Inspection for cracking of composite tubes in black liquor recovery boilers

Scope

This Technical Information Paper (TIP) provides guidelines and procedures that may be used to detect and characterize cracks in composite tubes of black liquor recovery boilers. The document addresses inspection frequency, boiler preparation and tube cleaning for inspection, critical inspection locations or features, nondestructive testing (NDT) methods and inspector qualifications. It does not cover interpretation of inspection results, nor consider inspection and quality assurance requirements for new tubes. These guidelines do not supersede or replace jurisdictional and regulatory requirements.

Safety precautions

The mill’s health and safety rules for recovery boilers should be complied with for confined space entry, lockout and for personal protection requirements and procedures. This TIP may require use of chemicals which must be handled as described on the Material Safety Data Sheets (MSDS) provided by the chemical manufacturer to the mill and the user of the chemical.

Background information

Composite tubes are commonly specified as corrosion-resistant tubes in recovery boiler floors, walls and occasionally in super-heaters. The most widely used is co-extruded as a 304L SS (UNS30403) outer layer over an SA-210 carbon steel inner tube. Composite tubes with proprietary variants of Alloy 825 (UNS N08825), Alloy 625 (UNS N06625) and other high-alloy outer layers have also been used.

An alternative to co-extruded tubes has the corrosion resistant alloy applied as a weld overlay onto the carbon steel tube, either around the entire tube or only on the side exposed to the hot gas environment in tube “panels.” All composite layer alloys, wrought and welded, have superior resistance to hot gas corrosion/sulphidation than carbon steel tubes. However, the high alloy external layer is susceptible to cracking – from stress corrosion cracking and thermal fatigue, or a combination of both. Some cracks attributed to thermal fatigue have propagated into the underlying carbon steel.

Composite layers made from 304L SS have the highest susceptibility to in-service cracking. Cracking also has been reported in Alloy 825 and Alloy 625 composite tubes, but tends to be less aggressive and slower. Prolific cracking, almost exclusively stress corrosion cracking, has affected composite floor tubes and membranes in many recovery boilers. Cracks also are found in tubes at smelt spout openings; in tubes that form air port openings and in wall tubes near the floor. The main focus of this TIP is cracks in the alloy cladding (or overlay), although cracks also occur in the membrane between tubes, in membrane welds and in other welds on the tubes. Cracks in welds and membranes are a concern where they could possibly grow into the tube.

The detection threshold for cracks in the composite layer depends on tube cleanliness and the crack testing procedure (Appendix). Cracks in stainless alloys are notoriously difficult to detect, even when the testing is done by qualified technicians. Consequently, the main purpose of this TIP is to guide where to look for cracks in composite tubes in recovery boilers and to describe testing techniques with the highest sensitivity. Further information about the nature of composite tube cracking, what cracks look like, and how to mitigate cracking in recovery boilers, is available in the references.
Inspection frequency

Rates of crack initiation and growth in composite tubes depend on the composite layer alloy and the local conditions causing cracking in each boiler. Cracks in 304L composite tubes can appear in a few months in floor tubes and at smelt spout and primary air port openings – the most crack-prone tubes. Typically some tubes are inspected during every major scheduled outage: the inspection scope should be based on results of previous inspections and industry guidance.

Boiler preparation

A clean boiler facilitates inspection of boiler tubes. When preparing the boiler for inspection, the char-bed should be adequately removed, especially if floor tubes are to be inspected. Water washing the boiler while tubes are still covered by remnant piles of hot smelt has been identified as a likely cause of composite floor tube cracking. Industry research has shown that water washing the boiler when the floor tube thermocouples are below (150°C) 300°F reduce the chances of experiencing cracking in composite floor tubes. If the smelt bed is not completely removed, using auxiliary burners to dry the walls after water washing is also believed to significantly increase the risk of creating stress corrosion cracks on floor tubes.

Tube preparation

Tube surfaces must be clean for inspection. Certain NDE methods require particular cleaning procedures. These are detailed in subsequent sections.

Wall tubes: Residues left on tubes after water washing must be removed prior to any inspection. Frozen smelt deposits, especially in air port openings, must also be removed where the tubes are to be inspected. Tubes in boilers dried by oil firing tend to have an oily residue that must be removed as a first step in surface preparation.

Floor tubes: It usually is simpler to expose and clean composite tube floors in a boiler with a sloped floor than in one with a decanting floor. In the latter, the smelt-and-lime layer covering the tubes must be removed to expose the composite tubes to be inspected. Note: Tubes can be damaged with jackhammers or other aggressive methods of removing frozen smelt or refractory.

