Contributing causes and risk reduction of crevice corrosion

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ABSTRACT

The occurrences of head-to-shell corrosion on Yankee dryers have increased over the past decade. The primary cause has been determined to be a gap in the head-to-shell fit; this gap can open under operating conditions. The gap, or crevice, allows corrosive media to penetrate, and the expanding corrosion product creates substantial jacking forces between the head/shell flanges, increasing the potential for steam leaks, bolt failure, and head cracking. While this gap most likely exists for many operating Yankee dryers, some processes appear to be more at risk of developing this problem than others. The purpose of this paper is to quantify potential secondary risk factors and to propose methods to minimize the associated risk.

Application:

If the risk factors of crevice corrosion are understood, a mill can test its system to determine the appropriate course of action.

THE INDUSTRY BEGAN TO experience problems with head-to-shell crevice corrosion in 1985. Using nonlinear finite element analysis, it has been determined that it is possible for a gap, or crevice, of up to 0.102 mm (0.004 in.) (1) to exist between the head and shell flanges under operating conditions. This gap is an ideal location for corrosion to flourish. Besides the often wet and ion-laden environment, the heterogeneous structure of gray cast iron, differential stresses (under gapping conditions), and differential temperature between the head and the shell all contribute to corrosion potential. These conditions, however, are common to almost all Yankee dryers, and the question remains as to why corrosion starts on some Yankees, while others appear immune. If this question can at least be partially answered, the risk factors involved could be reduced, and the industry could enjoy an increased immunity to the problem.

This study included 132 tissue machines of which 13 have experienced crevice corrosion. The selection of the machines was not scientifically random, nor were they specifically chosen for the purpose of this survey.

BACKGROUND

Chlorides

Chloride ions (Cl^-) are the most influential ionic species commonly found in paper machine environments *(2)*. Sources range from fiber streams to chemical additives to fresh water. The variability of system chloride ion concentrations can be seasonal or day to day. Each paper machine system has its own sensitivity to chloride ions depending on what other ions are also present in the process. It is known that the lower the overall concentration of chloride ions, the less the potential for corrosion. Chloride ions are extremely corrosive and are logarithmic with concentration in their effect. Corrosion rate is a function of ion content (current density) and oxidation potential.

Thiosulfate

Thiosulfate ($S_2O_3^{2}$) has long been associated with increasing corrosion potential in paper mill processes. The tissue processes studied had such low, or undetectable, concentrations of the thiosulfate ion that the data were considered not practical for this study.

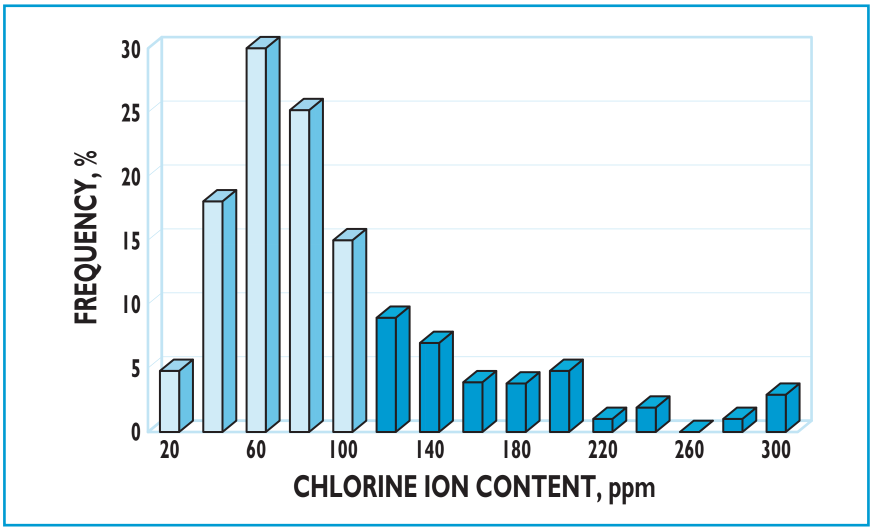
Oxidation potential

Oxidation potential controls the rate at which corrosion takes place when all other variables are held constant (i.e., chloride concentration, temperature, and pH). A corrosion reaction consists of two steps: oxidation and reduction *(3)*. In a paper mill system, oxidation is most often the rate-determining step. Oxidation potential can therefore be a powerful accelerator to corrosion or can, in theory, reduce the rate at which corrosion occurs *(4)*.

