ROOT CAUSES OF RECOVERY BOILER LEAKS

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A REVIEW OF RECOVERY-BOILER LEAKS OVER THE PAST DECADE REVEALS SOME INTERESTING TRENDS AND HIGHLIGHTS AREAS OF SPECIAL CONCERN

A DATABASE OF ROOT CAUSES OF TUBE LEAKS AND OTHER failures in recovery units is being assembled from information that mills have reported to the Black Liquor Recovery Boiler Advisory Committee (BLRBAC). The effort of classifying and examining the distribution of root causes for leaks is worthwhile because of the insights it provides. This information can help the industry operate more safely while reducing unscheduled outages and perhaps extending the useful life of capital equipment. Insights obtained from analysis of the database will help mills to focus inspection and maintenance activities on the areas where problems are most likely to occur. Equally important, the information gleaned from the database will guide future efforts to improve materials research and boiler design, upgrade field welding requirements, and enhance operational safety.

BACKGROUND

Industry database

Safety. Special emphasis is placed on safety in the recovery boiler. Recovery units have the potential for devastating explosions that can kill or injure workers.

Economics. The recovery system is a key production unit, and unscheduled shutdowns impose a severe economic penalty on the mill. Protecting the installed capital equipment from damage; avoiding unplanned downtime for repair; and returning to normal operation following an emergency shutdown all have a direct impact on lost production.

Source of data

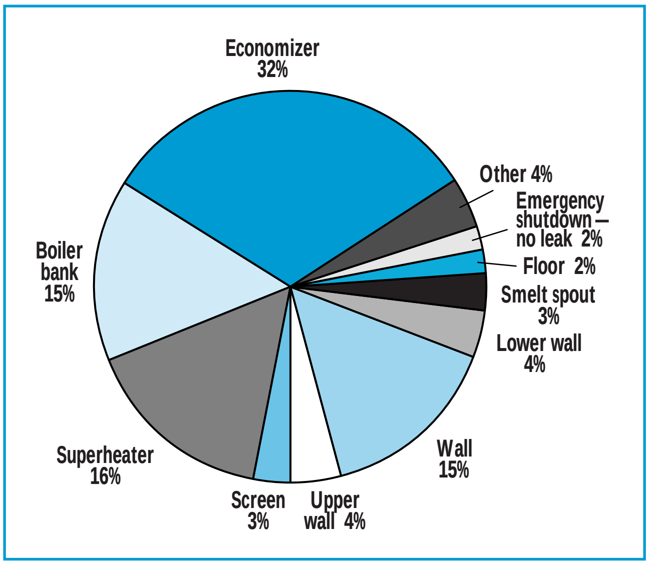
Recovery boiler explosions, fatalities, injuries, and near-miss data have been collected and tracked for over 35 years. The BLRBAC Emergency Shutdown Procedure Subcommittee and the American Forest and Paper Association (AF&PA) have classified cases into three categories—explosion, critical, and noncritical—and they have shared these data regularly. There are currently 156 explosions documented and about 450 "critical incidents," near-miss cases where water entered the furnace cavity but luckily did not cause a smelt–water explosion. The number of these worst cases—those causing death, injury, or damage—has accumulated to the point where it is possible to identify potential trends. Grace has shared these insights at the 1995 International Chemical Recovery Conference [1] and other industry events.

Additional information collected over the past 35 years is a valuable resource from which the industry can learn and take action. Between 50–80 incidents are gathered and discussed each year. To date, the database contains nearly 2000 incidents in the recovery unit alone that are available for review. This body of data has not been investigated recently for root causes. The industry will benefit from the current effort to classify all pressure-parts leaks, since any leak has the potential of causing an explosion, and each leak has a root cause. It is worth noting that many cases are not reported to BLRBAC. This work only considers those that have been submitted.

