CONTINUOUS DIGESTERS AND RELATED PROCESS VESSELS

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1.0 SCOPE

Recommendations are provided for the construction, protection, operation, and maintenance of continuous digester system vessels (impregnation vessels, blow tanks pressurized diffusers, etc.), primarily as used in the wood pulping industry. The primary focus of this data sheet is vertical-type digester systems, but horizontal and inclined systems also are included, although rare in pulp and paper mills. Recommendations may be applied, with judgment, to similar vessels encountered in other industries. Such vessels include digesters or cookers found in agricultural-related industries, and simple reactor vessels found in chemical process industries.

1.1 Changes

April 2025. Interim revision. Minor editorial changes were made.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Equipment and Processes

2.1.1 Construct vessels and piping in accordance with a recognized code, such as ASME Section VIII. Include provisions for wind, seismic, and precipitation loads that can be anticipated in the geographic area. Also address flood, surface water, and freeze potentials.

2.1.1.1 Maintain and keep available the original fabrication documents, including the following:

- Vessel drawings
- Code of construction data reports, such ASME Form U-1, Manufacturers' Data Report for Pressure Vessels, and other pertinent drawings, radiographs, etc.
- A rubbing or facsimile of the nameplate showing the vessel manufacturer, design and registration data, and the location of the nameplate on the vessel
- Documentation regarding whether the vessel was stress relieved at construction or later (if available), and stress analysis reports and design calculations identifying the minimum required wall thickness of heads, shell, knuckle radius, cone, nozzles, etc.

2.1.2 Provide a corrosion allowance or use corrosion-resistant materials to ensure vessel thickness will not be reduced below the minimum permitted by the construction code during the expected operating life of the vessel.

2.1.3 Use materials and construction processes that are less susceptible to stress corrosion cracking.

2.1.4 Post weld heat treat (PWHT) all welds of carbon steel, regardless of material thickness, in new vessels, as specified in acceptable local code. Stress relieve welds in clad carbon steel and other materials as required by the selected construction code.

2.1.5 Construct vessels with a maximum allowable working pressure (MAWP) that is at least 115% of the maximum expected operating pressure. Construct new digester system vessels that may be subject to vacuum (such as blow tanks and diffusion washers) for full vacuum.

2.1.6 Provide overpressure protection set at (or less than) the maximum allowable working pressure (MAWP) of the weakest system component. Either of the following methods can be used:

A. Provide a process protection scheme to begin shutoff of system inputs at 90% of system MAWP, and to open vents at 95% of MAWP. The intent of this arrangement is to permit operation at the necessary process pressure and avoid operation of safety relief valves or rupture disks, which may force interruption of the process.

B. Provide pressure-relief devices with sufficient relieving capacity to prevent exceeding the MAWP. This includes vacuum relief for systems not designed for full vacuum that may be subjected to vacuum. Install these relief devices so plugging by system contents is avoided. See Data Sheet 12-43, *Pressure Relief Devices*.

2.1.7 Provide a steam supply that can meet maximum demand (usually startup) of the digester system without causing upset in other mill areas. This may require a backpressure regulating device to ensure steam system pressure is not reduced below some minimum value.

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2.1.8 Provide overpressure protection on the steam supply with capacity to match the maximum available steam supply flow if the steam supply pressure can exceed the MAWP of vessels downstream of pressure-reducing stations.

2.1.9 Protect the steam supply to the digester system against reverse flow. If steam supply pressure is lost, it is undesirable to have digester system contents flow back into the steam supply system.

2.1.10 Monitor the liquor chemistry levels to ensure they are maintained within established process parameters. Take corrective action if levels are outside of process parameters.

2.1.11 Monitor the conductivity of digester system condensate, such as from indirect liquor heaters, for contamination. Provide for immediate isolation or diversion of contaminated condensate. Functionally test the condensate dump valve monthly.

2.2 Operation and Maintenance

Train operators on standard and emergency operating procedures. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs.

Have operating condition changes (physical and/or process) evaluated using Management of Change. See Data Sheet 7-43, *Process Safety*.

2.2.1 Startup Procedures

2.2.1.1 Document standard and emergency operating procedures (SOPs and EOPs) and keep them readily available for operator reference. Verify the startup procedure ensures the vessel is not pressurized until the shell temperature is well above the transition temperature.

2.2.1.2 For vertical digesters, follow the manufacturer's recommendations for the initial fill and batch cook to avoid potential plugging of the digester and damage to the outlet device.

2.2.2 Digester System Inspection, Testing, and Maintenance Program

Establish and implement a digester system (including all vessels and piping) inspection, testing and maintenance program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program. Include the physical condition of the system (with particular emphasis on the digester proper), the operating or control systems, and the safety or overpressure protection systems. Thoroughly examine systems (or individual components) when initially placing them in service or returning them to service.

2.2.3 External Inspection

2.2.3.1 Examine external surfaces of digester system vessels and piping in the vicinity of joints daily for indications of leakage. If insulated, examine the covering for wet spots and discoloration. If suspicious areas are noted, remove the insulation to permit examination of the shell or pipe. Carefully examine the vicinity of all openings (nozzles, thermometer wells, etc.) to determine if any defects exist in the attachments proper or in the weld metal.