A positive oxidation potential means that the process is oxidative relative to a hydrogen (calomel) reference. A negative oxidation potential is reductive relative to a hydrogen reference. Oxidation potential is expressed in millivolts (mV). Residual bleaching chemicals are the most common sources of high oxidation in tissue mill processes. Free chlorine and peroxides cause elevated oxidation potentials in most mills that draw slush pulps directly from the storage chests located at the end of the bleach plant. However, tissue machines that use a fresh chlorinated water source for felt showers can have a high oxidation potential at the Yankee/suction pressure roll nip when the process has an otherwise low oxidation potential.

System conductivity

Conductivity is indicative of the dissolved solids in a paper machine system and represents the fluid's ability to conduct current. Conductivity is



1. Chloride ions

expressed in micromhos, the reciprocal of resistance.

Conductivity represents all dissolved solids in the system, including chlorides. Because corrosion is a flow of electrons from one species to another, a highly conductive fluid generally facilitates the corrosion mechanism. High conductivity, however, does not mean a high corrosion rate. What is most important is the character (i.e., the chloride content) of the dissolved solids making up the conductivity. All other variables being equal, lower conductivity is directionally correct.

pH

The pH value is typically not a problem in tissue mill processes, which normally operate in the neutral range. In this range, pH has little effect on the overall corrosion rate of cast iron. However, if the pH approaches 5.0, the corrosion will increase dramatically.

OBSERVATIONS

Chlorides

During the study, it was determined that the most significant contributors to chloride concentrations were the bleaching of finished broke, the bleaching of recovered paper without the aid of postwashing, and certain chemical additives (i.e., red dye and hydrochloric acid for pH control). The increase in system chloride concentrations was particularly acute when the furnish contained broke from reprocessed towel grades, or red and blue dyed grades. This is due to the increased amount of bleach required to break down wet strengths and to bleach out red and blue dyes.

Chloride ion content was distributed among the machines studied at the frequencies illustrated in **Fig. 1.**

The data above 100 ppm chloride ion content have been shaded to illustrate the point at which the data were separated for analysis. In the machines studied, 9.8% have experienced crevice corrosion. The crevice corrosion experience (CCE) for machines that operate over 100 ppm chloride in the process waters is statistically the same at 11.7%. However, it is interesting to note that the CCE of tissue machines that operate below 40 ppm chloride experience crevice corrosion only 3.6% of the time, while the range of 40–100 ppm chlorides has basically the same CCE as that above 100 ppm at 11.4%. These data indicate that a certain minimum level of chlorides will better facilitate the corrosion process. However, 80% of all machines are above the 40 ppm chloride ion level, and there are no practical methods to reduce chlorides to such a low level if they are inherent to the process. There are methods to reduce very high chloride levels to a lower level (e.g., 230 to 90 ppm), but this study indicates that would produce little or no benefit regarding susceptibility to crevice corrosion.

Oxidation potential

The source of high oxidation potential is normally carryover from the bleaching processes. However, there are some cases where fresh waters, which are either high in dissolved oxygen or are chlorinated, are the source. A certain level of oxidation potential is fundamental for the corrosion process to take place.

Oxidation potential was distributed among the machines studied at the frequencies illustrated in **Fig. 2.**

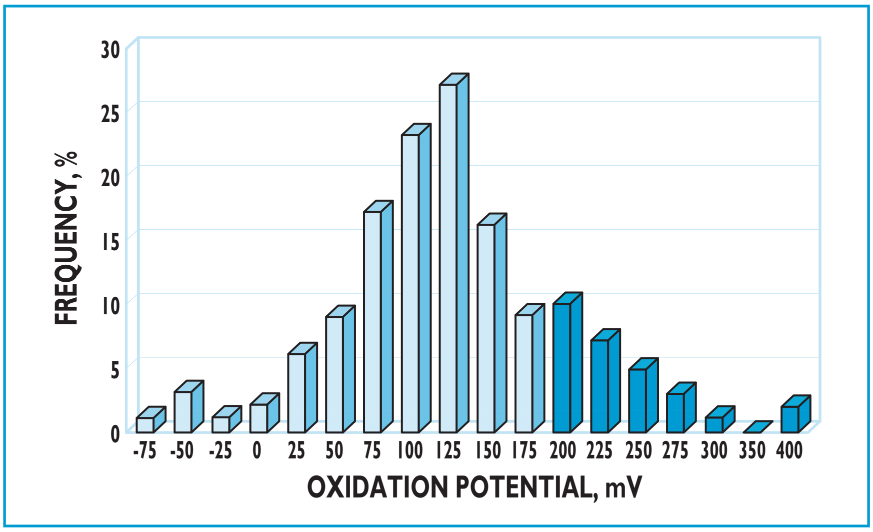
The data were split at 200 mV to determine relative CCE for the highest levels of oxidation potential. Industry-wide, 21% (28/132) of the machines surveyed had processes with oxidation potentials above 200 mV. More interesting is that 77% (10/13) of the machines that exhibited crevice corrosion had processes with oxidation potentials above 200 mV. Therefore, the CCE for Yankees exposed to a highly oxidative environment is 36% (10/28). Note also that the survey found no cases of crevice corrosion where the process oxidation potential was below 100 mV. In nine out of the ten crevice corrosion cases with high potentials, the source was bleaching residuals from an adjacent pulp/deinking facility. In one case, the source was from high oxidation in the felt shower waters.

