Paper No.
01423

CORROSION 2001

CORROSION PROTECTION OF KRAFT DIGESTERS

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ABSTRACT

This paper discusses novel applications of anodic protection, weld overlay, and thermal spray coating for corrosion protection of carbon steel batch and continuous digesters. Anodic protection now offers the possibility of protecting behind screens and blank plates. Stainless steel weld overlay can be applied behind headers for protection against erosion-corrosion. Thermal spray coatings can be applied over circumferential weld seams for protection against stress corrosion cracking. Also discussed are the advantages and disadvantages of each protection mode as well as their compatibility with each other.

Keywords: acid cleaning, anodic protection, clad plate, digesters, duplex stainless steel, erosion-corrosion, intergranular attack, pitting, pulp and paper, stress corrosion cracking, thermal spray, weld overlay

INTRODUCTION

Digester vessels (including impregnation vessels) constructed using carbon steels or austenitic stainless steels experience corrosion problems that may inevitably require some form of protection so that they can safely remain in service. Corrosion problems experienced in digester vessels include[1]:

Corrosion Mechanism	Continuous Digesters	Batch Digesters
Caustic stress corrosion cracking of carbon steel.	Yes	Rare
Corrosion thinning of carbon steel.	Yes	Yes
Preferential corrosion of carbon steel welds	Yes	Yes
Erosion-corrosion of carbon steel.	Yes	Rare
Acid cleaning damage of carbon and stainless steel.	Yes	No
Corrosion thinning of stainless steel.	No	Yes
Intergranular attack of stainless steel.	Yes	Yes
Stress corrosion cracking of stainless steel.	Yes	Yes

MECHANISMS OF CORROSION IN DIGESTERS

Stress Corrosion Cracking of Carbon Steel

Caustic stress corrosion cracking (SCC) is the most serious form of corrosion that can occur in a continuous digester and has resulted in the catastrophic failure of a continuous digester. SCC affects mainly welds in the impregnation zone or in the impregnation vessel in two-vessel systems. SCC occurs only within a narrow range of corrosion voltage potentials. In the impregnation zone of a digester the corrosion potential can remain in the SCC range long enough for cracks to initiate and propagate. Continuous digesters that were not post-weld heat treated or only partially stress relieved have high residual tensile stresses especially at welds and in conical sections and are most susceptible to SCC. SCC is rare in batch digesters due to the cyclic nature of their operation. The corrosion potential in batch digesters is not in the SCC range long enough for SCC to initiate.

Rapid Corrosion Thinning of Carbon Steel

Rapid corrosion thinning can result in the consumption of the corrosion allowance of a digester such that the wall thickness falls below that required by the construction code. Such vessels must either be restored to a satisfactory thickness (for example, by carbon steel weld buildup that itself is only a temporary measure) or de-rated in order to permit operation with a thinner wall. Rapid thinning of continuous digesters typically occurs around the extraction screens or in the wash zone near the bottom of the digester[2,3]. It is rare for thinning to occur near the top of a continuous digester. Corrosion potential monitoring suggests that the thinning of batch digesters occurs during the liquor filling and heating stages[4,5]. Corrosion thinning is most pronounced where the liquor splashes on the batch digester wall during the filling process. The most dangerous form of corrosion thinning of batch digesters occurs behind stainless steel weld overlays that have developed pinholes. Cavities that form behind overlay pinholes can result in external leaks.

Preferential Corrosion of Carbon Steel Welds

Preferential corrosion of carbon steel welds is usually a consequence of the higher silicon content of the weld as compared with the plate from which the digester was constructed. Steels with a higher silicon content tend to corrode more rapidly in kraft liquors than do steels with a lower silicon content[6].

Erosion-Corrosion of Carbon Steel

Erosion-corrosion occurs in continuous digesters at locations where a high velocity liquor flow is possible, e.g., above the internal cone or behind screens and header plates. Erosion-corrosion is typically localized but can be very deep. The digester wall area behind headers where a very high velocity flow can occur through the orifice holes in the circumferential backing bars between the screens and the header may be especially bad (Figure 1).