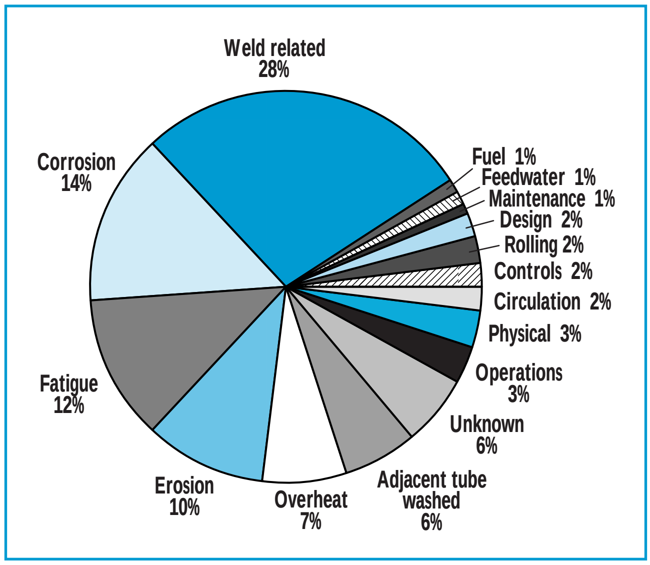
One significant difference between this and other BLRBAC reviews is that the current review is specifically designed to study root causes rather than simply classifying events and final consequences. This article categorizes the most recent 832 cases, whether critical or not, and presents the results graphically. This is less than half of the total cases available for review. Eventually, all the cases will be reviewed, and a followup paper will be prepared for publication.

The findings presented here are based on "as received" questionnaires from the voluntarily participating mills. These are often submitted before a metallurgical study has been completed and frequently without benefit of consistent technical identification. The findings, therefore, are best understood only as trends.

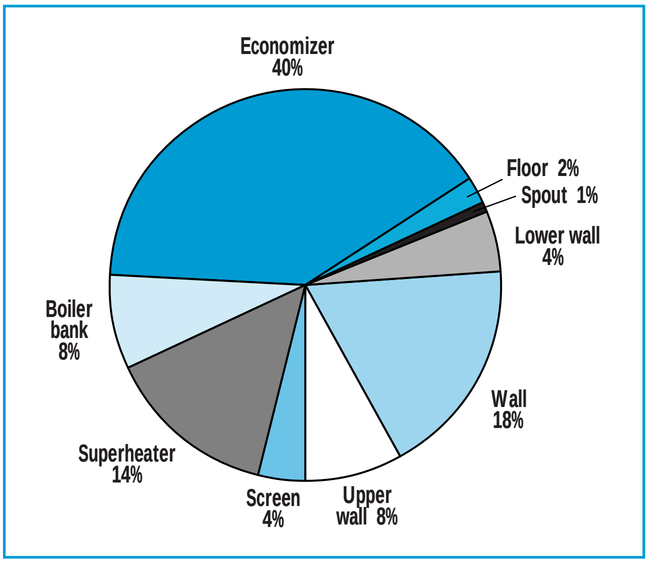
[1] Grace, T. M., *CPPA 1995 International Chemical Recovery Conference Proceedings*, CPPA–TS, Montreal, p. 199.



