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Guidelines for inspecting batch digesters

Scope

This Technical Information Paper (TIP) provides guidelines and procedures for inspecting batch digesters in pulp mills. It describes damage mechanisms and addresses inspection frequency, planning, methods, damage or inspection locations, cleaning and preparation, technician qualifications, test equipment and documentation.

The primary focus of this TIP is stationary, vertical, cylindrical welded, carbon steel digesters that make up the vast majority of the batch digesters in service. Batch digesters may be made from carbon steel or stainless steel. Carbon steel vessels may be wholly or partially internally protected with corrosion resistant alloy (CRA) weld overlay or clad layer. Thermal spray coatings also have been used to prevent steel corrosion. Vertical cylindrical digesters constructed of solid stainless steel are covered in this revision of the TIP.

Digesters of riveted or forge welded construction are not covered in this TIP. Inspection of batch digesters in acidic (sulfite) pulping service, which are stainless steel or have a brick-lining, is not specifically covered by this TIP, although the general guidelines herein apply. This TIP does not provide guidance on interpreting inspection findings, assessing fitness for continued service or designing acceptable repairs. The National Board Inspection Code (1) and API 579-1/ASME FFS-1 Post-Construction Code provide such guidance (2).

Inspection guidelines in this TIP are to supplement, not supersede jurisdictional and regulatory requirements.

Historical perspective

Hundreds of batch digesters are in regular service worldwide, most seeing 7 or 8 cooking cycles per day. Despite the possibility of rapid corrosion of carbon steel by cooking liquors, catastrophic failures of batch digesters are rare. TAPPI is aware of only two catastrophic failures of a batch digester since 1952 in the world. The catastrophic incident in Florida in 1994 was the first recorded failure of a welded, vertical, carbon steel digester. Explosive rupture of a stainless steel digester in a sulfite mill in South Africa in 2002 involved unusual metallurgical damage from a chip fire. Improving this good safety record is the main purpose of this TIP.

To maintain safe operation of digester vessels, corrosion (caused by damage mechanisms that generally are well understood) must be found and repaired before the mechanical integrity of the vessel is compromised. Modern vessel integrity management practice involves combining knowledge of damage mechanisms with digester-specific maintenance experience, plus qualified inspection and NDT methods to systematically manage each digester's fitness for continued service. An effective batch digester inspection requires competent and disciplined external and internal inspection for indications of known damage mechanisms. Easy internal access generally makes it convenient to internally inspect batch digesters, which is the recommended procedure.

Damage mechanisms

Carbon steel and CRA in batch digesters can be affected by the following corrosion damage mechanisms:

Carbon steel

Corrosion of boldly exposed carbon steel occurs in a general or uniform manner by the “hot-plate boiling” corrosion mechanism (see Section 5.1.1.2 in 3). Carbon steel can corrode at up to 2.5 mm/y (100 mpy) where liquor runs down or splashes on the shell during digester filling or when liquor continually runs down the hot steel surface. Steel normally corrodes at < 0.5 mm/y (< 20 mpy) where there is no active hot-plate boiling.

Carbon steel corrodes mostly by pits progressing to a modest depth and then expanding laterally instead of continuing to deepen, producing a reasonably smooth surface on which the pitting cycle recurs. Each carbon steel digester has its own pattern of internal corrosion, although corrosion patterns are fairly similar in a fleet of digesters in a mill. Patterns depend on filling practices; however, hardwood and softwood digesters in the same mill usually have different corrosion patterns.

Hot-plate boiling corrosion by liquor entering pockets or cavities behind a CRA lining or clad layer can cause leaks if these conditions are not detected in time. Improper repair of this type of corrosion can lead to serious consequences, including digester rupture. (“*Finger-nail corrosion*” can also occur; see description below.)

Another carbon steel corrosion mechanism in alkaline digesters is relatively localized, flow-accelerated corrosion (see Section 5.1.1.3 in 3) where the passive film on the steel is physically removed by process liquid flow. Common locations affected are behind extraction screens; in and around nozzles taking liquor to indirect heaters, and in and around the blow nozzle.

Carbon steel batch digesters in N. America are thermally stress relieved to satisfy ASME Code rules but caustic stress corrosion cracking (CSCC) of the welds and repair and overlay welds does not occur anyway because the steel potential changes from active to passive during each cooking cycle and does not reside long enough in the critical CSCC zone. Cracking of carbon steel welds at internal attachments almost always is due to corrosion fatigue. Fatigue cracking also can affect external welds at vessel supports and nozzles.

