

# Digester SAFETY

*Failures, failure prevention and repairs of batch and continuous digesters*

BY H. THIELSCH AND F. CONE

Last April, the catastrophic failure of a batch digester claimed three lives at Stone Container's Panama City, Fla., mill. As a result, digesters will reportedly be the next target of the Occupational Safety and Health Administration (OSHA) crack-downs.

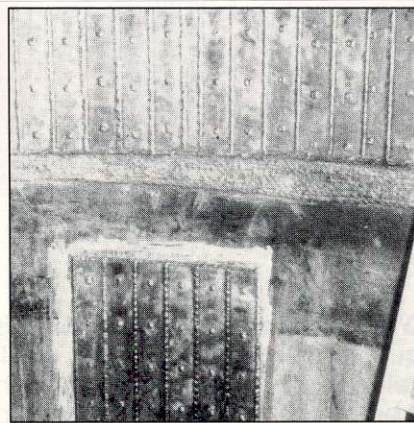
The Panama City incident is only one of a number of failures that have occurred over the 100 or so years that digesters have been used. Since both batch and continuous digesters process or cook woodchips at elevated pressures and temperatures and in a corrosive medium, they are subject to corrosion, erosion, fatigue and other types of service-related deterioration.

And because of catastrophic failures, the pulp and paper industry, as well as various insurance underwriters involved with paper mills have become increasingly concerned about the inspection, condition assessment, and repair of digesters.

It is important that those individuals inspecting any digester should be fully familiar with the design, construction, and fabrication of digesters due to their documented potential for catastrophic failure. They should also know the techniques used to complete any subsequent repairs. It is also important that these individuals be aware of the types of service-related deterioration that can occur in digesters. This article examines all these issues.

## BATCH DIGESTERS

Prior to the 1920s, manufacturers generally constructed batch digesters by riveting together steel-plate sections. While there are still a few riveted digesters in



*Upper left: Corrosion grooving apparent beneath pressure tap. Upper right: Stainless steel strip lining applied over integral stainless steel cladding.*

*Below left: Stainless steel cladding subject to stress corrosion cracking. Below right: Cracking observed underneath center pipe gusset plates.*

service, they have, for the most part, been replaced by welded vessels.

These modern/welded batch digesters incorporate a variety of different constructions, including digesters fabricated entirely from carbon steel plate material.

Also included are digesters where the carbon steel shell is protected on the inside of the digester shell by a stainless steel layer of some sort. This layer might involve roll-bonded cladding, a weld overlay, or a lining. Generally, kraft

digesters are fabricated from carbon steel plate material, while those digesters that employ pre-hydrolysis type cooking are equipped with a stainless steel liner or cladding.

Depending upon their construction, these digesters are subject to a variety of different types of service-related deterioration. For instance, those digesters that incorporate a carbon steel shell are subject to general corrosion, corrosion pitting, erosion, etc.

The photo of the pressure tap's corrosion is a case in point. It was blind, i.e., it had never been used in service. Despite this, there was a groove at the 6 o'clock position of this nozzle that extended 1/8-inch to 1/4-inch into the cross-sectional thickness of the shell. This grooving is typical of that produced by run-off. It is considered likely that white liquor entered this nozzle while the digester was being filled and remained trapped during mixing. It would then seep out of the nozzle during cooking, and, at the elevated temperatures involved, would gouge the digester shell.

Blind nozzles are not the only area of concern, as similar corrosion will occur at any crevice location, such as behind retaining bars, in white liquor injection nozzles, etc.

In some cases, it is possible to modify the operation to prevent this type of corrosion from occurring. For the most part, however, it is necessary to perform repairs by welding. To insure that the repairs have some degree of longevity, it is usually advisable to complete the repairs using a welding filler material with corrosion resistance superior to that of carbon steel. Several stainless steel and Inconel alloy grades are commonly selected. The repairs should be performed in accordance with a suitable procedure and under strict quality control as improper repairs can create more problems than they solve.

