CLEANING AND STORAGE PROCEDURES FOR REPLACEMENT BOILER TUBES

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INTRODUCTION

Utilities purchase replacement boiler tubes for routine maintenance and for large-scale tube replacement projects. It is important that these tubes be free of oil, grease, mill scale, rust and other debris that get on the internal surfaces during manufacture and fabrication. If not removed, these materials can interfere with heat transfer or fluid flow and cause tube failures. If dirty tubes are installed in superheaters and reheaters, debris and dirt can cause turbine blade erosion.

Grease, rust and mill scale can be removed by alkaline degreasing and acid cleaning but can increase the cost of an order by as much as 20 percent. It is therefore important to identify the level of cleanliness required for an application and specify it as part of the order, but not to require unnecessary or excessive cleaning.

Many companies have no policy for replacement tube cleaning. Likewise, there appears to be no industry-wide consensus on the level of cleanliness to specify. In a survey of 18 utility plants as to their ordering practices:

- 9 - Do not specify acid cleaning of any tubes.
- 2 - Specify acid cleaning on major replacements only.
- 2 - Specify acid cleaning routinely.
- 2 - Specify "no scale," but not the method of removal.
- 3 - Specify other than above.

Most plants did not know the economic consequences of their cleaning decisions. For example, at one plant acid cleaning was specified for no reason other than "just to be safe."

The utility chemist is often asked about cleaning and storage requirements for replacement tubes since these subjects are chemistry-related. To help provide the answers, this paper reports on the results of an effort to develop general guidelines for the cleaning and storage of replacement boiler tubes. Because cleaning and storage is less of a problem if tubes are properly prepared for shipment, recommendations are also presented which may be useful in the preparation of cleanliness specifications for replacement tube orders.

This paper will first discuss how clean replacement tubes have to be, assess the cleanliness of tubes from various manufacturing processes and finally determine the effectiveness of the cleaning alternatives.

REQUIRED TUBE CLEANLINESS

Tubes are purchased for replacement of sections of waterwalls, superheaters, reheaters and economizers. Typical heat transfer rates for each are:

Section	Typical Heat Flux (Btu/hr.)
Economizer	5,000
Waterwalls	50,000-150,000
Reheater	6,000-10,000
Superheater	10,000-25,000

It can be seen that the most critical need for clean tubes is in the waterwalls, where the heat transfer rate is so high that even a small amount of dirt or mill scale will increase the resistance to heat flow and cause the tube metal temperature to increase by hundreds of degrees. Figure 1 shows the typical temperature increase associated with various scale thicknesses. In addition to this effect, boiler water impurities can concentrate underneath scale and rust, resulting in corrosion and possible hydrogen embrittlement. The amount of dirt should be at an absolute minimum in waterwall tubes and <u>any</u> visible thickness of scale is too much.

Compared to waterwall tubes, superheater and reheater tubes operate in areas of lower heat flux. The problem here is that tubes are operating at or near the maximum allowable temperatures for the tube material. By design, they will last for a finite period of time before failures occur due to creep. Dirt, scale and rust decrease the creep life because their insulating effect increases the tube metal temperature. Cleanliness is most critical in tubes which are installed in the higher heat flux regions of the component, such as tubes on the outside of a bundle, or just before a material transition.

Growth rate curves for magnetite deposits in superheater and reheater tubes can be used to estimate the impact of leaving small amounts of mill scale in tubes. French (1) provides a method for developing such curves. Typical curves are plotted in figure 2 for superheater tubes and in figure 3 for reheater tubes. Assuming that the characteristics of mill scale and service-induced scale are similar, there is little difference between the remaining life of a tube that has accumulated a given amount of scale due to hot finishing and one that has accumulated the same amount of scale due to time in service. Examination of the curves shows that the loss of service life for tubes installed with a few mils of scale is not as great as one would initially think. This is because the first few mils of scale is quick to form in the tube when it goes into service.

In superheater and reheater tubes, hard mill scale is more of a concern than loose rust or debris, but loose material could cause turbine erosion or could accumulate at the bottom of loops or bends and interfere with steam flow.

Economizer tubes are the least critical from a cleanliness standpoint. Here the primary concerns are the accumulation of loose material which may enhance corrosion and the transport of dirt into the boiler. Hard mill scale is of little consequence.

TUBE MANUFACTURING AND CLEANLINESS

Tubes can be specified by the purchaser to be cold-finished or hot-finished. Figure 4 shows the typical appearance of tubes from each process. Hot-finished tubes are formed and worked at elevated temperatures where mill scale can be expected to form. Cold-finished tubes are subsequently worked at lower temperatures. Cold-finished tubes contain no visible mill scale, which is removed during the cold-working. They are usually shipped with a coating of preservative lubricating oil from the finishing process. This coating has the added benefit of preventing rusting after shipment. Hot-finished tubes on the other hand will still contain the mill scale that formed on the tubes during manufacturing. This scale, which can be up to 5 mils thick, is difficult to remove. The cost differential between these methods of manufacture is very close. Cold-finished tubes are more commonly supplied and are thus easier to specify, but may cost a few percent more.

