INVESTIGATION OF
CHEMICAL CLEANING PROCEDURES
FOR REPLACEMENT BOILER TUBES

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SUMMARY AND RESULTS

PP&L orders replacement boiler tubes for routine maintenance and individual tube replacement projects. It is important that these tubes be free of oil, grease, mill scale, rust and other debris that get into the tubes during manufacture or fabrication. If not removed these materials may interfere with heat transfer or fluid flow and cause tube failures, or in superheaters and reheaters cause turbine blade damage. Tubing for different applications requires different levels of cleanliness, with the most critical requirements being necessary for waterwall tubes.

All grease, rust and scale can be removed by complicated procedures for alkaline degreasing and acid cleaning. The procedures are often specified to be done by the fabricator as part of the replacement tube order. Such cleaning steps can increase the cost of an order by 25% or more, and thus represent a significant waste of money if they are not really required. 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.

PP&L has no company-wide policy for replacement tube cleaning. Specifications on orders from the plants and Engineering were found to run the whole gamut from no cleaning to acid pickling for similar orders, depending on who was ordering. Most often acid cleaning is specified for no reason other than "just to be safe."

The purpose of this investigation was to develop general guidelines for the cleaning of replacement tubes for the use of those who write specifications and place orders. As a result of this study, the attached "Cleaning and Storage Guidelines for Replacement Boiler Tubes" was developed. This can be used as a guide to determine cleaning requirements for replacement tubes for all PP&L boilers.

DISCUSSION

The investigation consisted of first determining how clean the tubes had to be, then assessing the cleanliness of tubes from various manufacturing processes and finally determining the effectiveness of the different cleaning alternatives. Also, the effectiveness of methods to keep tubes clean during storage at the plant was assessed.

Required Tube Cleanliness

Tubes are purchased mainly for replacement of sections of waterwalls, superheaters, reheaters and economizers. Typical heat transfer rates for each section 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 temperature to increase by hundreds of degrees. Reference Figure 1 which shows the typical temperature increase associated with various scale thicknesses. In addition to this heating effect, the scale and rust in the tubes causes concentration of boiler water impurities underneath the scale resulting in corrosion and possible hydrogen embrittlement. The amount of dirt should be at an absolute minimum for waterwall tubes and any visible thickness of scale is too much.

Superheater and reheater tubes operate in areas of lower heat flux but these tubes are operating at or near the maximum allowable temperatures for the tube material. They will last for a finite period of time before failures occur due to creep. Dirt, scale and rust in the tubes will decrease the creep life because their insulating effect will increase the tube metal temperature. Cleanliness is most critical in tubes which are installed in higher heat flux regions or just before a material transition. The amount of tube life decrease is variable, but since the effect is long-term, cleanliness is not considered to be as critical as in waterwall tubes where the effect can be an immediate tube failure. Hard mill scale is more of a concern than loose rust or debris which will be blown out of the tube during operation, but excessive loose material will cause turbine erosion, or worse, could accumulate at the bottom of loops or bends and interfere with steam flow.

Economizer tubes are the least critical. Here the primary concern is the transport of loose material into the boiler where it will deposit on waterwall tubes. Hard mill scale is of little consequence.

Tube Cleanliness after Fabrication

Tubes are made by either a cold-finishing or hot-finishing process. Figure 2 shows typical tubes from each process. Cold-finished tubes are generally clean and shiny with no visible mill scale. They are, however, covered with a film of oil which prevents rusting. This oil is easily removed by steam cleaning. Hot-finished tubes are usually covered with a layer of mill scale that forms on the tube while it is at high temperature. The scale is hard and difficult to remove. There is no oil

film on hot-finished tubes. Cold-finished tubes cost more than hot-finished tubes but the difference is not great and cold-finished tubes are easier to get. PP&L usually does not specify finish, and we often get cold-finished tubes.

Most replacement tubes are fabricated (welded into panels and bent to form) by an outside contractor. During fabrication, the tubes may be hot-bent. Hot-bending causes mill scale to form in the section of tube that is heated (i.e., the bend). The amount of scale can be significant. Cold-bending is best from a cleanliness point of view because no scale forms, but cold bending is not always possible.

Cold-finished tubes contain no rust or mill scale and, after degreasing, are clean enough for any application. During a visit to the Munroe, Inc., shop, the acid cleaning of PP&L 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 they were before. In fact, they were rusting after cleaning because the acid had removed the protective oil film and passive oxide film!

Cleaning Methods Available

Options that are available for cleaning are listed below in ascending order of cost and difficulty and effectiveness:

(1) Steam Cleaning
(2) High Pressure Jetting
(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 are added to the steam to increase its effectiveness in this regard. The method works very well for this application. Loose 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. A fabricator may steam clean tubes for debris removal prior to shipment. The success of the procedure would depend on the amount of steam available and the nature of the debris. Adherent debris or rust would not be removed unless very high pressures were used.