Acid Cleaning Damage

Acid cleaning is done mainly in North American in order to remove thick deposits of carbonate scale. Unfortunately, the acid most commonly used in this cleaning is muriatic acid, a technical grade of hydrochloric acid. Acid cleaning at temperatures above 70°C can result in pitting corrosion damage to both carbon and stainless steels regardless as to whether the correct inhibitor is used. End-grain corrosion of stainless steel can occur at the slots in the screens. The ferrite phase in stainless steel welds is particularly susceptible to corrosion by hot muriatic acid cleaning solutions. Girth welds in the central pipe are at high risk since the weld roots may be attacked by the hot muriatic acid

Corrosion of Stainless Steels

Corrosion thinning of conventional austenitic stainless steels, such as type 304L, is not a problem in continuous digesters. Type 304L stainless steel is suitable as a material of construction for screens, blank plates, central pipe, internal cone, and nozzles in continuous digesters. In batch digesters, however, corrosion thinning of stainless steels can occur at a rapid rate. Stainless steels having a low chromium contents such as type 316L (17% Cr) and older type 309 stainless steel weld overlays (with less than 20% Cr) are most susceptible to corrosion thinning[7]. Weld overlays in batch digesters are susceptible to localized rapid corrosion of individual weld beads that are lower in chromium content than the remainder of the overlay. Localized rapid corrosion can also occur at locations of hot cracking in fully-austenitic overlays.

Intergranular Attack of Stainless Steels

Intergranular attack (IGA) of conventional austenitic stainless steels can be problem if the stainless steel becomes sensitized during post-weld heat treatment[8]. This can occur in clad digesters that are constructed using roll-bonded compound plate where the carbon steel thickness is great enough to require mandatory heat treatment according to the construction code. The exposure of even low-carbon type 304L stainless steel to heat treatment temperatures results in the precipitation of chromium carbides at the grain boundaries in the austenitic microstructure. The surrounding grains are depleted in chromium content to the extent that they experience corrosion by IGA. Roll-bonded clad plate also has a zone of intense sensitization adjacent to the carbon steel substrate (the "carbide affected zone") that results from the diffusion of carbon into the cladding during hot rolling. If this highly sensitized layer becomes exposed to the process it will rapidly corrode by IGA (Figure 2).

Stress Corrosion Cracking of Stainless Steels

SCC of stainless steel welds, nozzles, and dome liner plates in continuous digesters is also a consequence of sensitization occurring during the post-weld heat treatment. The SCC is characteristically intergranular in nature. SCC of sensitized stainless steels can occur at any elevation in the digester, from the top to the bottom. SCC of stainless steels in batch digesters is a rare phenomenon but has been reported in an overlay that was behind a liner that leaked. SCC of type 304L stainless steel central pipes have been observed in some continuous digesters, mostly in vessels that had an old style (no longer used) type of central pipe cathode. This SCC may be related to the high anodic protection (AP) currents that were associated with this old design that shifted the potential of the central pipe into the range where SCC could occur.

PROTECTION AGAINST STRESS CORROSION CRACKING

In the early 1980's, a Digester Cracking Research Committee was formed to evaluate the various alternatives for protection against SCC of carbon steel continuous digesters. The three protective measures that were recommended by this committee (anodic protection, weld overlay, thermal spray coating) are still valid today[9], although much greater experience has been gained on the various limitations of these alternatives.

Anodic Protection for SCC Protection

AP has been found to be the most effective protective measure against SCC in continuous digesters and impregnation vessels[10-15]. The principle of AP is to install cathodes inside the vessel, either on the wall or alongside the central pipe, and to supply current from an external rectifier or rectifiers such that the corrosion potential of the digester wall is shifted above the range where SCC is possible. AP can be installed with new carbon steel batch digesters but is typically installed in response to the discovery of an SCC problem.

It is important that all pre-existing cracks be removed prior to energizing an AP system. There may be some "throwing power" of AP down existing cracks of shallow depth (such as less that 3 mm) but this is not at all well-established. Existing cracks of depth greater than 3 mm are liable to continue to grow even with AP. It is particularly important to energize an AP system as soon as possible in vessels with a serious cracking problem since stress corrosion cracks have been observed to grow to over 20 mm in depth in only a couple of months.

