or cinch the tubesheets (parallel to one another) until a satisfactory number of tubes are rolled to hold the tubesheets in position.
• Due to forces exerted upon the actual tubesheet material during tube rolling, most copper alloy tubesheets will enlarge (increase in diameter), usually in a shape consistent with the tube pattern and can result in diametrical enlargement of 0.063" to 0.250". The resulting problem is the floating tubesheet OD sealing surface no longer is "per design" with respect to the packing gland clearances, normally 1/32". Knowing this will happen, it is suggested that the floating tubesheet OD be accurately measured in four locations prior to tube removal and the measurements documented for later use in returning (machining) it to its original size. After tube rolling is complete, re-measure in the same locations as before and document the growth. Cover or shrink-wrap the tube bank carefully to prevent machined particles from contaminating the bundle and re-machine the floating tubesheet OD to its original diameter. Proper clearance between the floating tubesheet OD and the ID of the lube oil shell packing gland is important to the function and life of the refurbished cooler.
• Test large MTLOC bundles in a shell fixture as shown in Figure 13 to enable the test personnel full access to the tubesheet

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*Figure 13. Example of a shell side test fixture for lube oil cooler bundles*

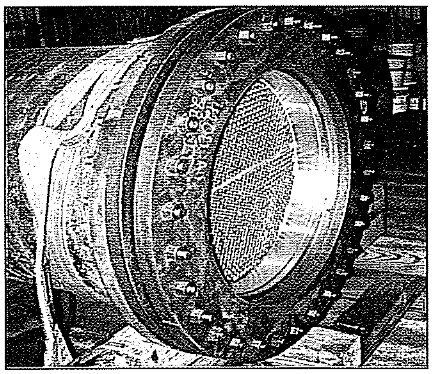

*Figure 14. Example of shell side fixture—access to tube ends*

faces during the hydrostatic test. As shown in Figure 14, leaks can easily be identified and corrected. In contrast, testing large blind flanges or covers installed on the ends of the bundle and filling the bundle (tube side) makes identifying leaks difficult because individual tube leaks cannot be easily identified in the tube bank. Also, the large flanges must be removed to correct a leak.

For large diameter or long MTLOC bundles, it may not be practical to test them in a shell fixture. It is suggested that separate test chambers be installed and secured on the tubesheets on each end of the bundle to allow for a sealed tube side test. Prior to performing a tube side hydrostatic test, perform a vacuum test (with tube side filled with water) using clear Lexan covers installed on the chambers so leaks can easily be identified and corrected prior to installing blind, test flanges to support the final hydrostatic test. It is suggested that 18" to 25" hg be used for the vacuum test.

- Handling large MTLOC bundles is difficult and requires proper planning, rigging and equipment. Use nylon straps wrapped only on the baffles to prevent tube damage and attach straps to a spreader beam for lifting.

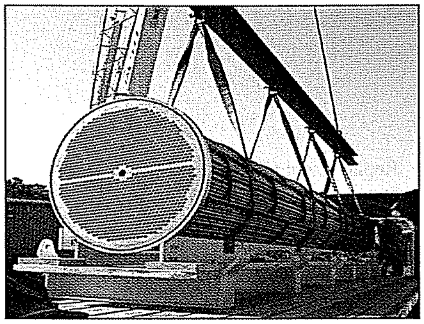

*Figure 15. Proper rigging for lifting main turbine lube oil cooler bundle*

- Wide flange beams make excellent fixtures for use in assembling, aligning and safely handling round lube oil cooler bundles. An example of this can be seen in Figure 15.
- Some bundle designs employ the use of a lifting rod that is threaded into the stationary tubesheet. An o-ring seal is used to seal this threaded through-hole joint to prevent cooling water and lube oil to mix. Problems have been encountered sealing this joint and to correct the problem it is suggested that the tubesheet be modified to include a threaded blind hole instead. An existing tubesheet can be modified in this way by boring out the existing rod threads, welding in a tapered plug (large end on back face) and boring and tapping a blind hole in the plug. If the stationary tubesheet is to be replaced, this modification can be included as an integral part of it's design instead of installing a welded plug. The downside is that it requires starting with a much thicker blank of material thus increasing the raw material cost and increasing blank machining man-hours.
- Some two pass MTLOC's were designed using a sealed return chamber (comprised of a floating tubesheet and threaded cover) that was welded or soldered after screwing the parts together. When refurbishing this design, we wish you luck! It is very difficult for several reasons. First, the enclosure is usually on the bottom of the vertically mounted bundle and it collects fouling that cannot easily be cleaned out. Consider what 30-40 years of fouling can do to any material! Second, to replace the tubes, the cover has to be separated from the sealed return chamber to allow access to the floating tubesheet. To accomplish this, the solder seal that seals the treaded joint must be removed. Usually, actual dimensional information is not available and damage results to the original seal configuration when trying to separate the parts. After cleaning, dye-penetrant testing and metal analysis, the result is always the same. The floating tubesheet and cover need to be replaced. It is suggested that refurbishment plans include the replacement of these parts.