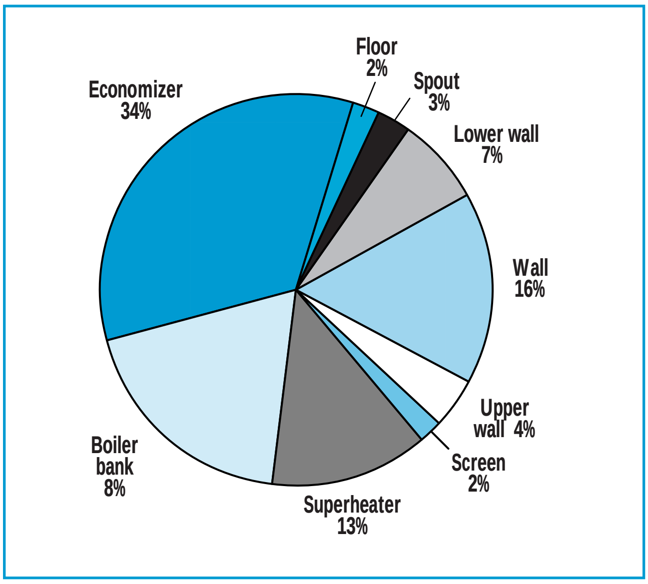
1. Location of leaks



2. Root causes of recovery boiler shutdowns



3. Location of weld-related leaks



4. Location of corrosion-related leaks

Multiple accounting

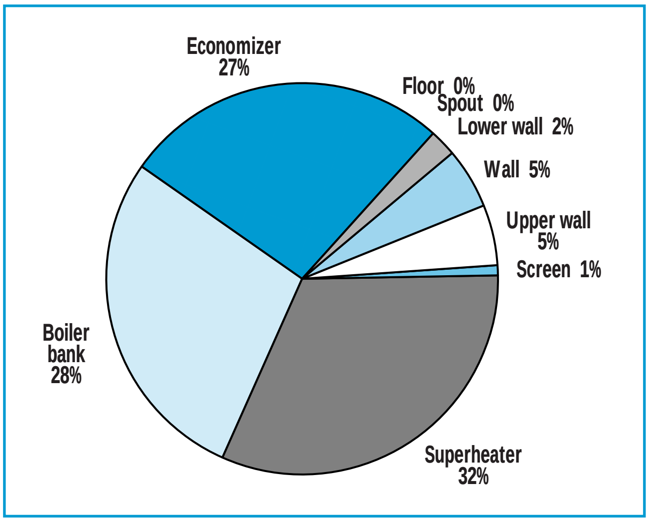
The total number of individual root causes is greater than the 832 cases in the database because of multiple accounting of causes. Although many individual cases do not simply fit a single root cause, these cases are still valuable in identifying trends. More is gained by cross-indexing a given incident rather than classifying it as "undetermined." Cross-indexing also highlights uncertainties that exist around the root causes. A full understanding of specific cases is needed to develop trends in this way.

FINDINGS

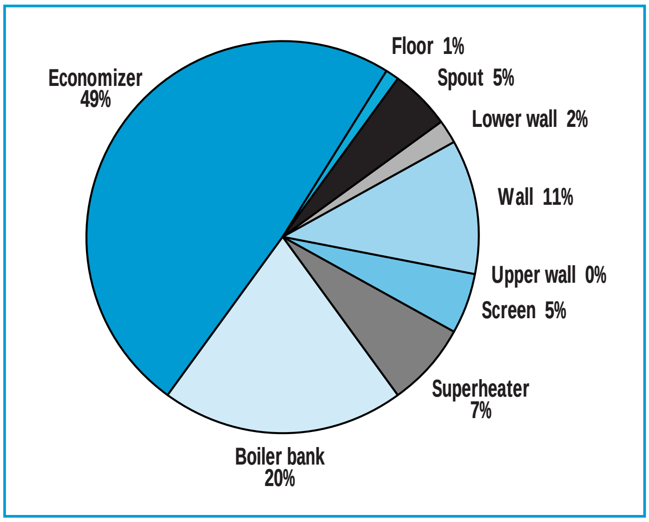
Location

The first look at the data shows where the incidents are located. **Figure 1** follows the recovery unit flow from the floor to the economizer. Most incidents are associated with pressure parts. The "other" classification includes dissolving tank, burners, feed pipes, chemical line, desuperheaters, valves, etc.