The photograph on page 54 is that of a stainless steel strip lining, and is an example of a repair gone awry. It was applied to a digester that already possessed integral (roll-bonded) stainless steel cladding. During subsequent service, the fillet welds that connected the strip lining to the cladding cracked, allowing liquor to become trapped between the strip lining and the original cladding. After a short period of time, severe stress corrosion cracking devel-

oped in the original stainless steel cladding. (The red coloring in the photos is a red liquid penetrant dye used in liquid penetrant inspections. The dye seeps into and outlines the cracks, thereby detailing every location of every crack.)

Stress corrosion cracking is due to a combination of stress, corrosive environments, and metallurgical susceptibility. In stainless steels, stress corrosion cracking generally relates to applied or residual stresses in conjunction with chloride contamination. In this instance, the fillet welds would have introduced residual stresses into the cladding.

Stresses can also result from cold rolling, end sizing, cutting, surface grinding, bending stresses, hoop stresses, fatigue, etc. The rate of attack depends on the concentration of the specific corrosive, the temperature, and the stress level. The higher the concentration of corrosive, the higher the operating temperature, and/or the higher the stress levels, the more severe the cracking is likely to be.

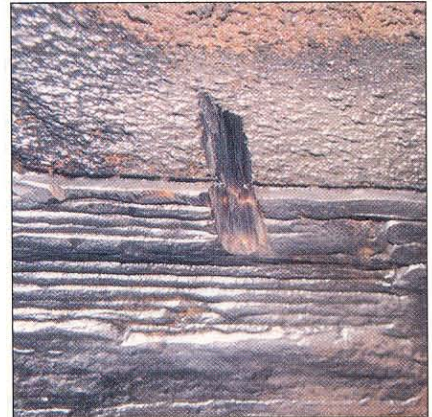
The stress corrosion cracking in the stainless steel cladding did not extend beyond the cladding into the carbon steel shell due to the presence of a nickel bond layer at the interface. This nickel bond layer was heavily compressed, and thus provided an effective barrier to stress corrosion cracking, which will not progress in the absence of tensile stresses.

Spider web fissuring is related to stress corrosion and can be seen in the photo of the integral stainless steel cladding in the cone of a digester. Despite the severe appearance of the fissuring, it did not pose any threat to the integrity of the digester, as it would not propagate beyond the nickel bond layer at the interface.

Penetration welds are an exception to this as they do not contain a nickel bond layer. The nozzle in a screw-type

*Top: Ditching observed in toe of overlay weld.*

*Bottom: Catastrophic rupture of continuous digester at top transition weld.*



digester ruptured as a result of severe stress corrosion cracking, resulting in life-threatening injuries.

Other digesters where the bond layer between the stainless steel and the carbon steel consists of iron rather than nickel have also experienced problems as the iron layer can readily disbond. In time, this can lead to bulging (blistering) of the stainless steel cladding. If the bulging is sufficiently severe, the protruding portion of the stainless steel cladding will be subject to erosion.

Stainless steel cladding is also subject to other types of deterioration, including corrosion pitting. Generally, however, it seems that the welds in stainless clad vessels are the most severely affected by service-related deterioration. Due to their increased ferrite content, they are subject to preferential corrosion. When the stainless steel weld deposits become rusty in appearance, this is an indication that the corrosion has reached the portion of the weld that has been diluted by the underlying carbon steel. At this point, repairs by weld overlaying are considered advisable.

Stainless steel weld overlays are not without their difficulties, such as pitting

and the possibility that a pinhole leak in the overlay might result in rapid corrosion of the underlying carbon steel. Care must be taken during the weld overlaying process to insure that the overlay is free of serious defect conditions, such as lack-of-fusion, buckshot porosity, etc., that would result in pinhole leaks. More importantly, any inspection of an overlaid vessel must be altered accordingly, because this corrosion is undetectable by conventional inspection techniques.