2.2.3.2 External corrosion under insulation can become a significant thinning problem. If there are any indications of corrosion under insulation on digester system vessels and piping, use an appropriate testing method, such as UT thickness testing applied either internally or externally, to determine if repair is necessary. Vessels and piping in damp or humid environments, tending to be alkaline, acidic, or containing chlorides, are susceptible to external corrosion. Operating temperatures of 160° to 220°F (71° to 104°C) are known to rapidly accelerate corrosion. The following are some warning signs that corrosion may be present under insulation:

- Weathered, damaged, or missing caulking
- Dislocated jackets, exposing insulation
- Punctured, torn, loose, dislodged, bulged, or missing jacketing
- Reddish brown or white stains, deposits on jackets or holes in jacketing from insulation-side corrosion
- Dented jackets resulting in opened seams and connections
- Unsealed piping insulation terminations
- Unsealed inspection ports
- Gaps in jacketing around pipe hangers and other protrusions

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- Insulation system designs and jackets that do not shed water
- Exposed insulation support rings

2.2.3.3 Digesters are typically located outdoors. Areas of known corrosion due to entrapment of rainwater are within the buckstay or retaining rings of the digesters. Vessel jacketing may be improperly installed and allow water to enter this area. If noted, have the area inspected and the jacketing reinstalled properly.

2.2.4 Testing of Digester System Controls

2.2.4.1 Functionally test and calibrate the digester system controls and safety devices at each major outage. A shorter test interval is advised for any controls or safety devices that do not function properly during testing. The test interval may be extended once devices are proven reliable, but should not exceed three years. Digester system controls and safety devices requiring functional testing include the following:

- Overpressurization system
- High-amperage/high-torque protection on feeders and inlet/outlet devices

2.2.5 Digester System Internal Inspection

Inspect the complete digester system (vessels, piping, mechanical devices, etc.) prior to placing in service. Internally inspect vessels by VT after thorough cleaning. Further evaluate any indications using an appropriate NDE method. (See Table 1 in Section 2.2.7.)

For digester vessels, determine the remaining thickness of carbon steel construction by ultrasonic testing (UT), or other NDE method that provides similar results, on a set grid that is duplicated on subsequent inspections. Test localized areas of more rapid corrosion/erosion, (as identified by visual inspection or determined by operating history), at this same frequency.

Examine for wasted carbon steel beneath corrosion-resistant surfaces of digesters that are partially or entirely clad (compound plate), corrosion-resistant weld overlay, or thermal spray coated. Test any thinned areas with a copper sulfate solution to determine if base metal has been exposed. Thickness testing of the base metal is only needed if areas of the carbon steel are exposed. It is assumed that the thickness of corrosion-resistant materials will generally not be significantly reduced by corrosion.

If visual inspection of corrosion-resistant materials reveals indications of erosion or other thinning mechanisms, thickness testing of the corrosion resistant material may be necessary in the development of a corrective action plan. Similar inspection/testing is advisable for other corrosion-resistant metal-clad, weld overlayed, or thermal spray coated vessels and piping in the digester system.

Reinspect vessels and piping preferably six months after initially placing in service, but after no more than 12 months operation. Do not allow the vessel internal inspection frequency to exceed 24 months. Reinspect within 6 months if any of the following conditions is identified, or if the process is modified (chips, liquor, pressure, temperature, etc.):

A. Thinning, general or local, greater than 10% of the corrosion allowance (or remaining corrosion allowance for used vessels).

B. Discovery of indications in pressure-containing welds that require grinding or weld repair.

If no indications requiring repair are found in pressure-containing welds:

1. Continue complete internal visual inspection and complete thickness testing at maximum 24 month interval.
2. Continue visual inspection and examination of all welds by other appropriate NDE method (in addition to visual) at maximum of 24 months.

2.2.6 Inspection Priority of Pressure-Containing Welds in Vertical Digester System Vessels

The first inspection priority is welds having a history of cracking. For welds with no prior cracking history or for the first-time inspection of digesters, accumulated data indicates three major areas of concern:(1) welds that were not PWHT at the time they were made; (2) welds exposed to the highest alkaline concentrations; and (3) structural transition welds (changes in shell diameter) and nozzle attachment welds. (See Figure 1.)

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The most critical factor for carbon steel vessels originally constructed without protection of the welds is lack of PWHT. Ensure a record is kept of exactly which welds received PWHT. Generally, only welds required to have PWHT by the construction code receive PWHT. The fact that a manufacturer's data report and the code stamping indicate PWHT does not necessarily mean the entire vessel received PWHT. Manufacturers' drawings often indicate the extent of PWHT. In the absence of records, only the minimum requirements of the applicable code can be assumed to have been met.

The second most critical factor is active alkali concentration. This is dependent on the type of digester vessel and system operation. This could be the impregnation zone or the upper cooking zone. In general, it is an upper zone of a single vessel system. In a two-vessel system, the highest alkaline concentration will occur in the impregnation vessel.

The third most critical factor is stress level. The group of more highly stressed welds are those at structural transitions, i.e., any joint including a tapered (truncated cone) section where the vessel changes from one diameter to another. Also in this group are nozzle attachment welds for all digester vessels.

The priority for inspection of welds is the following:

- Welds having prior history of cracking.
- Welds having all three of the factors.
- Welds having two of the three factors.
- Welds having one of the three factors.
- Welds having none of the factors.

Figure 1 shows welds in each of the priority groups.

