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Ultrasonic testing (UT) for tube thickness in black liquor recovery boilers:

Part I - Guidelines for accurate tube thickness testing

Part II - Default layouts for tube thickness surveys in various boiler zones

1. Scope

This TIP is a review of general considerations related to UT thickness testing of black liquor recovery boiler tubes:

Part I of this TIP provides guidelines and procedures for acquiring accurate ultrasonic thickness readings on boiler tubes, where the tube material and condition are conducive to such non-destructive thickness testing.

Part II describes how tube thickness surveys are commonly laid out for different zones of a typical recovery boiler. It also stresses that a customized survey is essential for each boiler.

2. Limits of responsibility

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The content of this document makes no deliberate attempt to reflect or represent the requirements of any relevant federal, state, or local laws, codes, and regulations. Awareness of and compliance with the requirements of any such laws, codes, and regulations are the responsibility of anyone inspecting recovery boilers.

These guidelines do not set, and should not be construed as setting, standards for acceptable practices, policies, procedures, limits or goals. Conversely, not following the procedures contained herein shall not necessarily constitute improper or negligent practice.

3. Safety precautions

All parties involved in thickness testing work are responsible for ensuring that a safe work environment is always maintained. Keys to safe boiler inspection include assuring that:

- Applicable safe entry procedures are followed.
- Boiler lockout/tag-out procedures are diligently followed.
- Protection from falling material is assured.

- The air in the boiler furnace and drums meets the mill's requirements for safe entry.
- All access platforms and scaffolding conform to regulatory and industry standards.
- Devices are in place to ensure electrical safety and function correctly.
- Personnel wear the prescribed personal protective equipment.

4. General considerations

4.1 Objectives of tube thickness testing

Accurate monitoring of boiler tube corrosion or erosion is an important element of a program to assure safe and reliable operation of a black liquor recovery boiler (BLRB). Tube failures due to corrosion or wall thinning have caused explosions in BLRB's. Such explosions have caused costly repairs, economic losses, and in some cases, injuries and fatalities.

Surveying the thickness of boiler tubes, primarily using nondestructive ultrasonic testing (UT) methods, is an essential part of any program for quantitatively monitoring and trending tube corrosion. Trends derived from thickness surveys can be used to optimize intervals between inspections. They also can be used to plan tube replacement or corrosion protection measures during regularly scheduled outages. Bauer and Sharp's papers provide useful discussions about trending tube thickness data (1, 2).

Surveys of boiler tube thickness on their own do not constitute adequate inspection of a boiler. **Surveys should always be complemented by a thorough visual inspection to locate and evaluate corrosion and other potential tube problems.**

This TIP aims to inform recovery boiler operators how to obtain valid UT thickness readings at each measurement location for the various kinds of boiler tubes most commonly used in BLRB's. It also offers advice on how to lay out a general thickness survey in a recovery boiler based on the Working Group members' collective experience with tube corrosion phenomena in the various parts of such boilers.

Thorough visual inspection always should precede and accompany any UT thickness survey. The visual findings may influence the layout of the thickness survey, and vice versa. A practical, step-by-step approach to visually inspecting a recovery boiler and conditions to look for are described in Vol. 1 of the Recovery Boiler Reference Manual (3) and in a NACE report (4).

Localized corrosion and distress of boiler tubes may be manifested as cracks, bulges, dents, flat spots, discoloration, etc. of the tubes. When such conditions are observed, the thickness of the affected tubes may need to be accurately determined to assess their suitability for continued service. (In some cases, one or more of the affected tubes may need to be removed for metallurgical analysis. Removed tubes also can serve as standards for UT technician qualification and instrument calibration for thickness testing.)

4.2. Instruments and techniques

4.2.1 Instruments for manual and semi-automated testing

UT for thickness measurements involves sending and receiving low energy, ultrasonic frequency, sound pulses into the component whose thickness must be measured. This technique is called "straight-beam" UT because the pulses are sent perpendicular to the accessible surface. The thickness is characterized by the time it takes the pulse(s) to travel in the material from the probe and be reflected back to the probe from the opposite (hidden) surface of the component, along with the velocity of sound through the material. A calibration standard should be used to ensure the accuracy of the measurements being taken in the boiler.

Many types and brands of devices are available for UT thickness measurements. Manual instruments can be as basic as small, hand-size units that display a simple digital reading of the thickness at a point. There also are more sophisticated instruments which display both the time signature of the ultrasonic reflection (called the A-scan) and the digital thickness reading for the test location.

Instruments with both digital thickness readout and the A-scan presentation of the UT signal provide the most information in measuring the thickness of recovery boiler tubes, provided the testing is done by a qualified technician who can interpret A-scan information. Instruments with a digital thickness readout and A-scan

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presentation should be used to limit the acquisition of erroneous data that can be obtained using digital only UT instruments. Instruments with A-scan capability also are essential for thickness scanning over an area of tube.