Where tube cracking occurs

Floor

Cracking of 304L/SA-210 composite floor tubes is very common in both decanting and sloped floor boilers (Fig. 1). Cracking has also been detected in composite wall tubes that extend underneath the smelt bed. Cracks occur almost anywhere on the boiler floor, but are more likely to be found on portions of the floor covered by the smelt pool. In some cases, cracking has been confined just to the membrane, but more often, cracks are present in the tube as well as the tube-to-membrane weld. Cracking in the crowns of the tubes is also observed. In cases where the cracks have existed for a long period of time, pieces of the stainless steel may spall, exposing the underlying carbon steel.

Cracking of Alloy 825 and Alloy 625 floor tubes is less likely to occur compared to 304L composite tubes.

Spout openings

Cracking has been reported in tubes at smelt spout openings with a composite layer of 304L SS, Alloy 825 and Alloy 625. Tubes in openings with external spouts are at high risk of cracking due to thermal cycling of the tubes from variations in smelt flows through the opening (Fig. 2). These tubes also are subject to mechanical damage from regular rodding to clear the spout opening: cracks sometimes initiate at gouges and dings in the composite layer, which should be removed by carefully re-profiling the tube surface.

Cracking affects spout openings differently, even in the same boiler. In at least one case, the clad layer has come off tubes forming one opening while tubes in adjacent openings had no cracks. In other boilers, every spout opening has had to be replaced. Cracking frequently is associated with welds at membranes, seal bars, crotch or stud plates, and rodding damage repair welds, but may also affect tube surfaces some distance from the welds. The most susceptible tube surface on spout opening tubes is the lower half of the opening two-pack. In some boilers, severe
cracking has occurred only on the cold side of wall tubes, inside the spout hoods. This usually is attributed to weak wash spray, which can also cause rapid corrosion.

Fig. 1: Cracks on floor tubes and membranes – note also the crack indication along tube/membrane weld.

Fig. 2. Cracks at spout openings. In this boiler, several tubes on either side of the opening were also affected by cracking.
Walls

Cracking has been found in 304L/SA-210 composite wall tubes where they intersect the floor; typically to as high as 25 cm (10 inches) above the floor (Fig. 3). On spout walls, it is common for 4 to 5 wall tubes on either side of the spout opening to be affected. In a few boilers, up to 13 tubes on either side of the opening have cracked. There are reports of wall tubes cracking up to 2.6 m (10 ft) above the floor where the smelt bed has been in contact with the wall - the cracks were not associated with openings.

Air port openings (bent tubes)

Primary air ports are generally more susceptible to cracking than openings higher in the furnace. Many cracks in air port tubes originate in or next to welds, including tube-to-membrane welds, stud or crotch plate welds. However, cracks also occur away from welds. Cracks of greatest concern at air port openings are thermal fatigue cracks, which are most likely to arise on the crown and sides of the bends in the bottom half of the opening. In a primary air port, the two-pack forming the opening is most severely affected. These tubes always crack sooner and more severely in the lower half of the opening than the upper half; cracks are seldom found in the top half of the opening (Fig. 4).

Butt welds

Cracking affects butt welds in composite tubes, especially where the weld reinforcement is excessive. This is attributed to thermal fatigue from poor cooling of the extra material.

Inspection techniques

A number of techniques are used to inspect black liquor recovery boilers for cracks in composite tubes. A brief description of the most commonly used methods and their limitations are provided. Note: Every NDT method and procedure used in the boiler must be calibrated and qualified in the hands of the technician(s) before it is used on the work-piece.
Fig. 4. Cracks at primary air port openings – the photo on the left shows typical craze cracking and indications at the membrane termination below the port casting. Linear indications suggesting thermal fatigue are shown on the right. Note that cracks at primary air port openings are most often found in the bottom half of the opening.

Visual

Visual inspection identifies areas of tube roughness, corrosion and mechanical damage. Bright oblique lighting reveals discontinuities and bulges in the tubes that might otherwise be missed. Unusual patterns, textures or colours on portions of a wall or tube may indicate regions that have experienced different process conditions than the balance of the boiler – these areas merit closer inspection to assure damage hasn’t occurred. Some fire-side cracks are visible to the eye, but most are not, even after the surface is thoroughly cleaned.