Most replacement tubes are welded into panels and bent to form by a fabricating contractor. During fabrication, the tubes may be hot-bent. This hot-bending may form a significant amount of mill scale in the section of tube that was heated. Cold-bending is best from a cleanliness point of view because no scale forms, but not all forms can be made using cold-bending.

Cold-finished tubes contain no rust or mill scale and, after degreasing, are clean enough for any boiler application. During a visit to one fabricator's shop the acid cleaning of supercritical unit waterwall replacement tubes was observed. It was noted that these cold-finished, cold-bent tubes were no cleaner after the acid cleaning than before. In fact, extensive rusting occurred after cleaning because the cleaning process had removed the protective oil and passive oxide film!

Many of the cleaning steps discussed below would be unnecessary and can be avoided by specifying cold-finished material.

CLEANING METHODS AVAILABLE

There are a wide range of cleaning methods for boiler tubes. Some are listed below:

(1) Steam Cleaning
(2) High Pressure Jetting or Mechanical Cleaning
(3) Alkaline Degreasing with Trisodium Phosphate
(4) Acid Cleaning, usually with Hydrochloric Acid

Steam cleaning is best suited for the removal of oil and grease. Chemicals such as trisodium phosphate may be added to the steam to increase its oil removal effectiveness. Debris such as dirt and rust will also be removed if the steam velocity is adequate to blow it out of the tube. This is usually not the case in field cleaning as the amount of steam required exceeds the capacity of a typical portable steam jenny. PP&L has used small portable steam jennies for removal of oil and grease from tubes up to 3-inch I.D. with success, but the method is time consuming.

Air blowing is sometimes also used for debris removal. The same velocity problems and limitations apply as for steam cleaning.

High pressure jetting involves cleaning the tube with high pressure water (up to 10,000 psi). A vendor must be contracted for the job. Vendors claim that this method will remove all dirt and scale, even hard mill scale. PP&L has no experience with these methods.

Mechanical cleaning involves the use of air-driven high-speed brushes or cutters which are inserted into the tube and which clean by abrasive action. The method is fast, economical and safe. Even hard mill scale is removed. PP&L has had good success using both brushes and cutters, cleaning tubes from 3/4-inch to 3-inch ID. Using an external air-driven motor coupled to a flexible shaft it is possible to get the brush through 90 degree bends in larger diameter tubes. Figure 4 shows this procedure being used. Mechanical cleaning is the method of choice at PP&L for the removal of dirt, rust and mill scale. A two-man crew can clean up to 30 straight tubes per hour at a cost that is insignificant compared to chemical cleaning. Unfortunately, the presence of sharp bends in small diameter tubes may preclude the use of mechanical cleaning.

The last two methods, alkaline degreasing and acid cleaning, are usually done together. Hard mill scale and oxide films are removed along with oil, grease, dirt and debris. The process is expensive and requires a high level of expertise. Usually, the whole job is subcontracted to a chemical cleaning contractor by the fabricator or purchaser. One problem with chemical cleaning is the rapidly increasing costs of disposal of waste solvents. Chemical cleaning done by the fabricator can increase the cost of an order by up to $60 per tube depending on material and solvents.

Chemical cleaning can also be done in the field but the process becomes even more hazardous and time consuming. Vendor pricing for on site cleaning ranges from &25 to $100 per tube, with the lower prices only being encountered on larger jobs. At PP&L we have cleaned tubes ourselves using inhibited hydrochloric acid but we are moving away from the procedure in favor of mechanical cleaning which gives results just as good but is faster, safer, and more economical.

CLEANING RECOMMENDATIONS

The most economical way to get clean tubes is to specify cold-finishing and cold bending wherever possible.

For superheater, reheater and economizer applications, it is not necessary to remove every trace of scale. If cold-drawn material is specified, the tubing will be free of mill scale before fabrication. During fabrication some tubes may be hot-bent resulting in some mill scale formation. This scale might decrease the service life of reheater and superheater tubes if they are installed in sections where the tube material is borderline for the service temperature. Here a judgement must be made as to whether the decrease in service life is more costly than the cleaning of the tube order. As noted earlier in this discussion, the decrease in service life can be estimated by developing and examining a plot similar to Figures 2 and 3. Our experience has been that the loss of service life usually does not warrant the additional cost of cleaning.

Waterwalls are the most critical areas for tube cleanliness because of the potential for increased corrosion rates and overheating due to the high heat flux. No scale or dirt should be present in waterwall tubes. Cold-drawn tubes are acceptable for waterwall applications as long as no hot-bending is done during fabrication and the tubes are stored to prevent corrosion and dirt accumulation. If hot-bending during fabrication is required, the tubes should be chemically or mechanically cleaned to remove any mill scale that is present.