Semi-automated UT equipment has been developed for special purposes. Examples include rotary UT testing for generating bank tube corrosion or erosion, as well as semi-automated equipment to measure corrosion especially adjacent to the mud or steam drums (See Section 7.2.8.2). There are also rapid-scanning, electro-magnetic acoustic testing (EMAT) systems designed to screen tubes for metal wastage. These techniques may or may not involve direct coupling of the sensor to the surface. They typically involve programmed (encoded) scanning of a surface and rapid, computerized accumulation of the thickness data. Specially trained technicians must operate the equipment.

As discussed in Section 6.4, all technicians must be trained, certified and qualified on the same type of instrument they will use for the UT work.

4.2.2 Probe (transducer) selection

Probably the most common probe for manual UT thickness testing on boiler tubes and headers is a 6.4 mm (0.25 in.) diameter dual element transducer with a frequency of 2.5-5 MHz. Smaller diameter ("pencil"), or specially shaped, probes are available to access the tube surface between studs, in wall openings or when the tubes are in closely spaced platens or rows. A small diameter transducer can increase the amount of detail obtained when an area of tube is scanned. The designs and sizes of probes for semi-automated UT systems are purpose-driven.

4.2.3 Instrument calibration

All ultrasonic thickness instruments should be calibrated according to ASTM E-797 (5) requirements. Calibration standards should be similar in diameter and material to the tubes to be tested. There should be discrete calibration thickness steps with the value legibly stamped on each step that covers the range of thickness expected. Calibration with dual element transducers should "bracket" the thickness range to be examined to ensure accuracy in the range to be tested.

Calibration of manual UT instruments should be checked regularly (typically every 30 minutes) during the data gathering. This should also be done at the beginning and end of each technician's shift and whenever the technician or any of the equipment is changed. An instrument is considered "in calibration" if the calibration check reading is within ± 0.1 mm (± 0.004 in) of the selected calibration standard thickness.

If an instrument is not in calibration, all readings taken since the last time it definitely was in calibration should be repeated. The purpose behind frequent, ritualistic calibration is to avoid accumulating a large population of "off-calibration" readings. A calibration check is also recommended when any "below flag or below minimum" thickness is encountered, so as to increase the confidence in the accuracy of these specific readings. Boiler tubes have a "minimum" wall thickness requirement as per the original code of construction. In many cases, companies use a "flag" value, which is a percentage above the "minimum" requirement to help track, trend and develop repair options for the boiler before the tube reaches the "minimum" thickness value.

Calibration techniques and frequency for automated/specialized UT thickness instruments should be established ahead of the job with the contractor providing the service. Whenever practical, a tube "standard" containing similar features to those being tested should be used to refine and calibrate the testing procedure. This type of standard is also recommended for on-site calibrations and technician qualification. (See Section 6.4 for more on technician qualification.)

4.2.4 Spot readings and area scanning

Most thickness data consist of spot readings taken at positions on the tube predetermined in the thickness survey plan. For wall and floor tubes, the thickness is most often measured in three spots at each test location, such as left, right, and center (Fig. 1). The left and right readings should be taken as close as possible to the membrane weld or adjacent tube. These readings should be made within 15 mm (0.6 in) of the membrane weld to be valid "crotch" readings.

The area scanning technique is useful for finding where a tube is thinnest in the scanned area. Area scanning can also help determine the extent of any thinning that is detected either by visual inspection by spot reading or grid surveys. Area scanning is useful to detect thinning patterns in the curved tubes that form airport openings. It can also detect waterside thinning or pitting, such as in super-heater tube loops. Area scanning can be done manually or with

semi-automated procedures that scan tube thicknesses with UT probes that rotate inside the tubes. Generally the semi-automated procedures capture and present UT data better than manual procedures.

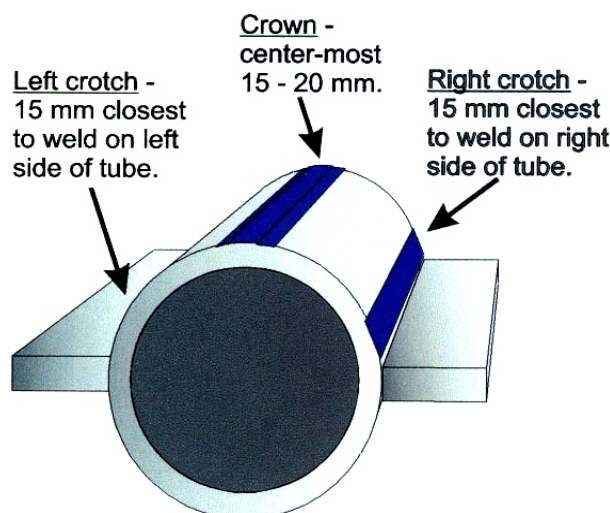


Fig. 1. Crown and crotch locations for boiler tube thickness testing.