Air blowing is also used for debris removal. The same velocity problems and limitations apply as with 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. Sometimes a pig is forced through the tube in conjunction with the cleaning. Vendors claim that this method will remove all dirt and scale, even hard mill scale. PP&L has used the process successfully at Montour for cleaning waterwall tubes but otherwise our experience is limited.

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. One problem with chemical cleaning is the rapidly increasing costs of disposal of waste solvents. Chemical cleaning can increase the cost of an order by up to $50,000 depending on material, solvents and number of tubes. Chemical cleaning can also be done in the field but the process is hazardous and time consuming.

Cleaning Recommendations

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. In some situations, this mill 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. Balanced against this is the cost of removing the last traces of scale, the fact that many tubes do not contain any mill scale, the fact that the mill scale is located in bends (which are usually not in the critical sections) and the fact that most tubes fail by erosion, corrosion or dissimilar metal weld problems - not stress rupture. Many superheater and reheater tubes are now in service with 20 to 50 mils of scale on the tube I.D. In view of the above, a judgement is being made that cold-drawn tubing is acceptable for reheater and superheater tubes without acid cleaning, even if these tubes are hot-bent.

Waterwalls are the most critical areas for replacement tube cleanliness because of increased corrosion rates and overheating due to the high heat flux. No scale or dirt should be present in waterwall tubes, and in fact these tubes are routinely acid cleaned every 4-5 years to maintain this high level of cleanliness. Cold-drawn tubes contain no mill scale and are acceptable for waterwall applications as long as no hot-bending is done during fabrication. If hot-bending is required, the tubes should be chemically cleaned to remove mill scale.

No hot-finished tubes should be used for any application unless they are chemically cleaned for the removal of mill scale. This is because thick mill scale is present on the whole length of the tube I.D. which could interfere with heat transfer or raise tube metal temperatures above design.

Tubes which have become rusty due to improper storage by the tube supplier, fabricator, or plant should also be chemically cleaned before acceptance by PP&L or installation in the boiler.

These judgements were confirmed in discussions with Combustion Engineering and Babcock & Wilcox. Both do not recommend routine chemical cleaning of replacement superheater, reheater and economizer tubes. Munroe Inc. also recommended not acid cleaning replacement tubes and further stated that they are aware of no utility other than PP&L that routinely specifies chemical cleaning of all replacement boiler tubes.

Through FOMIS, the following questions were asked of other plants:

> F86-5-77 Martins Creek normally specifies acid cleaning of replacement boiler tubes by the fabricator. Some fabricators have stated that this cleaning is not necessary.
>
> A. Do other plants specify chemical cleaning of replacement boiler tubes for:
>
> 1. Waterwall tubes?
> 2. Superheat tubes?
> 3. Reheater tubes?
> 4. Economizer tubes?

The following summarizes the responses:

(1) Total responses: 16
(2) Do NOT specify acid cleaning of any tubes: 7
(3) Specifies acid cleaning on major replacements only: 2
(4) Specifies acid cleaning routinely: 2
(5) Specifies "no scale," but not method: 2
(6) Other: 3

In addition, the central office chemists for Duke Power and Texas Utilities were contacted. Both reported that their companies do not specify acid cleaning for routine boiler replacement tube orders.

Finally, the tube failure record was checked. There is no record of tube failures since 1983 in superheaters, reheaters or economizers of any unit due to inadequate cleaning of replacement tubes. Tube bulging and failures have occurred in Montour #1 and Brunner Island #2 waterwalls that have been attributed to dirty replacement tubes.

Storage Requirements

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 and should not be removed until the tube is ready to go into the boiler. The oil can be easily removed by steam cleaning according to the attached procedure. These tubes should be capped before shipment. If the oil film is removed, these tubes should be treated as chemically cleaned tubes, discussed below.

Chemically cleaned tubes are very susceptible to rusting during storage if not properly sealed. Many tubes inspected by this writer were found to be rusted (some severely) despite being acid cleaned before shipment. Sometimes rusty tubes were witnessed being installed in boilers. Obviously, if the tubes are not properly stored, the benefits of cleaning by the fabricator are lost. Actually, the reverse is true - the tubes would be in better shape if not cleaned at all. This is because cleaning removes the films of oil and passive oxides which protect the underlying metal from rusting. The same is true of steam cleaning, but to a lesser degree since steam cleaning does not remove the passive oxide film.

The first requirement for protection is that all replacement tubes should be capped by the fabricator before shipment. This protects the tube from getting dirt, debris or water in it. Most vendors use cheap plastic caps for this purpose. The caps get brittle as a result of exposure to the elements and some crack, letting in rainwater and moisture which condenses in the tubes. Severe rusting is the result, especially if the tube has previously been acid cleaned. Two solutions to this problem are more-expensive metal caps or a weekly inspection to replace damaged caps. A weekly inspection might not catch damaged caps before moisture gets in the tubes and experience indicates that weekly inspections might not get done, so it was opted to go with metal caps.