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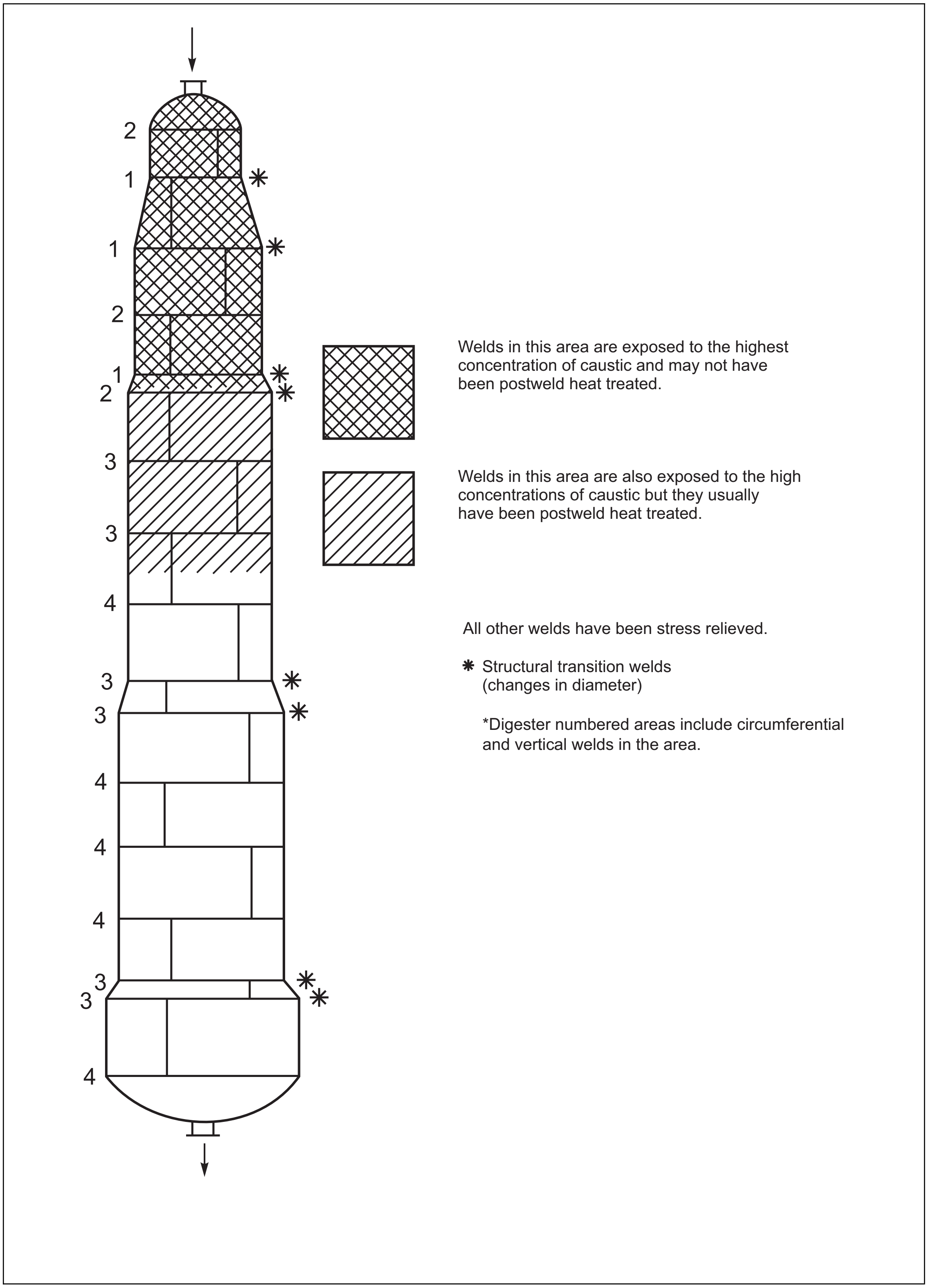

Fig. 1. Typical configuration of the digester unit depicted here is only one of many potential configurations. Actually, very few digesters are identical. They vary in physical size, number of shell courses, and the location and number of structural transitions. Numerals indicate priority for examination.

2.2.6.1 Pressure-Containing Welds With Prior Cracking History

Within six months but not more than 18 months of the last inspection:

A. Examine all welds previously reported as cracked by WFMT (PT reexamined if stainless capped). Include the entire length of the previously cracked or repaired portion of the weld plus 18 in. (0.5 m) on both ends of that portion. In addition, examine at least 50% of the remainder of the weld (WFMT or PT). Have this length broken down into 3 ft (1 m) long segments spaced equally apart. Also examine (WFMT or PT) at least 18 in. (0.5 m) of longitudinal weld at the intersections of the circumferential and longitudinal welds.

B. VT examine all welds previously reported as cracked. Have any areas showing extensive ditching (a long narrow excavation) or grooving at the toe of the weld, or crazing (checking), pitting, or other indications of attack considered to be potentially serious examined with WFMT. These areas of WFMT examination may be included in the 50% remainder of the weld described above.

2.2.6.2 Pressure-Containing Welds Not Previously Examined

A. WFMT examine all Priority 1 welds in carbon steel vessels that are not protected (corrosion-resistant material not provided over the weld) and all non-PWHT Priority 2 welds at the very first opportunity. Preferably examine the entire length of the welds but examine at least 50% of the weld length in equally spaced 3 ft (1 m) long segments, and

B. Spot examine all non-PWHT Priority 3 welds with WFMT at four equally spaced 3 ft (1 m) long segments.

C. VT examine all welds, regardless of weld priority or vessel construction. WFMT (or PT if welds capped with stainless material) examine any indications discovered by VT.