5. Data management and review

Boiler tube thickness surveys generate large amounts of data. To get the most value from the data, they should be recorded, analyzed, and reported in an effective manner. Data recording can be either manual or electronic, as discussed below.

The original, nominal wall thickness should be documented for the boiler tubes. Tube thickness survey reports in the form of many pages filled with thousands of measurements make effective analysis of the data impractical and time consuming. Computer-based data analysis and reporting methods that utilize color-coded tables or colored graphic data presentations are readily available and are preferable. These “tools” are useful for rapidly identifying both tube wastage areas and systematic thickness measurement or calibration errors. Systems that provide color-coded, condensed graphical presentations of the thickness data, preferably presented as they were taken in the boiler, allow rapid evaluation of boiler tube thicknesses and may be used to estimate wastage rates.

Three or four sets of readings obtained over a period of several years may be analyzed statistically to determine wastage rates in different regions in the boiler. When the wastage rates are known, the projected remaining life of a given area or section of the boiler can be calculated. This value should be the primary basis for the number of survey points and the frequency at which the tubes in that area of the boiler are tested for thickness. The data from the inspections can be trended and used for condition-based inspections for the boiler. A visual inspection test (VT) is needed even if the number of measurements is reduced to look for evidence of wastage.

The operational characteristics of the boiler should be considered when determining wastage rates. Changes in operation of the boiler, such as adding an over-fired air system, changes in the liquor solids for burning, burning non-condensable gases, changes in liquor chemistry, etc., can cause changes in historical wastage rates in the boiler.

The value of tube thickness data depends entirely on the diligence with which the data is reviewed and acted upon by mill management.

6. PART I - Guidelines for accurate tube thickness testing

The key elements in obtaining accurate thickness readings on boiler tubes are:

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- Know what type of tube is involved
- Ensure access is adequate
- Ensure adequate surface preparation
- Qualify the test method (standards, scan vs. spot, etc.) and technicians
- Take the reading at the correct place and record the data error-free
- Verify the accuracy of some of the readings before the survey is concluded.

6.1 What type of tube is involved?

Many recovery boilers use mostly plain carbon steel tubing. Densely studded carbon steel tubes may be also used in the lower parts of the boiler (such as floor and walls). Some generating tubes and many economizer tubes are finned carbon steel tubes.

Other materials with superior high temperature properties or corrosion resistance have been widely used where tube temperatures or heat flux are highest. These include tubes of low-alloy carbon steels, nickel alloys or stainless steels, composite tubes with stainless steel or nickel alloy outer layers, pack-diffusion coated (e.g. chromized) tubes or weld overlaid tubing. Thermal spray coatings have also been used to protect carbon steel tube against corrosion and erosion.

Figure 2 shows schematically the different types of tube configurations used in recovery boilers. The UT testing company must know in advance of doing a thickness survey what type and sizes of tubing they will be asked to test for thickness in each part of the boiler. This knowledge helps them prepare adequately for the job, especially with regard to having appropriate qualification and calibration standards.

UT thickness testing of plain tubing is straightforward. This covers all carbon steel tubes, corrosion-resistant alloy tubes or (carbon steel) tubes with a diffusion layer. Pin studs on tubes present challenges in getting adequate access with the UT probe to the tube surface between the studs, especially on the sides of the tubes. Getting the tube surface clean enough for UT testing is important for accurate measurements. Special, smaller diameter, “pencil” probes are often used to access the tube surface between the studs, but these probes require more highly skilled technicians. (Section 6.3 contains more information about cleaning pin-studded tubes.)

KEY:

- A - Plain - carbon steel or low alloy carbon steel
- B - Pin-studded carbon steel
- C - Diffusion-coated carbon steel
- D - Composite tube – co-extruded or weld overlaid
- E - Weld overlaid on fireside
- F - Thermal spray coated on fireside