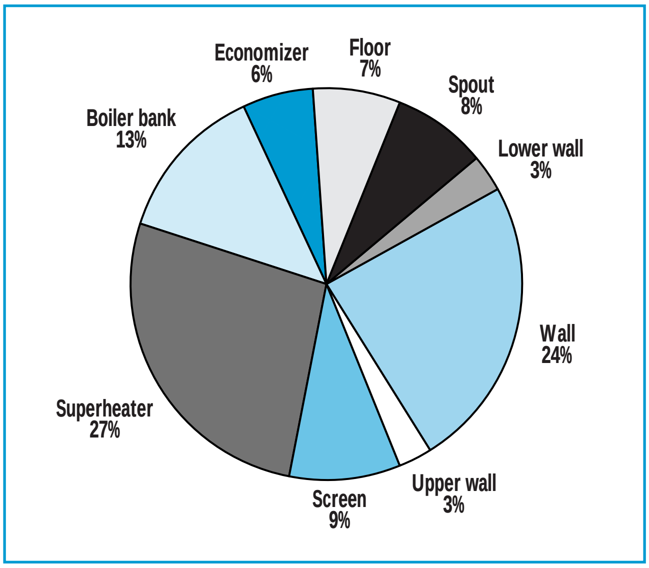
The major finding here is the large number of leaks associated with economizers—one-third of all reported cases of hazard-caused shutdowns. It is likely that this is also the component most often not reported, since many consider economizer leaks to be nonhazardous. If economizer leaks are indeed underreported, then the effect of economizer leaks on boiler reliability is even greater than the data suggest. The data show no particular trend by manufacturer; the results are about evenly divided. However, 13,000 hours of unit downtime are associated with this component.



5. Location of fatigue-related leaks



6. Location of erosion leaks



7. Location of water-side-related leaks

A quarter of the leaks are associated with the walls. While "upper" and "lower" wall locations will give some valuable insight in the future, many of the cases were not sufficiently described and located, so the three "wall" categories are best combined until further information is developed.

Root causes

Figure 2 lists the root causes of recovery boiler shutdowns in descending order of occurrence.

Weld-related. By far, the largest root cause of failures is related to welds. The importance of welds will be highlighted later in this report, but the sheer size of this category calls for a more rigorous treatment of weld procedures. It elicits such recommendations as mandatory training and certification of all welders who work on the boiler in any capacity; proper review of, buy-off of, and adherence to all weld procedures (including materials, techniques, and heat treatments), and proper inspection of all welds at time of execution. Over 23,000 hours of downtime are related to weld failures.

Corrosion. Most corrosion is slow acting and can be detected through proper and timely inspection. While many locations in the recovery unit are difficult to examine, a cooperative effort with the manufacturers should lead to future designs with inspectable configurations. Almost 17,000 hours of downtime are related to corrosion surprises.

Fatigue. The size of the fatigue category points to design deficiencies that could be addressed by the manufacturers. It is hoped that the information in the database will raise awareness of this issue and that manufacturers will take action to mitigate the effects of metal fatigue. Hours of downtime for this and subsequent root causes have not yet been determined.

Erosion. The erosion category includes smelt erosion, erosion from wet sootblowers, and erosion of adjacent tubes from small leaks. Note that washing of adjacent tubes accounts for 6% of the shutdowns. At least 70 such incidents have been found to date.

It could be argued that the washing of adjacent tubes should not be classified as a root cause, since the root cause is really associated with the original small leak. However, this category needs to be highlighted, since many leak reports only mention the resulting rupture. Owner–operators need to be aware of the importance of catching small leaks as soon as possible before they result in a massive rupture of an adjacent tube. Several leak detection methods are available to the industry.[2]

Root causes by location

The discussion in the previous section identified the root causes but did not identify *where* these events occurred. Where are the welds failing? What areas are most vulnerable to corrosion? Such information would help both owners and manufacturers choose effective proactive measures to minimize failures.

The next five pie charts highlight the locations of the five most frequent root-cause categories (welds, corrosion, fatigue, erosion, and water-side-related leaks). As in Fig. 1, the locations are each presented in the order of the recovery unit flow from the floor through the economizer.