2.2.6.3 Pressure-Containing Welds – If Cracking Is Detected

A. WFMT (or MT) the entire length of any weld in which cracks are detected, and have a volumetric examination made of the crack location plus 18 inches (0.5 m) beyond the ends of the detected crack. If additional cracking is found, have a volumetric examination made of the entire length of the weld. Additionally, if a crack is found within 18 inches (0.5 m) of an intersecting weld, have a volumetric examination made a minimum of 18 in. (0.5 m) from each intersecting weld. If additional cracking is found, have a volumetric examination made of the entire length of the weld.

B. Record the location of all cracking accurately and remove all cracks.

C. Weld repairs are to adhere to the recommendations in Section 2.2.7.

2.2.6.4 Pressure-Containing Welds (Carbon Steel) **Previously Examined With No Prior Cracking History**

A. VT examine all welds at a maximum of 24 months.

B. Within 24 months of the last WFMT or PT examination, examine all vertical welds, transition welds, welds exposed to alkaline, and welds not subjected to PWHT. Include at least four equally spaced 3 ft (1 m) segments of each circumferential weld joint.

C. Examine all other welds at a period of no less than six years.

2.2.6.5 Additional Examination Recommendations

If an adverse condition develops between the set inspection interval or is discovered during planned inspection, reduce the interval for test/inspection of that area or weld to 6 months or less.

WFMT is the preferred examination for welds in carbon steel digester vessels (not having a corrosion-resistant barrier) that are not stress relieved (pre- or post-weld). Dry color contrast magnetic particle is an acceptable alternate method. Digesters that are not fully stress relieved are particularly susceptible to cracking.

Ultrasonic imaging may be externally applied to vessels. Base metal integrity, weld integrity, and base metal thickness can be determined for vessels that are not insulated or have insulation that can be readily removed. UI may be applied while a vessel is in use, providing surface temperature does not exceed limits of the

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instrumentation. Extent of examination is as described for internal NDE methods. Similar inspection/testing is advisable for all carbon steel vessels and piping in the digester system. Use of UI is not an acceptable substitute for 24-month internal visual inspections.

2.2.7 Repair Recommendations

If the recommended pressure-containing weld or shell thickness examinations reveal indications exceeding limits permitted by the original construction code or the jurisdictional inspection code, implement the following repair recommendations:

2.2.7.1 Cracks may be repaired by grinding or arc-air gouging, provided the remaining wall thickness exceeds the minimum required by the code for the vessel MAWP plus twice the corrosion-erosion allowance necessary for operation until the next planned examination. Examine the repair weld by WFMT after grinding (carbon steel) or PT (corrosion-resistant metals).

2.2.7.2 Reduced thickness areas, including welds, may be restored by welding. Thickness restoration with a similar filler material or with a compatible corrosion-resistant filler material is acceptable. The procedure for restoration of thickness by welding should address stress relief and weld shrinkage.

Welded repairs should meet all requirements of the original construction code and any jurisdictional requirements. For North America this is generally Section VIII and Section IX of the ASME Code and requirements of the National Board Inspection Code (NBIC). Provide stress relief of repair welds as recommended above for new construction. Examine the completed weld repair by an appropriate NDE method. This procedure is applicable to all digester system vessels and piping.

2.2.7.3 Angle beam (shear wave) UT examine 100% of any butt weld repair., including overlay welding. Heat input from the welding process (or arc-air gouging), particularly at butt welds, may lead to weld cracking; therefore, stress relief is needed.

2.2.7.4 In addition to wear-resistant weld overlay, thermally applied metal coatings or anodic protection systems may be used to mitigate thinning and weld cracking. Sections of vessel shell may be replaced with more corrosion-resistant material or with clad material to reduce rate of thinning. The pulping process also may be altered to reduce vessel thinning. When such measures are implemented, examine the entire vessel as described above after 6 months to a maximum of 24 months of operation. If anodic protection is provided, confirm the system is functioning as intended.

2.2.8 Deficiency Management

2.2.8.1 Develop and implement a deficiency management process as part of the asset integrity program to ensure deficiencies are evaluated and tracked to closure. This process can include the following:

A. Fitness for service: Perform a fitness for service evaluation when the inspection, testing, and maintenance program (ITM) identifies one or more deficiencies and repair, alteration, or replacement is not to be performed prior to restarting the digester.

B. Remaining useful life: Perform remaining useful life analysis when digester deterioration based on ITM results has exceeded predetermined acceptable limits but is still considered fit for service. This analysis may be performed when suitability of the equipment to operate for the intended duration is in question.

See Data Sheet 9-0, *Asset Integrity*, for guidance on fitness for service and remaining useful life.

Tables 1 and 1A summarize inspection recommendations.