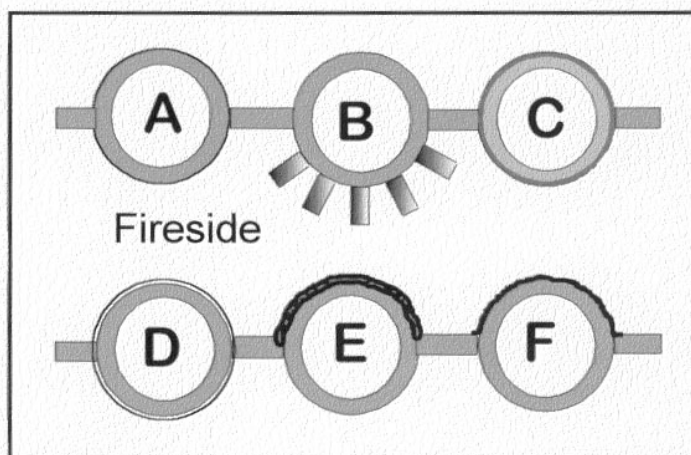


Fig. 2. Different types of recovery boiler tubes

The total thickness of composite tubes and weld-overlaid tubes can be tested as if they are typical tubes, because their external, corrosion-resistant layer is supposed to be fully metallurgically bonded to the carbon steel core everywhere and the velocity of sound in the corrosion-resistant layer is similar to that in the carbon steel substrate. UT thickness testing is also used to check the continuity and integrity of the metallurgical bond at the interface between the composite layer and the substrate.

If the outer layer of a composite or a thermal sprayed coating is not ferro-magnetic (e.g. it is stainless steel), the separate thickness of the layer can be measured with a magnetic lift-off (MLO) gauge or eddy current coating

thickness (ECT) gauge (MLO may not be accurate on weld overlaid tubes). The separate thickness of a ferromagnetic or partially magnetic external layer, including the diffusion layer on a chromized tube, cannot be measured reliably using non-destructive test methods. In addition to UT testing, chromized tubes should be inspected visually for rust bleed-through, which indicates the chrome layer has been compromised. Weld overlaid tubes can be inspected with UT.

Calibration procedures for these types of tubes and measurements must be reliable and easily transferable to in-boiler testing.

6.2 What access is available?

The UT probe must be properly positioned on the tube to acquire a valid UT reading. The technician should not be straining or stretching uncomfortably to place the probe in the assigned location.

Proper use of maintenance beams, pole scaffolding, sky-climbers, pick boards, etc., are critical to good safety and satisfactory job progress. Careful installation and removal of scaffolding is necessary to avoid damaging the tubes. Platforms must provide convenient and safe access to the test lines and locations. Adequate lighting also is essential.

Other work, usually including welding and grinding, often is also going on in the boiler during an outage. Visual inspection work and UT thickness testing must be dovetailed and coordinated with other work in the various parts of the boiler.

6.3 What surface preparation is necessary?

Salt cake deposits and buildup must be washed away both for safety and to expose the boiler tubes for inspection. This typically involves burning out the smelt bed as the boiler is taken out of service and water washing the boiler from the top down before it is entered. Special attention should be paid during washing to eliminate large salt cake deposits, which may dislodge from the upper areas of the boiler and pose a safety hazard to anyone below.

If the boiler is force-dried, firing with natural gas usually dries the boiler tubes more rapidly than drying with hot air. Firing with oil-burners can cover the tubes with a layer of soot that may impede inspection. This is not a good practice and is not allowed at many mills.

All inspection locations must be clean for accurate UT thickness testing. Very thin, tightly adhering scales can be left in place.

Cleaning can be done with abrasive blasting, with power tools (e.g., wire-brushes, sanders or grinders), or with hand tools. Water (Hydro-) blasting is often used to clean recovery boilers. Blast cleaning of the tubes can be especially disruptive of other work and must be scheduled at the most opportune time. Blast cleaning is essentially the only way to remove residues from the tube surfaces between the studs on studded tubes, especially if the studs are longer than 12 mm (0.5 in.). The appearance of rust bloom after surface cleaning is not a cause for concern.

The tube surface must be smooth enough to properly seat the manual probe on the surface without excessive rocking. Corroded surfaces should be ground carefully to the bottom of the corrosion roughness, pits or fissures in an area big enough to make a repeatable thickness reading. High viscosity couplant can be used to obtain more accurate UT readings of rough surfaces. Another option is the use of small diameter ("pencil"), or specially shaped, probes to measure the remaining thickness in the corroded area.

Thermal spray coated tubes are conventionally cleaned by controlled "brush blasting" that does not thin the coating significantly, or by alternative abrasive blast cleaning procedures recommended by the thermal spray coating applicator.

If aggressive mechanical cleaning methods (e.g., jackhammers) are used to remove frozen smelt or refractory from floor tubes, careful visual inspection of the tubes after cleaning is essential so that any significant damage produced by the cleaning can be assessed for repair. Use of jackhammers must be done without damaging the tubes. Less aggressive cleaning methods such as abrasive or hydro-blasting are preferred whenever possible.

6.4 Are the technicians and the test procedure qualified?

An NDT technician obtains certification by meeting the education, training, examination and practical work experience requirements of the certifying organization. Only certified NDT technicians should perform recovery boiler tube thickness surveys.