Last is the introduction of a special mobile cart, shown in Figure 16, for large

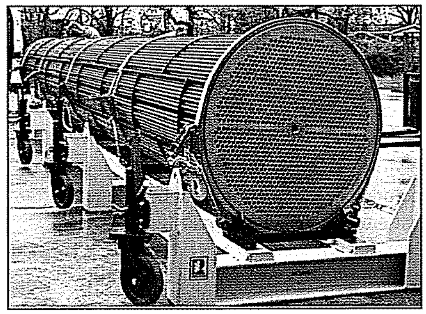

*Figure 16. Mobile cart "The Crab" for large main turbine lube oil cooler bundle*

MTLOC bundles. Nicknamed "the crab," this cart was designed for use in moving, installing and/or removing large MTLOC's around in the plant. The cart design includes jacking casters along both sides to allow the cart to be raised and lowered as necessary to match the centerlines of the bundle and shell. Also included are heavy equipment skates guided by rails on the cart and designed to attach to the bundle's segmented baffles using nylon straps and ratcheting clamps. The result is a cart that aligns the bundle to the shell and supports the bundle for easy insertion into/removal from the shell. It even has an integrated wooden enclosure to allow for long term storage.

## Specific Hydrogen Cooler Techniques

Several techniques specific to the refurbishment of hydrogen cooler bundles are offered as follows:

- Most hydrogen cooler frame designs include both permanently welded and bolted tube support plates. Usually every other support plate is bolted. The bolted support plates are designed to be loosened during finned tube insertion into the frame and once all the new tubes are inserted, they are carefully jacked into place and bolted. The bolts are then tack welded to secure them. This in effect pinches or secures the finned tubes to minimize tube vibration.
- When finned tubes are inserted into the newly painted support plates, small paint shavings or particles are scrapped from the support plate hole surfaces. It is suggested that the tubes be inserted from the top down to allow these paint shavings to drop to the floor. Inserting the tubes from the bottom up will allow the undesirable condition of these paint shavings being captured in the fins of the tubes below.
- Because hydrogen coolers must be leak-tested on the tube side (water inside tubes), the tube ends are inherently hidden behind the test flanges. Due to this, it is suggested that the rolled tube ends be 100 percent inspected for expansion prior to testing. This can quickly and efficiently be accomplished by using GO/NO GO gage pins sized slightly

smaller than the desired rolled ID (GO) and larger than the unrolled tube (NO GO).

- Replacement of all tubesheet/cover/chamber threaded studs is recommended.

## LAND MINES

Experiences can be good or bad. The bad experiences are always remembered and some of those bad experiences are offered below as "Land Mines. They are characterized as "Land Mines" because if you experience one of them it can be catastrophic. Some of these relating to lube oil and hydrogen coolers refurbishment are:

Asbestos gaskets may be present in older cooler assemblies.

Order tubes to the actual length not the effective length commonly listed on OEM data sheets. The effective length does not account for the tube inside tubesheets and the tubes cannot be stretched after cutting.

Excessive tightening of bolts that secure the cooler covers can result in irreparable damage to cast covers flanges.

Small metal particles are created when machining integral fins on the tube OD. These particles if left captured in the fins by dried, lubricant can be released in the lube oil and wreak havoc. Verify that the tubes have been thoroughly cleaned after finning.

Rolling tubes beyond the back face of the tubesheet can cause unwanted stresses in the tube wall and that may cause tube failure in the future. Monitor the setup of the tube expander depth at every benchmark tubesheet hole.

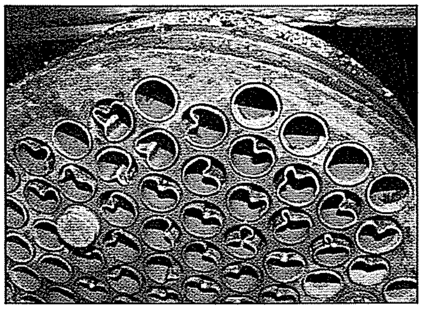

*Figure 17. Typical cleaning damage to tube-to-tubesheet joint (pressure washing)*

Recommend or specify that the bundle be refurbished, at least assembled, in a clean area environment. Particles resulting from arc-gouging, grinding and normal fabrication shop activities can result in contamination of the tube bundle and your lube oil or generator.

Carefully choose a contractor who knows how to clean coolers without damaging the tube-to-tubesheet joints. You do not want to experience the type of damage shown in Figure 17.

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