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Table 1. Digester and Impregnation Vessel Inspection Matrix

Shell Material[1]	*Inspection Interval*[2, 3, 4]	*VT*	*UT*[5]	*MLO*[5]	*MT*	*PT*
Carbon Steel SA 285 and/or SA 212	24 months	Full Visual	Shell	Not Required	Figure 1, welds 1-3	Not Required
Carbon Steel SA 516-70 or equivalent	24 months	Full Visual	Shell	Not Required	Figure 1, welds 1-3	Not Required
Carbon Steel with SS clad	24 months	Full Visual	If cladding deteriorated and/or exposed carbon steel	Random	Not Required	Exposed carbobn steel welds & VT identified indications
SS Weld Overlay over Carbon Steel	24 months	Full Visual	If overlay deteriorated and/or exposed carbon steel	Not Required	Not Required	Exposed carbobn steel welds & VT identified indications
Carbon Steel Metal Thermal Spray Coated	24 months	Full Visual	If coating deteriorated and/or exposed carbon steel	Random	Not Required	Exposed carbobn steel welds & VT identified indications
Duplex Stainless Steel	36 months	Full Visual	Shell	Not Required	Not Required	Not Required

Note 1. All new vessels should be inspected after 6 months of operation but not more than 12 months after startup. For any new digesters fabricated with carbon steel, the annual inspection should be repeated until the corrosion performance of the digester has been established; typically for at least three years.

Note 2. Ultrasonic thickness testing must be performed to confirm that the digester exceeds the minimum required thickness as calculated in accordance with the applicable code (e.g., Section VIII of the ASME Boiler and Pressure Vessel Code). The results of the ultrasonic thickness testing can also be used to trend corrosion rates over time. The locations for testing should be established based on prior thinning. At a minimum, thickness measurements should be obtained on every shell course to monitor thinning. Additional measurement locations should be added if significant thinning is detected. Carbon steel digesters are built with a substantial corrosion allowance to protect the pressure boundary minimum required thickness. Corrosion rates in excess of 25 mpy are a cause for concern and mean that corrosion protection with thermal spray or weld overlay will be required before the corrosion allowance is entirely consumed.

Note 3. Reinspection of vessel should be conducted at 12 months of operation if thinning (general or local) is identified at a 10% rate higher than the corrosion allowance.

Note 4. Reinspection of vessel should be conducted at 12 months of operation if indications are found in the pressure-containing welds requiring grinding or weld repair.

Note 5. An internal inspection should be performed within 12 months of a process change that has not previously been evaluated. Changes can include any process modification such as repairs, recent process changes affecting the temperature and/or alkalinity profiles in the digester; changes in furnish and wood species, recent inspection results; or any intentional process change that has not been confirmed to be acceptable with respect to its effect on the condition of the digester. It would also include any non-intentional process change (i.e., an upset operating condition or excursion that involved a significant deviation from the normal operating parameters). The inspection following an unevaluated process change should be comprehensive in scope. It should also be fully evaluated to determine the effect on the integrity or reliability of the digester.

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Table 1A. Digester and Impregnation Vessel Components Inspection Matrix

Component	*VT*	*UT*	*MT*	*PT*
Top Separator Carbon Steel or Stainless Steel	External visual examination in seal water immersion zone at each major outage	As required per VT	Not Required	Screw flights at random locations at each major outage.Additional PT may be required for Stainless Steel Top Separator based on VT.
Internal Cone	Full Visual at each major outage	As required per VT	MT (or PT) shell attachment welds at each major outage	PT (or MT) shell attachment welds at each major outage
Center Pipe	Full Visual of all exposed welds at each major outage.	UT adjacent to each weld in carbon steel center at each major outage	MT (or PT) shell attachment welds and each accessible center pipe circumferential butt weld at each major outage	PT (or MT) shell attachment welds and each accessible center pipe circumferential butt weld at each major outage
China Hat	Full Visual at each major outage	Not Required	As required per VT	As required per VT
China Hat Support Structure	Full Visual at each major outage	Not Required	MT (or PT) of each accessible gusset-to-ring weld at each major outage	PT (or MT) of each accessible gusset-to-ring weld at each major outage
Scraper Arm	Full Visual at each major outage	Manual A-Scan	MT or PT as appropriate based on fabrication material at high stress areas around the hub at each major outage	As required per VT
Screen and Blank Plates	Full Visual at each major outage	UT on Blank Plates at each major outage	Not Required	PT seal welds at each major outage as required
False Bottom (Impregnation Vessel)	Full Visual at each major outage	Manual A-Scan on each pie segment	Window out in false bottom to test bottom head-to-shell weld (External UT may be substituted)	Not Required
Anodic Protection[1]	At each major outage			

Note 1. All components of the anodic protection system, if installed, should be inspected. Cracks or breaks sometimes occur in cathodes and buss bars and in the support hardware. A technical representative of the system manufacturer should confirm the condition of the anodic protection system components, including the reference electrodes.

2.2.9 Contingency Planning

2.2.9.1 Equipment Contingency Planning

If a continuous digester breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop, and maintain a documented, viable continuous digester equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

In addition, include the following elements in the contingency planning process specific to continuous digesters:

A. If an integrated pulp mill, consider alternate sources of pulp to minimize paper machine production losses. Even if outside sources of pulp are available careful consideration has to be given to the impact of the balance of the mill if the continuous digester is out of service for an extended period of time. Other potential impacts to consider include the following:

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- Is operating the mill on 100% purchased pulp feasible from a stock preparation perspective (i.e., the logistic of receiving and storing significant quantities of baled pulp, the availability of ample hydro-pulpers for making down pulp bales)?
- If the digester is idled, there will be limited/no black liquor fuel for the recovery boiler. Does the shutdown of the recovery boiler result in limited steam production for the mill and associated paper mill curtailments? Does the recovery boiler have load burners which can supplement steam supply when there is no supply of black liquor? Would there be any seasonal impacts (i.e., natural gas curtailments), which could impact the ability to generate sufficient steam for the paper making process?
- What is the impact on electrical power availability if the recovery boiler is idle and it is paired with a corresponding turbine generator?