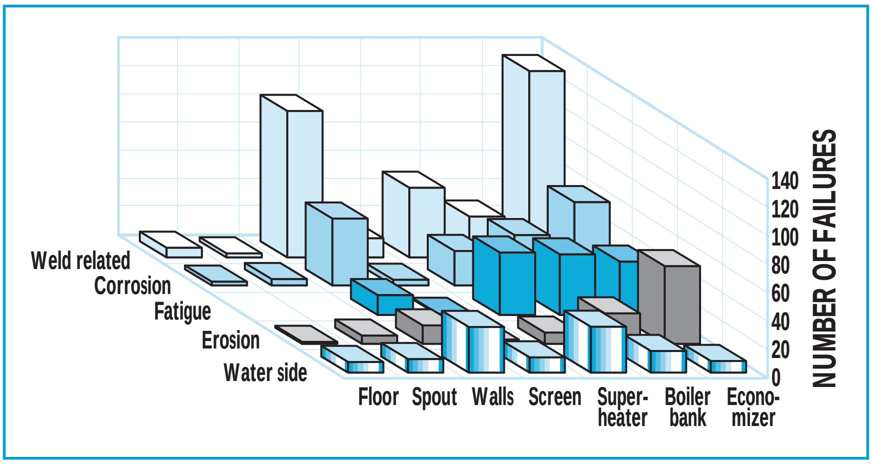
Weld-related leaks. **Figure 3** shows that the areas with the highest frequency of weld-related leaks are the economizer (40%), water walls (31%), and superheater (14%). This is not surprising, since these components have the highest concentration of welds. The issue of weld-related failure is examined in greater detail later in this report.

Corrosion-related leaks. Corrosion-related leak locations in **Fig. 4** confirm an expected high incidence in the walls (27%), superheater (13%), and boiler bank (19%), but a higher-than-expected incidence in the economizer (34%). The issue of corrosion-related failure is examined in greater detail later in this report.

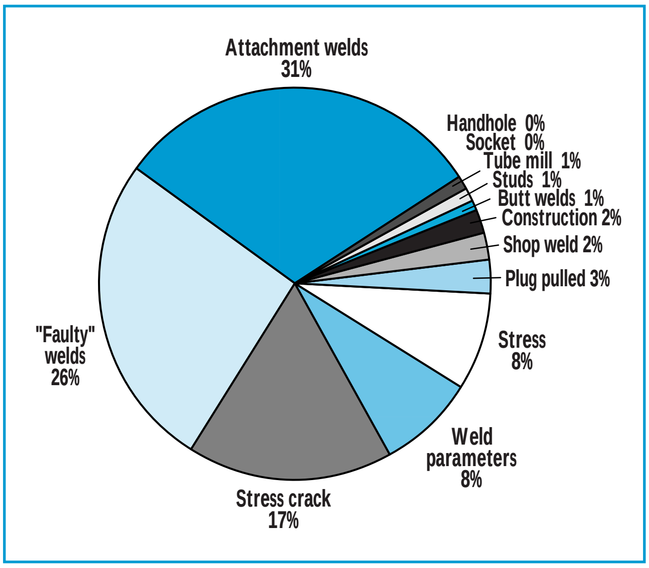
Fatigue-related leaks. One would expect locations of fatigue-related leaks to occur most often in areas where long tubes are not fully supported against vibration forces, such as those generated by sootblowers. **Figure 5** bears out this expectation.

Erosion-related leaks. **Figure 6** shows a surprising number of erosion-related leaks in the economizer.

Water-side-related leaks. The water-side-related leaks combine three less-frequent categories on the premise that they are likely related. The three categories are feedwater (scale), circulation deficiencies, and overheat, both short term and long term. As noted earlier, specific cases do not always fit the trends, and there are specific cases where combining these three categories is obviously a wrong premise. Consider, for example, a situation where overheat failures of a superheater tube are due to improper selection of material rather than insufficient cooling flow ("circulation") through the tube. **Figure 7** shows the location of water-side-related leaks.