The data indicate that a highly oxidative environment increases the probability of developing crevice corrosion. The source of high oxidation is normally bleached slush pulps, as baled pulp processes tend to have much lower potentials. High oxidation, however, is nothing new to bleached pulps but can increase under the following conditions:

- Increased brightness targets
- Changes in bleaching sequences
- Increases in pulp production (i.e., less dwell time in the washers, less water/ton)
- Closing the bleach plant water system (increases oxidative potential of wash water)
- Operating at or above the bleach plant production limits.

Oxidation potential can be as easily controlled as pH in most tissue processes. The control method involves an in-process oxidation probe in combination with a variable-speed pump to meter in an antioxidant (e.g., sodium metabisulfite).This is typically done around the headbox white water loop.

As previously stated, high oxidation potential is only part of the corrosion equation and has been around since the advent of tissue.While high oxidation accelerates the corrosion mechanism, the question remains as to whether a fundamental change has occurred in our industry to create a problem that was undocumented prior to 1985.



2. Oxidation potential

Conductivity

It has been surmised that the closure of white water systems resulting from the 1970s energy crisis may have added to the corrosive potential of the process *(5, 6).* For this reason, this study included conductivity (relative to dissolved solids content) data to determine if more closed systems might be more prone to crevice corrosion.

Process conductivity was distributed among the machines studied at the frequencies illustrated in **Fig. 3**.

The data split considered processes that operate at 1200–2000 micromhos vs. processes that operate below 1200 micromhos. The processes above 2000 micromhos are 100% recycle furnishes and appeared to be a separate distribution; these processes were therefore not considered for the comparison.

The analysis shows that the incidences of crevice corrosion were relatively evenly distributed throughout the range of conductivity values. While the concentrations of corrosion-supporting elements increases when a system is closed, so do the concentrations of corrosion-buffering elements, such as calcium and sulfite. It is likely that the equilibrium that exists between corrosion-causing elements and corrosion-buffering elements remains basically the same when a system is closed, but only at a higher solids levels. It is more likely that the ratio of corrosion-causing elements to corrosion-buffering elements would be the significant factor in crevice corrosion rate. This study did not include detailed data on concentrations of buffering elements; therefore, this comparison could not be made.

There was no correlation found between closed systems and open systems and CCE.

Felt width

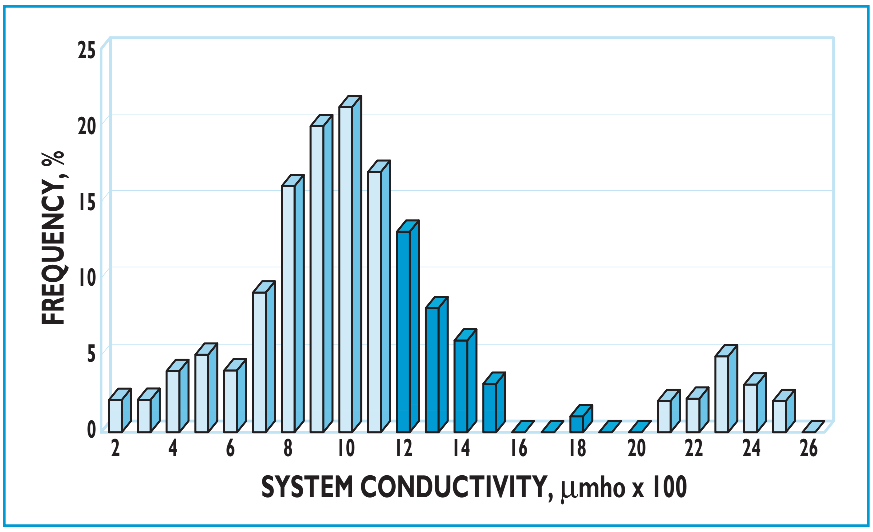
Anecdotal evidence indicates that the ratio of felt width to Yankee width has increased over the years. It has been proposed that increased felt width would increase the moisture and therefore the corrosive potential at the head/shell joint. Intuitively, this makes sense. Certainly the nearer the felt to the edge of the Yankee, the wetter the joint will be. Also, process waters carry the corrosive elements; therefore, the joint must be wet for corrosion to occur.