It should also be considered that purchased pulp prices are very dynamic and, in some cases, it would not be economically feasible to operate the paper machine on purchased pulp. Many mills would likely elect to produce the highest margin paper grades on purchased pulp to offset the cost of the purchased pulp but may otherwise take market downtime until the pulp mill is once again operating.

2.2.9.2 Sparing

Sparing can be a mitigation strategy to reduce the downtime caused by a continuous digester breakdown depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

2.2.9.3 Equipment Breakdown Spares

Equipment breakdown spares for continuous digesters are spares intended to be used in the event of an unplanned outage of a continuous digester to reduce downtime and restore operations. Provide the following equipment breakdown spares for continuous digester:

- Low-pressure feeder
- High-pressure feeder
- Inlet device/top separator (screw feeder & basket)
- Outlet device – Includes the internal gears, bearings, couplings, shaft(s); External gear box and drive unit (electric motor or hydraulic)

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Equipment and Processes

Constructing vessels and piping to a recognized code better ensures the equipment will function as intended over the planned equipment life, and will facilitate future repairs. Specific requirements for structural loads beyond pressure containment are generally not provided in pressure vessel construction codes. These loads need to be considered to minimize damage from environmental factors.

Construction codes generally address minimum material thickness required for containing pressure, and do not provide specific guidance on material allowance for corrosion and erosion for specific service applications. As an example for vessels, see UG-25, Section VIII, ASME B&PV Code. For piping example, see 102.4.1, Corrosion or Erosion, ASME B31.1, *Power Piping*. Digester liquors may be either highly alkaline or highly acidic, leading to rapid corrosion. Digester feedstock may contain erosive material (dirt, sand) that may accelerate thinning of vessels and piping.

Carbon steel vessels and piping may require substantial additional material thickness due to corrosion and erosion over the planned equipment life. Stainless steel clad carbon steel plate, stainless steel plate and stainless steel piping have proven to have greater resistance to corrosion and erosion in digester service. Corrosion and erosion resistance of existing carbon steel vessels can be improved by protecting with high nickel content weld metal overlay or metal spray coating.

Stainless steel plate and stainless steel clad carbon steel plate is less susceptible to stress corrosion cracking in digester service. Stress corrosion cracking, in the form of caustic embrittlement, has occurred in carbon steel vessel welds that were not stress relieved.

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Carbon steel digester vessels that have been stress relieved have been much less prone to stress corrosion cracking.

Overpressure protection devices typically begin to open at less than the set pressure so full opening is achieved at no more than 110% of the set pressure. Therefore, vessel design MAWP must exceed the intended operating pressure by an amount to prevent operation of the selected overpressure protection scheme (safety relief valve, rupture disk, process limit controls). For safety relief valves, this amount is generally at least 110% of the planned operating pressure. It is not possible to operate vessels at the design MAWP. Constructing vessels for full vacuum avoids the cost of installing a vacuum protection scheme and the ongoing expense of maintaining such a system.

Process upsets and external exposures, such as fire, can result in vessel pressure exceeding intended pressure. Provision of fixed overpressure protection ensures that the vessels do not experience pressure significantly above the MAWP, which could reduce the vessel life. Data Sheet 7-49/12-65, *Emergency Venting of Vessels*, provides guidelines for the evaluation of overpressure protection systems. It indicates the overpressure protection scheme should be based on the evaluation of the worst credible case. The actual overpressure protection system design should be left to specialists.

Designing process controls to reduce inputs and to open vessel outlets at a pressure below overpressure protection device set pressure reduces the probability that the overpressure protection device will operate. Digester contents are in suspension and will generally flow toward any opening in the vessel, including overpressure protection devices connected to the vessel vapor space. The vessel contents may plug the relief piping as the flow dissipates, and can be expected to cause sticking of a pressure relief valve. Such plugging would require taking the vessel out of service until the overpressure protection system is restored. Also, safety relief valves or rupture disks are the final overpressure protection safety element. Unnecessary operation is to be avoided.

Rapid pressurization of direct steam heated digesters can seriously reduce steam supply pressure throughout a facility. This can induce unnecessary fatigue stresses on steam system equipment and may upset steam dependent operations in other areas of the facility. A backpressure regulating device can ensure some minimum pressure is maintained on the steam supply system when initially steaming a digester.

Steam distribution pressure is frequently much higher than process demand pressure. Pressure regulating valves are generally installed to limit steam supply pressure to vessels. If the regulating valve fails in the full open position or if the typically provided manual bypass is left open, supply pressure to vessels may exceed the MAWP. To avoid operation of the vessel overpressure protection scheme, relief devices are installed on the steam supply downstream from the regulating valve. The relief capacity is determined by the maximum flow that can be supplied at the lowest connected vessel MAWP.

Sudden loss of steam supply can result in digester contents flowing back into the steam supply lines. Such flow back may require system shutdown to flush liquor and pulp out of the system and neutralize any remaining acid or alkaline residue. In extreme cases, flow back may contaminate other processes in the facility and result in degradation or loss of the other products.