8. Location of leaks by major root causes



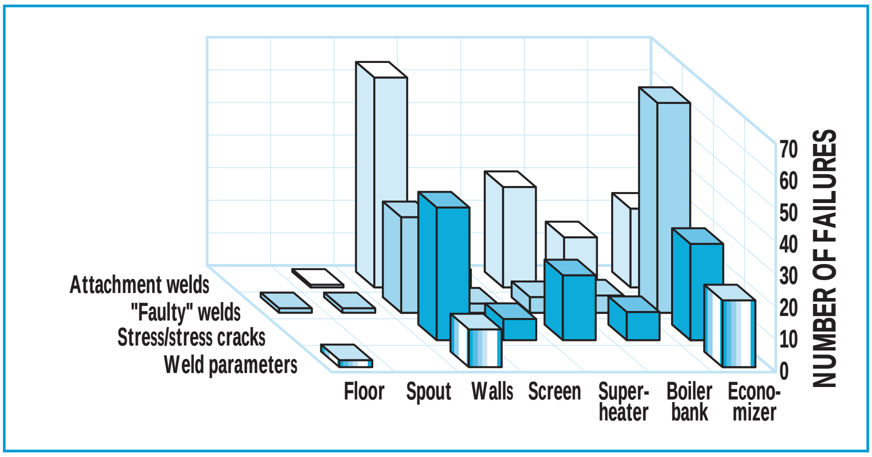
9. Classification of weld-related failures

Combined summary of root cause vs. location. **Figure 8** summarizes the previously discussed results (Figs. 3–7) by showing the distributions of the five major root causes in each of the seven locations within the recovery unit. This combined view shows the likely cause of failure at each location. It also provides some perspective regarding the frequency of each root cause. For example, note that the large pie slices depicting wall and superheater failures in the water-side cases of Fig. 7 are less prominent when compared with the higher bars in the other root-cause categories (weld-related, corrosion, fatigue, and erosion).

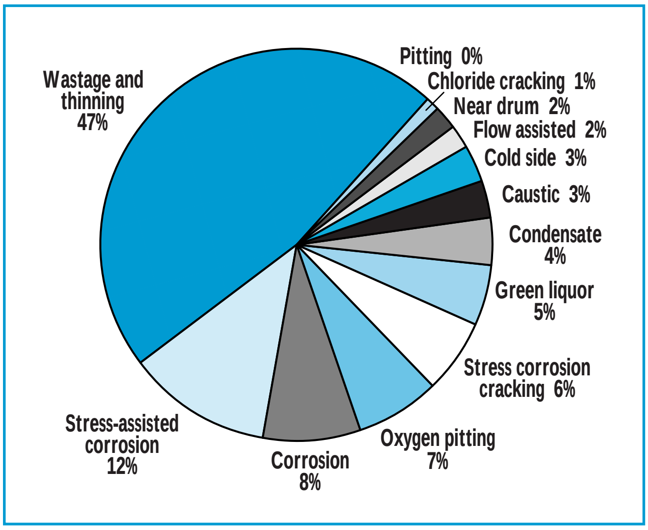
Classification of weld-related failures

Discussion. Because weld-related failures are so significant, this category was broken into subcategories depicting the types of weld failure. **Figure 9** shows the frequencies of failure in the weld subcategories.

[2] Gommi, J., *TAPPI 1997 Engineering Conference Proceedings*, TAPPI PRESS, Atlanta, p. 509.



10. Location of major weld-related failures



11. Classification of corrosion-related failures

There were very few butt-weld failures. Rather, most weld failures are related to attachment welds. This is an important finding. As suggested earlier, one expects weld failures to be higher in components where there are a lot of welds, such as economizer, walls, and superheater. The finding here indicates that the shop- and field-welding procedures and inspection methods used for butt welds have definitely paid off in their rigorous application. Clearly, it has been worth the extra effort that this industry applies to ensure quality welders and butt welds.