From a crevice corrosion standpoint, running as narrower felt would be directionally correct. However, the data showed no correlation between felt width and CCE. In fact, three machines that ran the felt over the edge of the heads have no indication of crevice corrosion. Again, the overriding factor is not the amount of water (almost all joints run somewhat wet); what is in the water is what counts.

It would make an interesting finite element analysis study to determine if the difference in thermal deformation caused by widening the felt would make the joint more likely to have the necessary gap.

Dryer size

A head/shell crevice occurs when the bending moment around the head and shell is great enough to decrease the force at the outer edge of the clamp zone to zero. Because of the geometry, larger dryers will have a higher bending moment when all other factors are equal. In theory, this would make larger dryers more likely to reach the critical point where outside clamp force drops to zero. Therefore, it is important to look at the size of the dryer to determine if a relationship exists between dryer size and CCE.



3. System conductivity

Since 1960, 328 Yankee dryers have been delivered to North America. The size distribution is shown in **Table I** *(7)*.

Of the 13 dryers with CCE in the survey, 12 were 15 ft diameter (92%) and one (8%) was a 12 ft diam dryer. Only two 18 ft diam dryers were included in the survey due to the more proprietary nature of high-speed tissue production.

These data support the theory that larger dryers are more likely to reach the critical stress point where a head/shell gap can exist under operating conditions.

Spray boom applications

The use of spray booms as a method to control sheet adhesion on Yankee dryers began to gain industry acceptance in the mid- to late 1970s. Industry experts estimate that less than 20% of tissue machines had spray booms in 1980. By 1985, the estimate is 75%, and by 1990, the estimate is 99%.

Until recently, the typical adhesives used in Yankee spray booms contained high levels of chlorides and pH values of about 4.5, a very corrosive combination for cast iron. Note that the most common adhesive chemicals used on Yankee cylinders are from the polyamide family. Processes that use polyvinyl alcohol (PVA), animal-based glues, or polyamide alternatives would not have such a corrosive combination.

Spray booms are often wider than they need to be for sheet adhesion in order to provide Yankee surface protection to the full shell width. In almost every application, the spray boom chemicals come in contact with the head/shell joint. On the shell surface, where the chemicals are constantly being doctored off, there appears to be no problem. However, in the joint, where these materials are not constantly removed, it is likely that they build up and concentrate. When moisture is then introduced from the process, the result is a highly corrosive environment.

The data indicate that the increased use of spray booms on Yankee cylinders correlates well with the emergence of the crevice corrosion problem. Industry-wide, 84% of tissue machines have used a high-chloride, low-pH polyamide adhesive on the Yankee; almost the same percentage still use a polyamide of some type. All of the machines in the survey that have experienced crevice corrosion have used a high-chloride, low-pH polyamide adhesive on the Yankee. This fact is not as significant as it might first appear because of the wide use of these products. Documentation showing when the use of these products was started or stopped on specific machines was not clear.

While recent changes to more neutral, lower chloride products have been initiated by the manufacturers, the switch to these products is not nearly universal.

Inhibitors

The most common inhibitor used in tissue machine systems is monoammonium phosphate (MAP). This is typically applied through the spray boom as a method to reduce Yankee surface wear.

Phosphate falls under the general heading of anodic inhibitors. These inhibitors usually produce thin films on metals. The films impart properties that are different than those of the substrate metal. Investigation has shown that the film generated under the proper conditions was a cubic oxide film. Electron diffraction has shown the film to consist almost entirely of Fe_2O_3 and Fe_3O_4. Cubic oxide films are harder and more wear resistant than cast iron itself; this is the reason for their application to Yankee cylinders. However, phosphates are also one of the most effective corrosion inhibitors for cast iron. The cubic oxide layer is quite passive and is therefore an excellent corrosion inhibitor *(4)*.