Condensate contamination indicates that a pressure boundary, such as a heat exchanger tube, has been compromised and prompt repair is needed. Contaminated condensate should be immediately isolated and not returned to the condensate collection system. Failure to isolate can result in damage to downstream piping, vessels and boilers.

Liquor chemistry changes in the digester process have the potential for severe and rapid deterioration of the vessel pressure parts in the form of stress corrosion cracking (SCC) of structural welds and shell corrosion. Any changes should be thoroughly examined through a management of change process.

Calcium carbonate scaling of digesters and black liquor evaporators is frequently identified as an inorganic deposit problem in the kraft cycle. Buildup of scale in the kraft digester and black liquor evaporators is a major contributor to lost pulp mill productivity. Scale deposition occurs in areas such as the heaters and extraction screens of continuous digesters and the liquor side of heat-transfer surfaces in the evaporators.

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3.2 Operation and Maintenance

Planned maintenance of operating controls can prevent unintentional overpressurization of digester system components. Proper function of overpressure protection devices, should an overpressure condition occur, can be ensured by regular maintenance and testing. Digester system components have been damaged due to failure of operating controls and protective devices to vent pressure and failure to relieve vacuum.

A thorough inspection, testing, and maintenance program can locate indications of thinning or cracking to permit timely corrective action. Catastrophic failure of a digester vessel can result from wall thinning or cracking of vessel welds.

Construction and inspection codes generally provide for some thinning and some crack-like indications. When the allowable limits are exceeded, repairs compatible with the original vessel design and materials become necessary. Provision of stress relief for all welded repairs, including weld metal overlay, is essential to avoid weld cracking or shell buckling from weld shrinkage.

Many factors can improve the material performance of digester system vessels and piping. As these factors or methods are implemented at individual mills, the effect of the implementation needs to be monitored to ensure the desired result is achieved. Depending on original process and materials, changing of some factors may have no impact and others may have undesirable impact.

Digester system materials that have performed well under a particular process regimen may exhibit rapid thinning or weld cracking upon change of the process.

3.3 Loss History

The catastrophic failure of a vertical 925 T/D (839,000 kg) continuous digester in 1980 revealed the serious problem of stress corrosion cracking (SCC) susceptibility of carbon steel vessels in continuous digester service. Previous incidents of SCC damage did not result in actual digester failures and did not reveal the magnitude of the problem. Careful, subsequent inspection of many digesters revealed that SCC damage was widespread.

Stress corrosion cracking is caused by the action of a tensile stress during exposure to a specific corrosive environment. Considerable progress has been made in understanding the origins of SCC in the digester vessels. Laboratory studies in simulated cooking liquors suggest that the cracking is a form of SCC known as caustic cracking or caustic embrittlement.

The most serious cracking generally has been found in or immediately adjacent to welds that were not postweld heat treated. In the 1980 catastrophic failure, the digester failed at the uppermost transition weld. This joint had not been postweld heat treated. In other digesters, shallow cracking has been reported in some areas remote from welded joints and in some joints that were postweld heat treated.

At a mill on the west coast, a continuous digester that was erected in 1963 had a leak in a nozzle through the digester shell. The nozzle provided a connection to the central distribution chamber of the digester. When the repair was made, it was found that the nozzle was cracked between the outer and inner welds to the digester shell.

Subsequent analysis indicated the failure was due to intergranular corrosion of the nozzle material, resulting from the interaction of intergranular carbides with the cooking liquor used during operation.

Nondestructive examination (NDE) methods have been documented by the TAPPI Corrosion and Materials Engineering Committee’s Task Group on Continuous Digester Cracking. In many recent digester inspections, cracking was found that violated the minimum shell thickness permitted by the construction code. The cracks were removed and repaired by welding. In some cases the weld repairs were locally post weld heat treated (PWHT).

3.4 Illustrative Losses

3.4.1 Lack of Inspection Leads to Rupture

A four-tube horizontal digester was used in a kraft mill. The fourth tube was 51 in. (1.3 m) diameter and 41 ft (12.5 m) long. The digester normally operated at 160 psi (1.1 MPa). During startup of the digester, a steam leak was noted. Before the steam could be shut off, the fourth tube ruptured at the inlet end. The auger was rocketed 80 ft (24.4 m) across the building, damaging other equipment and the building.

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Examination revealed shell thinning occurred 6 in. (152 mm) from the inlet end head. The digester had not been internally inspected nor thickness tested for three years. After this incident, the client agreed to perform ultrasonic thickness tests on the digester. In addition to repairing the fourth tube, the first tube required seven flush patches, the second tube required a flush patch and pad welding, and the third tube required pad welding to restore shell thickness.

3.4.2 Failure to Correct Condition Causing Safety Pin to Shear Results in Shutdown of Inclined Wood Pulp Digester

A drive shaft safety pin sheared on a five-year-old 100 in.(2.54 m) diameter by 80 ft (24.3 m) long inclined digester. The pin was replaced. After operating 4 hours, the second pin sheared. A third and fourth pin were installed and immediately sheared. The mill then decided to inspect for cause of safety pin shearing. Many chain sections and bucket flights were bent. The 12 in. (305 mm) diameter conveyor drive shaft also was cracked. The digester was out of service for a total of 10 days for repair.