What is of major significance is that the failures of attachment welds are undermining reliability so much. The incidence of stress and stress–cracking failures in attachment welds calls for a major review of attachment methods. The industry has addressed the failures of the 1960s and 1970s, where "tangent welds" (welds made on the tangent of a tube to a crossing attachment member) were banned and replaced with the requirement to weld on membranes, use doubler plates, or use scallop bars. Some of the failures in this category likely can be traced to preexisting tangent welds. Nevertheless, based on the trends uncovered here, further work *must* be devoted to develop a reliable field stress-relieving procedure and requirement for attachment welds.

The "weld parameters" category, which accounted for 8% of weld-related failures, includes lack of penetration (LOP), lack of fusion (LOF), porosity, inclusions, undercut, arc strikes, blow-through, and torch cuts.

The "faulty welds" category, which accounted for 26% of weld-related failures, has the greatest potential for improved performance in the future. If the results presented here can spur the industry to demand improvements in welder training, then proficiency at the job site will improve. Reporting of weld failures should include an explanation of the type of failure. The general "faulty" or "bad" weld category is too broad to advance our knowledge of failure or improve our welders' qualifications.

Figure 9 further confirms the weakness of field welding ("attachment," "faulty," and "weld parameter" categories) compared with "shop" and "tube mill" results.

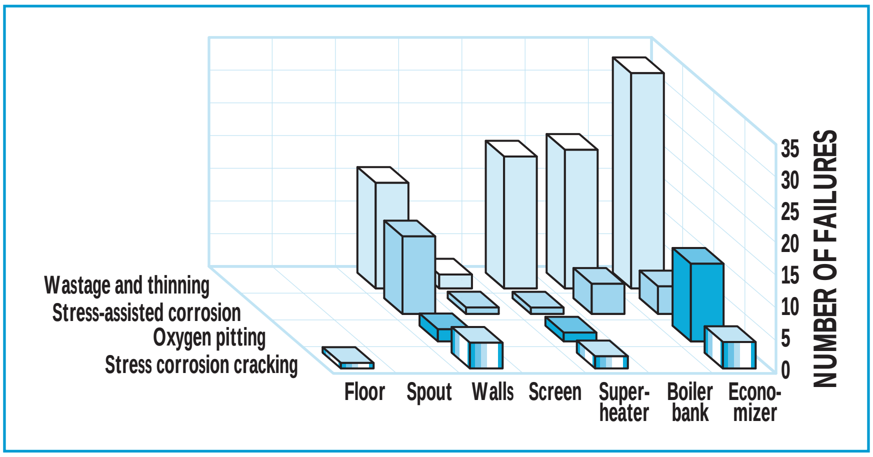
There are four different kinds of welds showing up in the reports: butt, socket, hand hole, and attachments. These categories need to be reinvestigated and better categorized in the future. There are many weld failures related to socket welds and header hand-hole caps, but they were not recognized as classifications in this investigation. The graphical results of "zero" percent is inaccurate and is simply a placeholder for future reporting improvements.

Location of major weld-related failures. **Figure 10** shows the distributions of the four major weld-related failures in each of the seven locations within the recovery unit. "Attachment" and "faulty" welds in the walls and economizer stand out as the primary areas of opportunity. Nevertheless, better reporting of weld failures is required to clarify this area of weakness.

Classification of corrosion-related failures

Discussion. After weld-related failures, the next-largest root-cause classification was corrosion-related failures. This category was broken into subcategories depicting the types of corrosion failure. **Figure 11** shows the frequencies of failure in the corrosion subcategories.

Corrosion is often a slow process, albeit insidious. General wastage and thinning represent half of all the root-cause mechanisms that "surprised" the operations with leak failures. Continued emphasis on corrosion containment is a valid strategy for improving safety and increasing uptime. Knowledge of the causes and locations of corrosion, as depicted by these data, can help owner–operators plan proper and timely inspections with greater confidence.



12. Location of major corrosion-related failures

Unfortunately, many sites of external corrosion are difficult to access. Because of the nature of the leaks that occur, special efforts for inspection are warranted to document corrosion as early as possible. Otherwise, the repairs of the first corrosion leaks are simply a sign of the widespread condition that will continue to manifest itself with ongoing failures.