Weld Overlay for SCC Protection

At one time it was thought that "banding" of circumferential weld seams in continuous digesters with stainless steel or nickel-base weld overlay would provide protection from SCC. Such "banding" only resulted in moving the SCC problem to the carbon steel heat affected zones top and bottom edges of the overlay bands. Weld overlay banding is not recommended since it does not solve the SCC problem. Nondestructive testing of the overlay weld toes is often complicated by the presence of "fingernail corrosion" of the adjacent carbon steel that needs to be removed by grinding before effective crack inspection can be done. Due to this difficulty in inspection the overlay bands in many digesters have been removed.

In those more recent cases where weld overlay has been applied in the impregnation zone it is recommended that temper bead welding be used. This involves grinding away the top half of the final four or five beads (of horizontal weld overlay) and then re-applying an additional four or five beads on top. The tempering effect on the heat-affected zone of the carbon steel may improve SCC resistance.

Weld overlay for SCC protection in the impregnation zone (or in an impregnation vessel) can be effective in combination with other forms of protection such as AP or thermal spray coating. A complete weld overlay of the impregnation zone where no overlay edges exist could also presumably be effective in SCC protection.

Thermal Spray Coating for SCC Protection

Thermal spray coatings can provide SCC protection by creating a barrier between the digester liquor environment and the digester wall. The coating also locally alter the corrosion potential of the carbon steel so it is possible that thermal spray coatings may also serve to shift the corrosion potential out of the range where SCC could occur. Even if a coating is porous it could still provide SCC protection. Sealing of coatings was once recommended but is no longer common practice. The development of enhanced arc spray or high velocity oxygen fuel coatings having lower porosity than the conventional twin wire arc spray coatings eliminated the necessity for coat sealing. No heat-affected zone is created when a thermal spray coating is applied.

The most promising use of thermal spray coatings for SCC protection is as bands on susceptible weld seams such as stainless steel to carbon steel transition weld seams (Figure 3). Such bands only need to be wide enough to cover the weld and heat-affected zone of the weld. Since some thermal spray coatings are applied thin and experience thinning in service, annual measurement of the coating thickness using a magnetic lift-off gauge is recommended. Maintenance of the coatings is required for long-term protection.

PROTECTION AGAINST CORROSION THINNING

Although there were a few cases of rapid thinning of continuous digesters reported as early as the 1960's, the problem of rapid corrosion thinning did not become widespread until the 1990's with the adoption of such extended delignification practices as extended modified continuous cooking and isothermal cooking. Even digesters in conventional operation experienced a rapid thinning in the so-called wash zone if the washing was moved outside the digester. It is now understood that the rapid corrosion is related to the operation at higher temperatures (especially temperatures greater than 160°C) and possibly with lower hydroxide content in the extraction liquor (less than 8 g/L as NaOH)[16].

AP for Protection Against Thinning

Corrosion thinning of digesters is a form of active corrosion that occurs in a well-defined range of corrosion potentials. With AP, the potential of the digester wall is shifted above the range where active corrosion occurs and into the zone where the digester is passive. Passive corrosion rates for carbon steel are typically very low (ten to one hundred times lower than the active corrosion rates). At high temperatures as high as 165°C the passive corrosion rate may be appreciable. In such cases fine-tuning of the AP protection potential is essential in order to minimize the corrosion rate during operation.

The AP of continuous digesters from corrosion thinning is typically accomplished using either wall-mounted or central pipe-mounted cathodes and external rectifiers. Installation is readily accomplished well within the time span of a normal shutdown. The wall-mounted cathodes can either be of circumferential or vertical orientation. The spacing between such cathodes is designed such that the protective current can reach the digester wall at the most remote points. Wall-mounted cathodes can also be installed on blank plates (Figure 4) or behind blank plates (Figure 5) and screens. Central pipe-mounted cathodes can be either linear or tee-type.

AP of batch digesters helps the natural passivation process that occurs during a batch cook. Passivation without AP may take 1 hour. With AP passivation is typically accomplished within minutes. AP has been used in many batch digesters in Scandinavia but has yet to be tried in North America.

Weld Overlay for Protection Against Thinning

Weld overlay can be used for protection of large areas in the wash zones or below the cooking and extraction screens in continuous digesters. Both stainless steel and nickel-base overlays have been applied[17-20]. Below the impregnation zone SCC at overlay edges does not seem to be a problem. A minimum as-deposited chromium content of 20% is recommended for stainless steel overlay in continuous digesters as a measure of comfort against corrosion by the process.