3.4.3 Improper Weld Repair Results in Failure of Presteaming Vessel Serving Vertical Wood Pulp Digester

A 15-year-old presteaming vessel rated for 30 psi (210 kPa) was 58 in. (1.5 m) diameter and 24 ft (7.0 m) long. The shell was carbon steel with a stainless steel liner. The vessel was operated at 14 psi (97 kPa). After nine years of service, mill welders installed a 26 in. (660 mm) by 13 ft (4 m) patch in the bottom of the vessel. The plate was narrow for the opening, and rod material was used to fill the space. The ⅛ in. (3.2 mm) stainless liner became the pressure retaining boundary. Six years after the repair, the liner ruptured and the entire patch opened along one longitudinal edge.

3.4.4 Lack of Inspection Program for Digester Liquor Heat Exchanger Results in Mill Shutdown

This 30-year-old, 30 in. (760 mm) diameter by 20 ft (6.1 m) tall shell and tube liquor heater was being returned to service after tube cleaning. Steam leakage at the heater made the local steam valve inaccessible. The steam supply header valve could not be fully closed. Ultimately, all boilers supplying steam to the digester area were shut down to stop the steam flow.

Investigation revealed a 52 in. (1.3 m) long circumferential crack at the steam chest to heater shell weld transition. The crack was determined to be due to either stress corrosion cracking or corrosion fatigue. Ultrasonic testing of three other heaters revealed crack-like indications. A decision was made to replace the steam chest portion of all six liquor heaters on the two continuous digesters at the mill.

Prior to this incident, the client had no program to periodically examine the welds in the liquor heater vessels.

3.4.5 Lack of Stress Relief Leads to Digester Rupture

A 12-year-old vertical 925 ton/day (840 t/day) continuous digester was under stable operation when the bottom transition weld on the top cone failed. The top section of the digester rotated off the shell and landed on the adjacent pulp mill roof.

Metallurgical examination determined the weld failed due to alkaline-sulfide stress corrosion cracking (SCC). All the prerequisites for SCC are present in carbon steel pulp digesters (corrosion potential in the range where SCC is known to occur, a material subject to SCC, caustic environment and a high tensile stress). Prior to 1965 the ASME Code required stress relief for vessels of the materials and thickness generally used for pulp digester construction. This Code change has resulted in digesters being constructed with only thicker vessel sections being stress relieved, as was the case with this particular continuous digester.

As a result of this incident, all sections of this digester that were not stress relieved, were field stress relieved. An additional digester that was being constructed was specified to have full stress relief, regardless of Code requirements.

4.0 REFERENCES

4.1 FM

The following data sheets provide additional guidance on continuous digesters and related process vessels:

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Data Sheet 7-43, *Process Safety*
Data Sheet 7-49, *Emergency Venting of Vessels*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-8, *Operators*
Data Sheet 12-2, *Vessels and Piping*
Data Sheet 12-43, *Pressure Relief Devices*

4.2 Other

The American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code*, Sections V, VIII and IX.
The American Society of Mechanical Engineers (ASME), *Extra-High-Strength Weather-Resistant Steel.* SA-516.
The American Society of Mechanical Engineers (ASME), *Power Piping,* ASME B31.1.
The American Society of Mechanical Engineers (ASME), *Specification for High Tensile Strength Carbon-Silicone Steel Plates for Boilers and Other Pressure Vessels,* SA-212.
The American Society of Mechanical Engineers (ASME), *Specification for Pressure Vessel Plates, Carbon Steel, Low- and Intermediate-Tensile Strength,* SA-285.

APPENDIX A GLOSSARY OF TERMS

There are no defined terms in the document.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

April 2025. Interim revision. Minor editorial changes were made.

October 2024. Interim revision. Minor editorial changes were made for additional clarity.

July 2023. Interim revision. Changes made to improve clarity on the scope of outlet device equipment breakdown sparing guidance.

July 2022. Interim revision. Made editorial changes for additional clarity.

January 2022. Interim revision. Minor editorial changes were made.

July 2021. Interim revision. The following significant changes were made:

A. Added NDE inspection, testing, and maintenance guidance for digesters.

B. Updated the equipment contingency plan and sparing guidance for digesters.

July 2013. Recommendation 2.2.7.2 was clarified regarding acceptable use of filler metals.

January 2012. The following changes were made for this revision:

1. The recommended maximum internal inspection interval has been increased from 12 months to 24 months. Table 1 has been revised for consistency with the new 24 month maximum internal inspection interval.

2. New recommendation 2.2.1.2 provided based on adverse loss experience attributed to improper start-up practices.

3. Section 4.0, References, has been updated.

4. Appendix C, Bibliography, has been updated.

January 2010. Revised recommendation 2.1.6 to reflect the acceptability of weighted-type valves for overpressure protection on all vessels associated with continuous digester systems (including NCG collection systems attached to the vessels) that are designed for operation at less than 15 psi (103 kPa).

September 2007. Minor editorial changes were made.

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May 2003. Existing information has been reformatted. Information is now included on vertical, horizontal and inclined digesters. Recommendations and descriptions have been expanded to cover all pressure vessels and piping involved in the continuous pulping process.

January 2003. Minor editorial changes were made for this edition of the data sheet.

1998 — Reformatted.

1986 — Major technical revision, stress corrosion cracking of circumferential welds.

1966 — First publication released.

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