Finally, all tubes should be inspected before they go into the boiler. Tubes should be free of oil, grease, dirt, rust and loose debris which may have accumulated during shipment or storage. Tubes with visible amounts of oil on the internal surfaces should be cleaned with a solution of trisodium phosphate and water, or steam cleaned. PP&L has installed tubes with small amounts of oil on the internal surfaces with no problems. The decision regarding how much oil is allowable is a judgement that depends on the type of oil, quantity of tubes, and type of boiler. Tubes which contain rust in amounts much greater than that which can be wiped off by hand should have this rust removed either mechanically or by acid cleaning. Loose debris and dirt should be removed by blowing out with water or compressed air. It is good practice to check all tubes for blockages with water or compressed air. This author has found everything from lunch wrappers to rodents in tubes.

STORAGE REQUIREMENTS

Poor storage practices at the plant can result in a rapid accumulation of rust, dirt, and debris in tubes regardless of the steps taken by the vendor or fabricator to clean them. Unlike cleaning, storage is unquestionably the responsibility of the purchaser.

Many tube suppliers specify heated indoor storage for replacement tubes. In most power plants there is simply not enough indoor heated space for this purpose so tubes are stored outdoors. This author's experience is that tubes can be stored outdoors for extended periods if proper precautions are taken to prevent rusting.

The first requirement for good storage is that all replacement tubes should be capped by the fabricator before shipment. This protects the tube from accumulating dirt, debris or water. Most vendors use inferior plastic caps for this purpose. The caps get brittle as a result of exposure to the elements and crack, letting in rain water and moisture. Severe rusting is the result, especially if the tube has previously been acid cleaned. More preferable are UV-treated polyethylene plugs which will not become brittle and are less susceptible to mechanical damage. These offer excellent protection for less than 5 cents per cap. For tubes with a weld end preparation, metal caps can be specified instead of plastic plugs for extra protection against the nicks and dings that happen to some tubes in every bundle.

Even with capping, some internal rusting can occur because of condensation. It is simply not possible to maintain an airtight seal in every tube. Thus, some form of corrosion protection is needed for outdoor storage regardless of how well the tubes appear to be capped. Cold-drawn tubes will be coated with a film of oil on the inside when they are received from the fabricator or supplier. This oil will prevent rusting of the tubes for the short term (up to approximately three months) and should not be removed until the tube is ready to go into the boiler. The oil can be easily removed by steam cleaning or by washing with a hot water and detergent solution. If the oil film is removed, the tubes should be used immediately or protected against corrosion as discussed below.

Chemically or mechanically cleaned tubes are more susceptible to rusting during storage than oiled tubes. Many tubes inspected by this writer were found to be rusted (some severely) after only a short period of storage despite being acid cleaned before shipment. Obviously, if the tubes are improperly stored, the benefits of cleaning by the fabricator are lost. Some form of corrosion protection is needed.

Freshly cleaned tubes can be oiled which will provide short term protection. Silica gel can be used to prevent condensation but experience indicates that it is of limited benefit because its dehydration capacity is quickly exhausted. A better solution is to use a Vapor Phase Corrosion Inhibitor (VPCI).

VPCI's are a relatively new development in corrosion protection. They have been used for protection of tubes for export and are also applicable for the protection of tubes in outdoor storage at power plants. VPCI's consist of tablets or powder containing an amine-based corrosion inhibitor. The material sublimes in the confined space of the capped tube and releases the amine which condenses on the walls and provides corrosion protection. Any residual inhibitor can be removed from the tube end by hand before installation. Even if not removed small amounts of the inhibitor are not harmful to the boiler.

VPCIs have been accepted by all the boiler manufacturers and many utilities, including PP&L. Installation procedures consist of manually placing or air-blowing a measured amount of inhibitor into each end of the tube. The cost of the inhibitor is less then 50 cents per tube. We have preserved some tubes in outdoor storage for more than five years with no rusting, using the methods described above.

The exterior surfaces of tubes in outdoor storage can be protected with an oil-based protective coating or paint. At PP&L we use a translucent coating so as not to obscure the identification marking on the tubes and to allow for easier inspections of surface details, such as welds. These coatings are applied at a thickness of 3-5 mils. Manufacturers recommend the use of a coating that dries to a soft waxy film instead of a paint because the softer material is self-healing after it is scratched, but in practice we have found that some rusting along scratch marks can be tolerated and paint is acceptable.

Finally, all tubes should be inspected during storage on a regular basis for missing or damaged caps, which should be promptly replaced. In tubes where the air seal is broken, the VPCI must be replaced.

THAT'S ALL FOLKS!

References

1. D. N. French, "Metallurgical Failures in Fossil-Fired Boilers", Wiley & Sons, New York, 1983.

2. B. A. Miksic, "Volatile Corrosion Inhibitors Find a New Home", Chemical Engineering, September, 1977.

Figure 1: Waterwall tube metal temperature increase associated with various inside scale thicknesses, assuming nucleate boiling and a magnetite scale. From reference 1.

Figure 2: A plot of calculated scale thickness vs. time for a typical superheater tube. Note that scale forms rapidly on a clean tube during the first several thousand hours in service. From reference 1.

Figure 3: A plot of calculated scale thickness vs. time for a typical reheater tube. From reference 1.

Figure 4: Typical appearance of cold-finished and hot-finished tubes. Note the complete lack of mill scale on the cold-finished tube. On the hot-finished tube, the mill scale was 2-4 mils thick.