Since the area to be protected in a continuous digester is often too large to be overlaid within a normal shutdown, weld overlay may need to be done over a period of several shutdowns in order to provide complete coverage of the digester wall, e.g., in the wash zone. There is considerable good experience with conventional horizontally-applied weld overlays. Weld overlay can be applied quicker by using the gas metal arc weld process that more readily accommodates multiple machines or by applying the overlay in the vertical mode. Vertical overlays are more susceptible to defects whose removal may consume the time saved during application.

Weld overlay in batch digesters is typically applied over the entire internal surface (sometimes excepting the top dome) in a period of 2 to 3 weeks. Corrosion testing has revealed that the corrosion rate of stainless steel weld overlays can be high if the as-deposited chromium content is less than 25%[7,21]. Type 312 stainless steel weld overlay deposits can have greater than 25% Chromium and are currently the material of choice for weld overlay of batch digesters operating under aggressive conditions. The chemistry of type 309 stainless steel submerged arc welding wire can be modified to yield deposits having 25% Cr, but this is not possible for type 309 bare wire used in the gas metal arc weld process. Nickel-base weld overlays may experience rapid corrosion in batch digesters and are not recommended.

It is particularly important that weld overlays in batch digesters be deposited without defects such as pinholes or cracks that can expose the underlying carbon steel substrate[21]. Complete penetrant testing is recommended after the overlay application is complete. Internal hot cracks in fully-austenitic type 309 weld overlays are particularly detrimental as these cannot readily be detected by nondestructive testing yet can become exposed by corrosion thinning of the overlay and provide a "fast track" for the liquor to gain access to the substrate. The cyclic operation of batch digesters causes the liquor inside pores or exposed hot cracks to be refreshed with each cook, resulting in rapid corrosion of the underlying carbon steel and the formation of cavities beneath the overlay.

If weld overlay procedures are qualified as groove welds (buildup) it is possible to take some credit for the overlay thickness in the total pressure wall calculation for the digester. Such qualification may be useful if the digester wall was close to or at the minimum value before the overlay was applied. It is relatively easy to qualify type 309 stainless steel welds but it is not easy to qualify type 312 stainless steel. Where the digester wall is significantly below the code minimum (which may be the result of arc gouging to remove a rough surface) it may be necessary to apply a layer of carbon steel weld buildup prior to overlaying with stainless steel.

Overlay of corroded stainless steel cladding in batch digesters should not be done on top of the existing cladding because of the danger of disbonding of the cladding due to the high residual stresses in the weld overlay. The cladding should first be removed by arc gouging so that the overlay can be applied directly on the carbon steel substrate.

Thermal Spray Coating for Protection Against Thinning

Thermal spray coatings have been applied for protection of large surface areas in the wash zone of continuous digesters and in batch digesters[22]. Coatings have predominantly been applied using the twin wire arc spray process where the coating is deposited up to 2 mm thick. Sealers were previously used but are no longer commonplace. High velocity oxygen fuel and enhanced arc spray coatings have been applied thinner than 1 mm.

Automated application is highly recommended for coatings such as high velocity oxygen fuel. Arc spray and enhanced arc spray coatings can be applied manually although automated application gives a superior coating. Extraordinary surface preparation is an absolute prerequisite for a successful thermal spray coating since the bond with the substrate is purely mechanical.

Thermal spray coatings have provided at least 8 years of protection in some digesters. The coatings can experience in-service problems such as corrosion, blistering, and attack of the coating edges. Maintenance is required for such coatings to be successful over the long term.

Lining for Protection Against Thinning

Some older continuous digesters had type 304L stainless steel liners in the top and bottom domes that, apart from SCC problems, have survived for many years. Leakage behind such liners did not produce significant corrosion of the carbon steel behind. In some continuous digesters linings of type 2205 duplex stainless steel have been successfully installed in order to protect the wall from further corrosion. The stable operation of continuous digesters makes lining a feasible alternative. Although some batch digesters have had liners survive nearly 50 years, lining of batch digesters is problematic owing to the cyclic pressurization that causes "oil-canning" of the liner plates and can cause failures at the welds. Leaking of liquor behind liner plates in batch digesters can result in high rates of corrosion of the wall behind.

Replacement of Carbon Steel with Stainless Steel

Carbon steel blank plates in continuous digesters often experience rapid corrosion thinning. Replacement in kind with new carbon steel blank plates does not solve the corrosion problem. Replacement of blank plates using type 304L stainless steel (or even type 2205 duplex stainless steel) is a more permanent solution.