### CONTINUOUS DIGESTERS

Initially, all digesters were of the batch type, but in the 1950s, improvements in the technology lead to the development of several different types of flow-through digesters. These digesters, which were capable of processing the woodchips in a continuous stream, were referred to as continuous digesters.

There are several different types of continuous digesters. However, the most widely used is the vertical downflow type. There are approximately 350 in service today.

Continuous digesters, like all digesters operating in North America, are designed and fabricated in accordance with the requirements of Section VIII of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. They range in capacity from 190 tpd to 1,175 tpd. They are fabricated from carbon steel plate material. The grade of plate material varies with the year of construction. Those digesters fabricated prior to 1967 usually involve carbon steel plate material produced to ASME Specification SA-212 or SA-285. In the summer of 1967, ASME Specification SA-212 was superseded by ASME Specification SA-516. Thus, most of the digesters constructed since that time have been fabricated from carbon steel plate material produced to ASME Specification SA-516. The heads of these digesters are clad with stainless steel to provide improved resistance to erosion.

A number of problems have developed in Kamyrdigesters during the last decade or so. Of these, probably the

most dramatic is the rupture of the continuous digester at a mill in Alabama on September 26, 1980. The top 25 feet of the vessel was separated completely and was thrown against a nearby building. The failure occurred at the lower weld of the transition cone (see photo).

The failure of this digester is commonly attributed to caustic stress corrosion cracking. In this particular case, the weld that failed had not been stress relieved and, therefore, contained fairly significant stresses. These residual stresses, in conjunction with the caustic black liquor, were sufficient to result in the gradual initiation and propagation of stress corrosion cracking.

As a result of this digester failure,

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owners began inspecting their own vessels. By January 1983, 107 Kamyrdigesters had been inspected. Of those vessels, 40% exhibited cracking that exceeded the 1/4-inch corrosion allowance, while 40% exhibited no significant cracking. The remaining 20% of the vessels exhibited minor cracking. The variation in the severity of the

cracking was attributed to the fact that the stress corrosion cracking only occurred in a very narrow potential range.

The morphology of cracking varied greatly from mill to mill. The most severe cracking—from the standpoint of digester reliability—was relatively deep, continuous cracking in the heat-affected zone of girth welds. This longitudinal cracking was occasionally found to crack 90% of the circumference of the weld to a depth of 1/2-inch or more.

Severe cracking was also observed in the toes of the fillet welds connecting the center pipe supports to the shell. (See the photo of the appearance of this cracking after the removal of the center pipe.)

An updated survey of the industry in 1985 confirmed that 73% of the digesters in alkaline pulping service had developed stress corrosion cracking. The vessels most prone to this condition involved those in the 300 tpd to 900 tpd range, those that were erected between 1965 and 1971, and those with only par-

tial or no post-weld heat treatment.

The fact that vessels fabricated after 1965 were more prone to stress corrosion cracking is explained by the fact that Section VIII of the ASME Boiler and Pressure Vessel Code was modified in that year. Previously, all welds in carbon steel plate material with a thickness in excess of 1 inch required a post-weld heat treatment. Under the revised edition, post-weld heat treatment was not mandatory for welds in carbon steel plate material in thicknesses up to and including 1.5 inches.

Different techniques were used to address this stress corrosion cracking. Some tried grinding out the cracking and repair-welding the resultant cavities using carbon steel filler material. In general, this technique was not very successful because the repair-welding lead to higher stresses and more rapid re-cracking. Some repair-welding techniques, which incorporated a low stress buttering procedure in conjunction with a high preheat (550 degrees F), proved more satisfactory.