Even with capping, some rusting may occur because of condensation. A solution to this problem is to use a Vapor Phase Corrosion Inhibitor, discussed below.

Lastly, all tubes should be inspected before they go into the boiler. Tubes should be free of all oil, grease, dirt, rust and loose debris. Tubes which "feel" oily or which cause water to bead up without wetting the tube should be steam cleaned with a solution of trisodium phosphate and water. Tubes which contain rust in amounts greater than that which can be wiped off with the finger should be acid cleaned. Loose debris and dirt should be removed by blowing out with water or compressed air. It is good practice to check bent tubes for blockages with water or compressed air. A procedure for field cleaning of replacement tubes with hydrochloric acid has been developed by the Construction Department. That procedure should be used. When field cleaning is not practical, a chemical cleaning contractor (Dow or Halliburton) can be called to do the job either on-site or at their facility.

Vapor Phase Corrosion Inhibitor (VPCI)

A relatively new development in corrosion protection applicable to tube storage is called the Vapor Phase Corrosion Inhibitor (VPCI). This product consists of soap tablets or powder laced with an amine-based corrosion inhibitor. The material sublimes in a confined space and releases the amine which condenses on the walls providing corrosion protection. The soap can be removed from the tube end by hand before installation and the inhibitor is not harmful to the boiler. This product is becoming popular for the protection of tubes in storage. PP&L has one experience with it - protecting the BI-3 economizer tubes which remained in storage for several months during the winter of 1985-86. Results were excellent.

VPCIs have been accepted by all the boiler manufacturers and several utilities, including TVA and BG&E. Instructions for the application of VPCIs to tubes for long-term storage can be obtained from the writer. The most commonly used inhibitor is CORTEC VCI-309, manufactured by Cortec Division, Sealed Air Corporation, 310 Chester Street, St. Paul, Minnesota 55107.

VPCIs should be specified for all replacement tube orders which have been chemically cleaned before shipment to PP&L.

Recommended Cleaning and Storage Guidelines for Replacement Boiler Tubes

The recommendations noted in the preceding sections have been combined into a set of guidelines for replacement tube cleaning and storage. These guidelines are applicable to replacement tubes being purchased for any boiler. Adherence to the guidelines will save PP&L a great deal of money which is wasted on unnecessary cleaning while providing assurance that only clean tubes are going into the units.

As with any generalized instruction, there will be "exceptions to the rules" and situations where strict adherence does not result in the best course of action. For example, it does not make sense to spend a lot of money to acid clean a large order of replacement tubes that will be installed during an outage when the whole boiler will be acid cleaned. In situations where there is some question about the application of these guidelines, PPE-Welding and Materials Section should be contacted.

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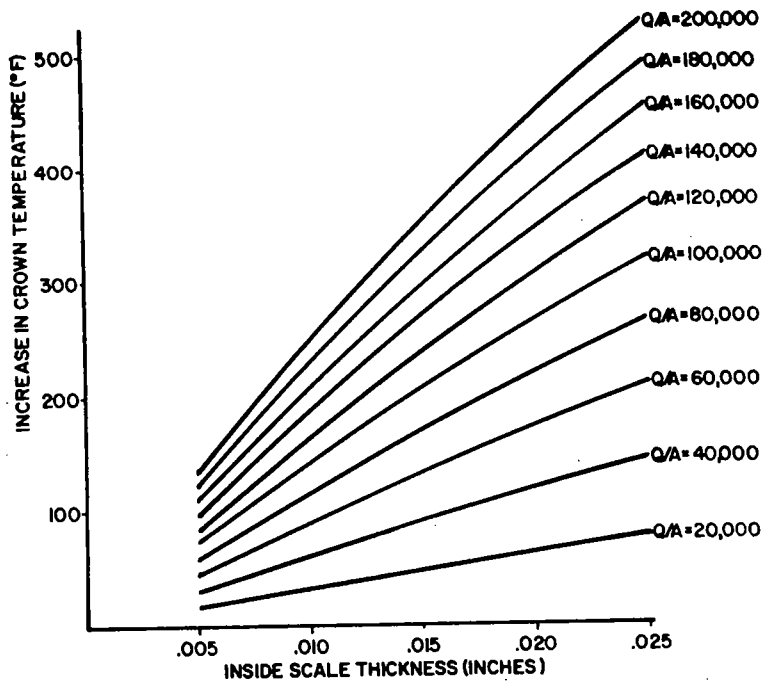

Figure 1: Temperature increase vs. scale thickness for waterwall tubes, assuming nucleate boiling.

Figure 2: Typical inside surface of cold-finished tube vs. hot-finished tube.