PROTECTION AGAINST EROSION-CORROSION

Erosion-corrosion of carbon steel occurs because its passivity is not stable where there is high-velocity liquor flow. Erosion-corrosion problems have been successfully overcome using AP, weld overlay, or replacement of affected parts using stainless steel. AP is particularly effective against erosion-corrosion problems that affect continuous digesters above the internal cone. AP strengthens the passivity of the carbon steel making it resistant to erosion-corrosion.

Stainless steels are resistant to erosion-corrosion problems in digesters due to their much superior passivity. Stainless steel weld overlay is an effective protective measure against erosion-corrosion particularly in locations that are difficult to inspect such as areas behind headers (Figure 6). Replacement of carbon steel internal cones with new internal cones constructed using type 304L stainless steel eliminates erosion-corrosion problems on the cone.

PROTECTION AGAINST ACID CLEANING DAMAGE

It is better to protect against the effects of muriatic acid cleaning by changing the cleaning process instead of changing the material of construction. Acid cleaning damage may affect carbon steels, austenitic stainless steels, and even duplex stainless steels. Acid cleaning should preferably be done cold (at a temperature of approximately 40°C once the heat of mixing of the acid with the water is taken into account). Preferably acid cleaning should be done with less-aggressive acids such as sulfamic or formic[23], or replaced altogether with high pressure water blasting.

NEW DIGESTERS

It is obviously better to have corrosion protection in mind when constructing a new digester than to have to react to corrosion problems when they suddenly occur in service. The three materials alternatives for new continuous digesters are carbon steel, clad stainless steel, and solid duplex stainless steel.

New Carbon Steel Digesters

Despite the serious SCC and thinning problems experienced in numerous continuous digesters carbon steel has served well for over 40 years in many vessels. If carbon steel were to be selected as the material of construction for a new digester it should of course be welded using low silicon content welding consumables. The vessel should be fully post weld heat treated after construction. One option for protection is to install an AP system in the new continuous digester and energize the AP system as soon as the digester enters service.

Carbon steel is a suitable option for new batch digester construction only if a generous corrosion allowance (e.g., 25 mm) is used. Even then the problem of protection or replacement is only postponed. Low silicon content carbon steels such as SA285-Grade C "Modified" are no longer readily available although such steels are preferable to modern pressure vessel grades such as SA516-Grade 70 that have a substantially higher silicon content. New carbon steel batch digesters could presumably be protected with an AP system that could be energized at digester start-up.

New Clad Stainless Steel Digesters

Construction of continuous digesters using roll-clad type 304L stainless steel compound plate will offer protection against the major corrosion problems that affect carbon steel (SCC, corrosion thinning, erosion-corrosion) but will not necessarily provide protection against acid cleaning damage, IGA, or SCC of the stainless steel clad plate. The cladding is typically the corrosion allowance and is not included in the pressure shell thickness calculations. Some clad plate weld procedures that do not require peel-back of the cladding are less expensive to install but can result in weld cracking if used carelessly. Where post-weld heat treatment is required by the construction code (where the underlying carbon steel wall thickness is greater than a certain minimum value) the time at temperature must be kept to the minimum required. Prolonged heating at post-weld heat treatment temperatures can result in the sensitization of type 304L stainless steel having less than 0.02% carbon.

Construction of batch digesters from roll-clad type 304L and 316L stainless steel is not recommended since these materials can experience rapid corrosion thinning in batch digester service. Type 304L stainless steel has a slightly higher chromium content (18% to 19% Cr) and is superior to type 316L stainless steel (16% to 17% Cr). In actual service, however, both materials can experience rapid corrosion thinning that results in exposure of the underlying carbon steel. It is possible that a new batch digester could be constructed having a new stainless steel weld overlay lining, for example, of type 312 stainless steel that would be preferable for this service application.

New Duplex Stainless Steel Digesters

Solid type 2205 duplex stainless steel (UNS S32205) is currently the best material option available for new digester construction[25,26]. Due to the higher tensile strength of duplex stainless steels the required wall thickness is significantly less than is the case for carbon steel or clad vessels. This can result in appreciable weight and cost savings. For continuous digesters construction using duplex stainless steel should eliminate all currently known corrosion problems with the possible exception of damage during hot muriatic acid cleaning. While corrosion testing suggests the possibility of corrosion of type 2205 duplex stainless steel in batch digester liquors, experience to date has shown that corrosion in service is very low. A 3 mm corrosion allowance is probably sufficient for a long service life of greater than 20 years.