The survey included 24 machines (18%) that have continually used phosphate for wear resistance for at least 10 years. None of these Yankee cylinders has developed any indication of crevice corrosion even though some operate in high-chloride and/or highly oxidative environments.

Machine type

It has been observed that dry-crepe processes are more prone to crevice corrosion than wet-crepe or machine-glazed (MG) processes. I do not have current statistics to verify this belief. However, the 13 machines with severe crevice corrosion included in this survey were all dry-crepe machines. One factor is that MG and wet-crepe processes tend to operate at lower steam pressures. Therefore, the critical stress required for the creation of a gap at the joint may not be reached. Based on the observations regarding spray booms, this makes sense. Wet-crepe cylinders tend to use much lower levels of corrosive adhesives than their dry-crepe counterparts. Also, in the wet-crepe machines studied, polyamide-type adhesives were not nearly as universal in their use. In regard to MG machines, where release and not adhesion is important, the use of polyamides was not found. Also, many MG processes operate at a very low pH (3.8–4.5) and still have a negligible CCE.

Thermally applied Yankee surface coatings

During the early 1970s, thermal coatings began to be used as edge repair materials. During the late 1970s and early 1980s, the practice became more common, and full-width thermal coatings had also gained acceptance. Typical materials used over the last 25 years were 420 stainless steel and molybdenum composites. In the early years, these were usually applied to the end of the shell and often left residual overspray in the head/shell joint.

Because the advent of this technology coincided with increasing incidences of crevice corrosion, it is important to understand if a relationship exists. **Table II** is a compilation of available data on thermally coated dryers in North America *(8)*. Note that some dryers shown in this table may have been thermally coated more than once.

These data indicate that the 12 ft diameter dryers were 55% of the thermally coated Yankee dryers, yet this percentage accounted for only 8% of CCE. Based on the comparisons shown in Tables I and II, there appears to be no relationship between thermally coated Yankee dryers and CCE.

	DELIVERED	
Diameter, ft	Number	Percent
10	31	9
12	128	39
15	72	22
16	23	7
18	45	14
Misc.	29	9
Total	**328**	**100**

I. Size distribution of Yankee dryers delivered in North America since 1960

	DELIVERED	
Diameter, ft	Number	Percent
10	9	9
12	55	55
15	17	17
16	7	7
18	6	6
Misc.	7	7
Total	**101**	**100**

II. Thermally coated Yankee dryers in North America

SUMMARY AND CONCLUSIONS

Note that crevice corrosion has a multitude of variables, all of which must be considered. However, all of these variables cannot be practically measured in the field. Field measurement is vital because ionic equilibrium changes with time and temperature; therefore, more sophisticated laboratory analysis could lead to incorrect conclusions.

When we review crevice corrosion, we must realize that chlorides and highly oxidative environments have been the nemesis of even the earliest papermakers. Yes, systems have been closed and dissolved solids have increased, yet some of the most open systems have suffered crevice corrosion. Finally, even the "gap" probably existed long before the onset of crevice corrosion problems in 1985. The questions remain: Why is this problem a relatively recent phenomenon. What has fundamentally changed?

Based on the information collected, the following theory is proposed:

- A gap at the head/shell joint is necessary for crevice corrosion to begin and flourish.
- Larger diameter dryers are more at risk for developing crevice corrosion. This is likely due to greater bending moments under operating conditions for these dryers.
- Spray boom chemicals are likely, but not imperatively, the sources of the ions necessary for corrosion to start.
- Corrosion proceeds more rapidly in highly oxidative environments.

RECOMMENDATIONS

Based on this study, the following recommendations are presented:

- Conduct a finite element analysis to determine if thermal deformations caused by increasing felt widths increase the probability for a gap to open at the head/shell joint.
- Conduct a finite element analysis to verify if 15 ft diameter and larger dryers are more at risk than smaller dryers due to clamp zone distribution.
- If the machines' spray boom contains chloride or low-pH compounds, take measures to prohibit overspray onto the heads (i.e., eliminate or adjust the outermost nozzles).
- Consider using an inhibitor in the spray boom or in separate edge sprays to create a passive layer on the edges and heads.
- Keep the head/shell joint clean. If the joint has a tendency to build up adhesives and other contaminants, it should be thoroughly cleaned with a wire brush during each felt change. A treatment of phosphate after cleaning would be a further benefit.
- Initiate a change to the neutral-pH and no/low-chloride products for Yankee spray boom applications.
- Follow the TAPPI guidelines for safety and condition assessment in regard to monitoring head/shell joint condition *(9)*. **TJ**

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