The age of the recovery boilers shows an expected tendency for older boilers to have more corrosion failures than newer ones. This is evidence that corrosion takes time. No incidents have been reported for units installed in the past decade. There are only 13 incidents reported for units from the early 1980s. There were 172 for the 1970s-vintage units and 58 for the 1960s-vintage units. The remaining 33 incidents occurred in units built prior to 1960.

Stress-assisted corrosion is classified herein only as those cases working on the inside diameter (ID) of the tubes related to welded attachments and heat-affected zones on the outside of the tubes.

Oxygen-pitting failures are exclusively associated with feedwater oxygen and economizer inlet locations. Deaerator and oxygen scavenger problems are unforgiving and cumulative. A short-lived upset establishes an equivalent pitting intrusion. Subsequent incidents, no matter how short, each add to the pit depth, and first failures are usually accompanied by ongoing failures. With oxygen pitting accounting for 7% of corrosion-related failures, it is clear that mills must be diligent in strictly maintaining target oxygen levels. Merely measuring the level of scavenger chemicals does not offer adequate protection.

Corrosion that shows by pitting, rather than thinning or cracking (but not economizer-inlet oxygen pitting), was mentioned enough times that it, too, will be a reexamined category in a future paper.

The general "corrosion" category would benefit from more informative reporting, and future reporters are requested to follow the suggested categories for better data review.

Location of major corrosion-related failures. **Figure 12** shows the distributions of the four major corrosion-related failures in each of the seven locations within the recovery unit.

A major finding is that half of the incidents occur where water might be expected to reach the hearth (i.e., the walls and the boiler bank). The superheater and economizer account for the other half. Luckily, the floor, screen, and spout have not played a major role in corrosion failure during the past decade. This suggests that procedures to detect and correct wastage in these areas are working.

CONCLUSIONS

A review of recovery-boiler leaks over the past decade revealed some interesting trends and highlighted areas of special concern.

Attachment welds

Weld-related failures accounted for a total of 23,000 hours of downtime. The most common type of weld failure was attachment welds. Given the high cost of downtime, the industry has a great incentive to push for significant improvement in this area.

Leak detection

A small leak in one tube will erode the surfaces of adjacent tubes. Early detection and repair of small leaks can prevent a major rupture from erosion. This is one of the strongest opportunities for immediate payback in the industry. Four leak detection schemes are defined in the literature.[2] Implementing one or more of these methods is well worth the effort to maintain both safety and reliability.

Economizer design

All trends indicate that the economizer is especially vulnerable to failure. While this may not rank high as a safety issue, the amount of uptime and reliability sacrificed to economizer failures warrants a concentrated effort by manufacturers to create a design that is more reliable.

Quality of mill data

The database is only as good as the information provided by the mills that voluntarily submit completed questionnaires to the Black Liquor Recovery Boiler Advisory Committee (BLRBAC). The information received to date has been enormously useful, enabling the industry to identify problems and focus on solutions. Nevertheless, greater progress could be made if mills would report *all* future incidents, not just those related to emergency shutdown incidents and near misses. This would make the database a more reliable and thus more useful tool for improving the safety and reliability of the recovery boiler.

Inspections

The high cost of downtime tends to cut into inspection time. However, the results presented in this report show that the cost of focused yet thorough inspections is justified by the benefits of greater operational safety and long-term reliability. Furthermore, the analysis of data submitted by mills over the past decade shows where maintenance efforts should be focused.

Corrosion-resistant materials

Past efforts to increase corrosion resistance are paying off. However, the data confirm that there is ample room for further improvement. The industry's current efforts are warranted, and these data will allow better focus.

Operator readiness

While operator-related lapses are not among the high-incident-rate failure categories, a review of the data confirms (a) the value of continued improvement in implementing emergency procedures and (b) the safety consequences of routine operating and maintenance procedures. Continuously improved awareness and understanding by operators comes from experience, training, and data sharing. TJ

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