Because most shops are not familiar with welding of duplex stainless steel it is absolutely necessary to have good quality assurance by a person experienced in working with duplex stainless steels during the construction of duplex stainless steel digesters. In addition to the requirements of the construction code, such as the impact energy requirements of section UHA-51, it is also desirable to test the welds and heat affected zones according to all three methods of ASTM A923 to ensure the welds do not contain brittle secondary phases.

DISCUSSION

The selection of the best protective measure for a given digester depends on the many factors. Not only should current corrosion conditions be taken into consideration but also the possibility and consequences of the sudden onset of corrosion problems. Many continuous digesters with rapid thinning operated for years without appreciable corrosion problems and then suddenly experienced corrosion that threatened the corrosion allowance.

The length of a shutdown may determine the most practical corrosion protection alternative. In a typical continuous digester shutdown of 7 to 8 days duration there may only be 4 to 5 days for work to be done inside the digester. Although an AP system can be installed within this time frame it is not possible to apply weld overlay or thermal spray coating over more than about 100 square metres (1100 square feet) in this time period. If it is intended to cover larger areas with either weld overlay or thermal spray then the applications must be done over a number of shutdowns, or an extended shutdown must be taken. If major work in another area (e.g., the recovery boiler) necessitates an extended outage this would be a good opportunity to apply as much overlay or thermal spray coating as possible.

Protective measures can be mutually compatible. As has already been mentioned AP can be used to protect the edges of weld overlay bands from SCC. In thinning digesters where weld overlay is applied over several years AP can be used to prevent the thinning of the digester wall to below the minimum required by the construction code before it is scheduled to be overlaid. Bands of thermal spray coating are also useful in protecting the edges of stainless steel weld overlay from both SCC and "fingernail" corrosion. Caution should be taken when combining AP with large surface areas of thermal spray coating. If the corrosion potential of the thermal spray coating is significantly lower than that of the carbon steel digester wall the rectifiers may provide current in order to raise the potential of the thermal spray coating.

Whatever protective measure or measures are selected it is very important that quality assurance be performed so that the work meets expectations. And well before the work is to be done it is recommended that corrosion testing be performed in the actual liquors from the digester. For AP corrosion testing this will involve the determination of the optimum control potential (the potential at which the lowest corrosion rate occurs) or the potential where passivation is the most profound. For weld overlay corrosion testing this will involve the determination of the minimum as-deposited chromium content to be applied in order to attain the minimum corrosion rate in the digester. For thermal spray coating corrosion testing this will involve what is the best alloy to apply, determine the coating process, and coating thickness necessary in order to obtain the minimum corrosion rate in the digester.

CONCLUSIONS

1. There are three primary methods for corrosion protection in batch and continuous digesters: anodic protection, stainless steel weld overlay, and thermal spray coating.

2. Anodic protection systems can be designed to protect against corrosion behind screens and blank plates.

3. Automatic stainless steel weld overlay can be applied behind headers to protect against erosion-corrosion of the digester wall due to high velocity liquor flow.

4. Thermal spray coatings can be applied in bands over weld seams to protect them from stress corrosion cracking.

5. Anodic protection or thermal spray coating may be used to protect the adjacent carbon steel at stainless steel weld overlay edges from stress corrosion cracking.

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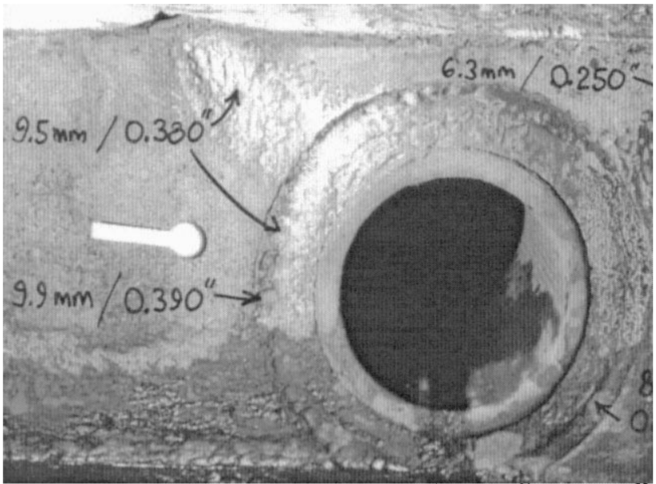

Figure 1. Erosion-corrosion of a continuous digester wall behind a wash header. Erosion-corrosion depths are indicated in millimeters and inches.