Liquid penetrant testing

Performed properly, liquid penetrant testing (PT) improves detection of cracks over visual inspection. However, PT sensitivity is reduced if the tested surface is not adequately clean or if cracks are filled with corrosion product or precipitated salts. Consequently, surface preparation is especially critical for penetrant testing. The most successful technique has been to use a 100 or 120 grit flapper wheel to clean the surface as a final step before penetrant pre-cleaning and application of a visible penetrant. The flapper wheel removes a small amount of material from the surface of the tube, and leaves the crack in an optimal condition to absorb the penetrant. Wire-brushing alone will never expose tight, fine cracks. Light grinding may be suitable, but extreme care is required to avoid damaging the surface and excessive removal of material.

Fluorescent and visible-color contrast (red) penetrants are the two types widely available, and both are available in solvent-removable, water-washable, and post-emulsifiable forms. Water-washable visible penetrant is an efficient method for inspecting large areas, but over-washing must be avoided. Inspection with visible color contrast penetrant must be performed with adequate white lighting. Inspection with fluorescent penetrant is performed with ultraviolet (black) light with the background suitably darkened. Because cracks are often tight and relatively shallow, they hold very little penetrant. Consideration should be given to increasing penetrant dwell time over ASTM/ASME recommended specifications. In addition, the development stage will be most sensitive when layers of developer are built up lightly. The heat of weld repairs performed on composite tubes often causes previously undetected cracks to open up and become detectable by PT. Consequently, PT should always be done after weld repairs to composite tubes.
CAUTION: PT involves the use and removal of significant volumes of organic chemicals that are potentially harmful or flammable, and appropriate safety practices must be followed.

Eddy current testing

Eddy current testing (ECT) is a rapid method of inspecting for cracks in composite tubes and membranes by sweeping the eddy current probe along clean tubes and membranes. An array of coils housed in a contoured probe induces eddy currents into the non-ferromagnetic part of the floor tube. Disturbances of the eddy currents by cracks and other discontinuities detected by the eddy current flux sensors indicate the crack or flaw. Because ECT commonly identifies non-critical surface and subsurface irregularities as flaw indications, skillful operator interpretation of the results is required to identify a crack. Cracks revealed by ECT must be verified with PT.

Other NDT methods

Acoustic emission testing (AET) and ultrasonic flaw detection (UT) have not been found reliable for finding or characterizing cracks in composite tubes, especially cracks in the composite layer.

Documentation

Inspection and NDT reports should document findings from visual observations and examinations and other relevant information. It is very useful to include data on sizing of linear indications as well as photographs, drawings, etc. of areas of special interest and of repairs for year-by-year comparison.

Keywords

Cracks, Recovery furnaces, Tubes, Inspection, Nondestructive tests, Stainless steel, Carbon steel

Additional information

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References

3. TIP 0402-18, “Guidelines for non-destructive thickness measurement of black liquor recovery boiler tubes”, TAPPI, Atlanta, GA
APPENDIX

Qualifications of nondestructive testing (NDT) personnel

1. NDT inspection personnel should be trained and certified in each NDT inspection method used to inspect the boiler. Practices used to certify the inspection personnel should be reviewed by the owner/operator to ensure that they comply with regulatory requirements, and with the needs of the job. Some owner/operators further require inspection personnel to demonstrate proficiency in locating specific types of defects in on-site test panels before allowing them to engage in inspections. In the United States and Canada, inspection personnel should be certified in accordance with either:

   - ASNT Recommended Practice No. SNT-TC-1A: Personnel Qualification and Certification in Nondestructive Testing. Recommended Practice No. SNT-TC-1A: Personnel Qualification and Certification in Nondestructive Testing (2011) provides guidelines for employers wishing to establish in-house certification programs. SNT-TC-1A establishes the general framework for a qualification and certification program. In addition, the document provides recommended educational, experience and training requirements for the different test methods. (www.asnt.org)

   - ANSI/ASNT CP-189-2011 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel. This ANSI-approved American National Standard establishes minimum requirements for the qualification and certification of nondestructive testing and predictive maintenance personnel and details the minimum training, education, and experience requirements for NDT personnel and provides criteria for documenting qualifications and certification. (www.asnt.org)


   - EN 473, Non-destructive testing — Qualification and certification of NDT personnel — General principles. This European Standard establishes principles for the qualification and certification of personnel who perform industrial non-destructive testing. Available from: http://engineers.ihs.com/document/abstract/SGUOHBBBBBBBBBBAA

2. Personnel certification records should be available to the mill representative for review before the inspection. Owner/operators may require additional information and documentation regarding specific experience of personnel performing this test work.

3. Written inspection procedures for all NDT should be reviewed by the mill representative before work proceeds.