Grinding or corrosion of welds may expose welding defects. Cracks in seam welds are presumed to be hydrogen cracks from original welding unless metallurgical analysis confirms another cause. [Note: “Critical lengths” for cracks perpendicular to the primary stress in carbon steel digester shells to become unstable typically exceed one foot, determined as part of a fitness-for-service evaluation as described in API 579-1/ASME FFS-1 (2).]

Stainless steel

Hot-plate boiling corrosion affects CRAs significantly less than carbon steel. Corrosion rates depend on the alloy composition: higher chromium content increases corrosion resistance; higher molybdenum content reduces corrosion resistance (3,4). Duplex stainless steels, used specifically because of their superior resistance to alkaline liquor corrosion, sometimes experience hot-plate boiling corrosion if directly splashed with cooking liquor.

Hot-plate boiling corrosion of CRA produces rough, frosted or etched surfaces. As with carbon steel, hot-plate boiling corrosion is more aggressive on surfaces directly impinged by liquor, producing a characteristic corrosion pattern. CRA welds and overlays can crack from hot-cracking when the welds are made and corroding welds can acquire networks of fine cracks. Stainless steel and CRA attachment welds can crack due to corrosion fatigue.

“*Finger-nail corrosion*” produces sharp edges on CRA overlays and welds due to continued corrosion of the carbon steel. The resulting ditches normally are not structurally significant. Repair is required if ditching is severe enough to trap liquor behind the CRA layer and local steel corrosion is accelerated.

Thermal spray coatings

Corrosion of thermal spray coatings normally produces an etched surface appearance similar to the as-coated surface texture. Arc-sprayed coatings, which predominate, are rougher and thicker than HVOF coatings. Coating corrosion patterns normally appear after a couple of years. Corrosion of the carbon steel concealed behind thermal spray coatings is less problematic than behind weld overlays, which are strong enough to trap large pockets of liquor.

Thermal spray coatings tend to fail due to local blistering and spalling, which can occur soon after the coating is installed due to inadequate quality of the coating or due to corrosion of the carbon steel substrate at coating defects.

Inspection frequency

Inspection intervals for carbon steel digesters normally should not exceed two years or 5,000 cooks.

Inspection intervals for CRA digesters or those lined with a corrosion-resistant barrier should be defined by the highest corrosion rates or the corrosion barrier's estimated remaining life, respectively. (The corrosion barrier typically is considered to "fail" when carbon steel is exposed.) Relevant state, local or jurisdictional inspection interval requirements may require inspection at some maximum time interval.

Factors to consider when determining the inspection frequency for a specific digester should include:

- Age and materials of construction.
- Condition and corrosion rates of the pressure envelope and corrosion barrier(s) as determined in most recent inspections.
- Process changes made after the previous two internal inspections.

Inspection planning

Safety

Personnel safety and industrial hygiene should be ensured by complying with established mill safety, lockout and confined space entry procedures.

Some testing described in this TIP involves use and handling of chemicals which present flammability and health hazards to humans. Procedures for safe handling these materials shall be as stated in the Material Safety Data Sheets, which must be obtained from the chemical supplier. Prior to using inspection procedures in this TIP, the user should determine which chemicals to be used are potentially hazardous in order to strictly follow the procedures specified in the MSDS and to meet local, state and federal requirements for safe use and disposal of these materials.

Review existing information

Inspection starts with an engineering review of the pressure vessel data sheets, drawings, repairs and recent inspection reports. Drawings must be updated to show vessel modifications, overlays, repairs, etc. Appendix A has guidelines for setting up a permanent file for a digester. If vessel records are inadequate or incomplete, an appropriate baseline inspection should be conducted as soon as practical.

Mill responsibilities

The mill should assign management of a digester inspection to someone who, by virtue of appropriate training, experience and authority can:

1. Manage safety measures for safe vessel entry and worker access.
2. Arrange for the digester to be adequately cleaned and prepared for inspection (see Cleaning)
3. Ensure the digester is thoroughly inspected as outlined in this TIP, and verify qualified NDT procedures and practitioners are properly used to accurately characterize the corrosion damage.
4. Ensure that conditions found are adequately reviewed and analyzed for fitness for continued service.
5. Ensure the inspection results, repairs, etc., are fully documented in the specified reporting format.

These issues are discussed below.