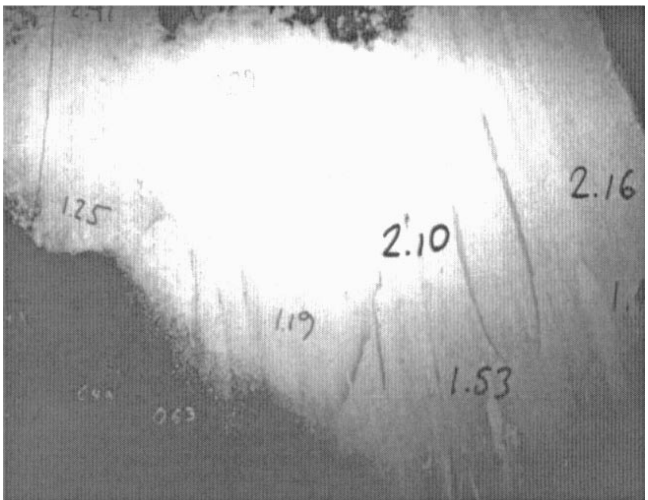

Figure 2. Corrosion of type 321 stainless steel clad plate in a batch digester that has exposed the "carbide affected zone in the cladding adjacent to the carbon steel substrate. Cladding thicknesses are indicated in millimeters.

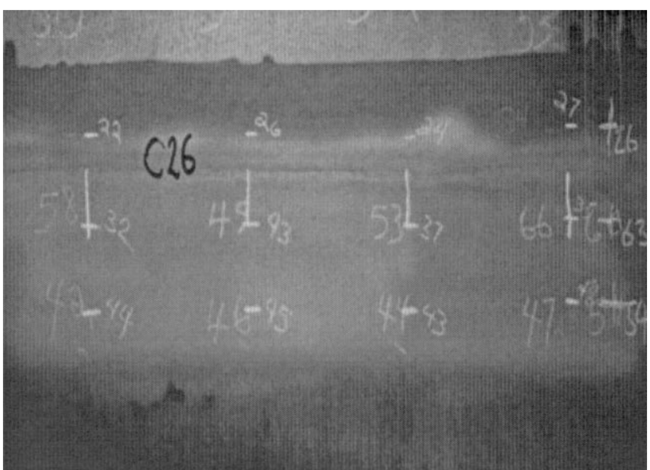

Figure 3. Band of thermal spray applied to protect a stainless steel to carbon steel weld in the impregnation zone of a continuous digester. Coating thicknesses are indicated in mils.

Figure 4. Blank plate cathode for anodic protection system in a continuous digester.

Figure 5. Cathode for anodic protection located behind blank plates in an impregnation vessel.

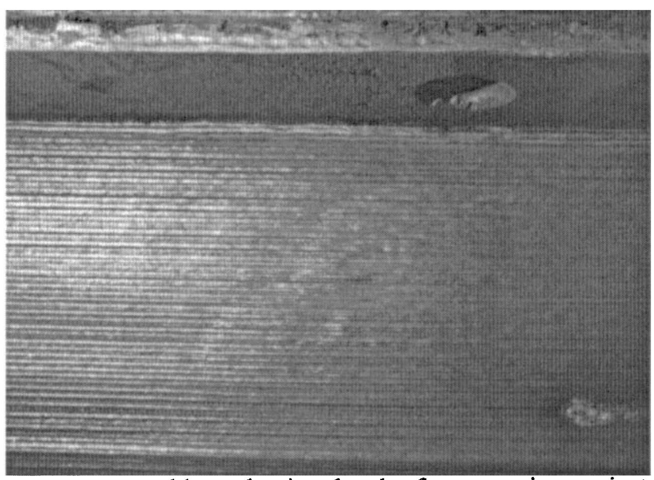

Figure 6. Weld overlay in a header for protection against erosion-corrosion.