Others decided to overlay the affected welds with either a 300 Series stainless steel or a nickel-alloy, such as Inconel, thereby isolating the welds from the caustic environment. This approach, which was probably the most common, was not without problems. In some instances, stress corrosion cracking developed in the heat-affected zone of the carbon steel shell. (Generally, if a suitable low-stress welding procedure is used, this condition can be avoided.) In other instances, the overlay itself developed stress corrosion cracking. (That is one of the reasons that a nickel alloy is increasingly selected in preference to stainless steel.)

One of the most prevalent conditions observed in overlaid welds is corrosion ditching or "fingernailing," so-called because fingernails can slide underneath the weld overlay. Corrosion ditching can be quite severe in appearance (see photo). Generally speaking, however, it progresses for a limited distance and then becomes static. Of course, there are exceptions to every rule and mills should closely monitor this condition during annual inspections.

One other condition relating to weld overlays, one that has been mentioned occasionally in the literature but never fully explored, relates to the galvanic couple formed between the overlay and

the carbon steel shell. It has been suggested that this couple will lead to accelerated general corrosion of the carbon steel shell in the immediate vicinity of the overlay.

Other attempts to reduce the potential for caustic stress corrosion cracking have included in-situ stress relieving, shot peening, flame spraying, and anodic protection. It is generally agreed that the first two methods are unsuccessful. There is still some debate regarding the effectiveness of flame spraying. When it was first utilized, the porous nature of flame spray materials and the likelihood of spalling made it a risky proposition—at best. Recently, greater success has been achieved when the flame spray materials are used in conjunction with a sealant.

Theoretically, anodic protection should be by far the best approach to combat stress corrosion cracking as it is well documented that the stress corrosion cracking will only occur in a very narrow potential range. Unlike other remedial measures, however, you cannot forget about it from one year to the next. Moreover, anodic protection has yet to be used on a wide scale basis. Thus, its efficacy has not been demonstrated conclusively.

A more recent problem of the last two to three years is severe corrosion in the lower cook zone of digesters. One mill indicated that its digester had experienced a 1/4-inch reduction in wall thickness in less than one year.

Investigations have been made by various TAPPI task force groups to determine why this accelerated corrosion is occurring. There have been no definitive conclusions offered. It appears that a combination of conditions produced by normal operations triggered the corrosive behavior.

Those digesters subject to reductions in wall thickness are generally repaired by weld overlaying. In some mills, the weld overlays are applied during conveniently planned outages in 6- to 12-month intervals until the original design wall thickness is restored. Other mills perform their weld overlays during a sin-

gle extended outage.

There are, of course, a number of different welding methods that can be used to complete a weld overlay. The three most common are shielded metal arc welding (SMAW), gas metal arc welding (GMAW), and submerged arc welding (SAW). The best choice depends on the amount of square footage that must be completed and the time frame available. Overlays of limited size can usually be completed satisfactorily by SMAW or "stick" welding. Much less set-up is required than with the automatic processes. Larger overlays should generally be completed with the GMAW or SAW processes. Of the two, the latter welding process seems to result in a "cleaner" weld.

There are currently three filler metal materials available for weld overlaying: carbon steel, stainless steel, and Inconel. There is a great deal of debate regarding the best selection. There are some who argue that applying carbon steel weld overlays to a digester that has shown rapid corrosion is throwing good money

after bad. This is probably true. In those instances, however, where the reductions in thickness have occurred gradually over an extended time period, carbon steel is by far the best choice. As discussed previously, stainless steel and Inconel weld deposits have definite "edge effects," and depending on the quality of the weld

overlay, the possibility of corrosion occurring underneath the overlay cannot be ruled out.

#### A FINAL NOTE

The importance of regular inspections of batch and continuous digesters cannot be overemphasized. These inspections should be performed by qualified, experienced personnel to insure that potentially dangerous conditions are not overlooked. It will also insure that harmless conditions are not repaired needlessly. Pm

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*H. Thielsch is the president, and F. Cone is a senior metallurgical engineer at Thielsch Engineering Inc., Cranston, R.I.*