Guidelines for integrity evaluation and remaining life assessment of recovery boilers – CENIBRA's experience

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ABSTRACT: The need for integrity evaluations and remaining life assessments of boilers arises from technical, economic, and legal reasons. The pulp and paper industry has less experience and tradition in using this engineering discipline when compared to other industries such as oil, petrochemical, and power generation. The pertinent Brazilian legal standard (NR-13) is concise in establishing this requirement, without providing details of applicable technical procedures. Furthermore, recovery boilers are a special type of steam generator, being very specific as to their inherent in-service degradation mechanisms and inspection needs.

In view of the above scenario, pulp and paper mill engineers often have doubts and encounter diverse interpretations of the official regulations when they need to carry out integrity evaluations of quarter-century old recovery boilers. This paper relates CENIBRA's recent experience in evaluating its recovery boiler No. 1.

Application: This paper may serve as a guide for other pulp mills and help answer questions about the process of integrity evaluation and remaining life assessment of aged recovery boilers.

Boilers and other installations operating at high pressures and temperatures are designed for a finite life [1]. This limitation is due to in-service degradation (i.e., damage that occurs throughout its years of operation). For a chemical recovery boiler, the typical, ongoing damage mechanisms that will limit the unit's life are summarized **Table I**.

The design life of a boiler often is not openly specified. Many designers and specialists consider 25 to 30 years to be a reasonable estimate for the life of water tube boilers and for the power plants of which they are part [2]. Practical experience, however, shows that the real durability of such installations, in most cases, is much greater than this estimation. This is especially true with the advent of new materials and improved operational and maintenance practices. Thus, a life of 40 years or more becomes a technically reasonable expectation for a recovery boiler, which is obviously very desirable from the economic point of view.

To achieve this life extension, a careful engineering evaluation is carried out to determine any necessary repairs and replacements required. The boiler's operations, maintenance and inspection history, and its current condition, are considered in projecting its remaining life.

Brazilian regulations (the NR13 safety standard) specify that every boiler should undergo a structural integrity evaluation and remaining life assessment upon completing 25 years in service [3]. The NR13, however, is a general requirement for all types of steam generators and does not provide technical guidance. This paper provides additional information and recommendations for conducting integrity assessments, specifically focusing on chemical recovery boilers, with the aim to assist pulp mills to fulfill this important technical and legal requirement.

TIMING FOR STARTING EVALUATIONS

Under normal conditions, integrity evaluations and remaining life assessments should occur:

- On completion of 80% of the design life, or
- On completion of 25 years (the legal time period in Brazil, which under no circumstances should be exceeded) [4].

Evaluations should occur sooner in the following cases:

- Operation above nominal capacity
- Excessive cycling (stop and start) and/or variation of load
- History of stops and starts faster than those anticipated by the design
- Known evidence of accumulated damages
- History of accumulated damages on similar units [5].

BASIC PREMISES FOR STRUCTURAL INTEGRITY EVALUATION (SIE)

Basic Requirements

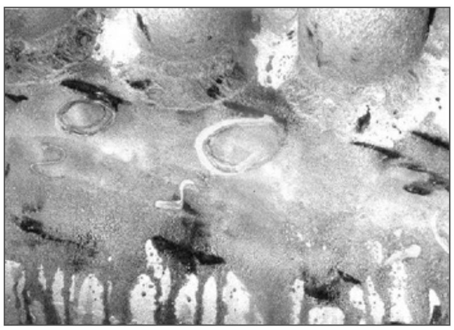
The objective of a structural integrity evaluation (SIE) is to enable a safe continuation of the unit's operating life, generally beyond the period first intended. Of course, there is not a single formula for conducting such investigations. However, some basic requirements must be taken into consideration in these procedures.

Annual inspections do not fully address such requirements. An SIE differs from routine inspections in the following ways:

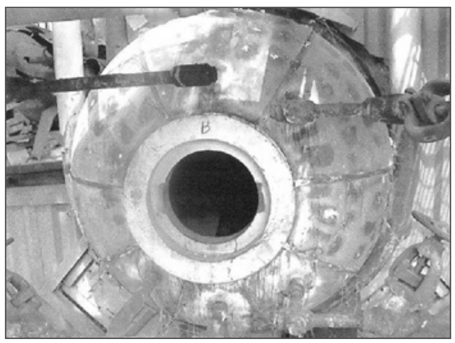
- It investigates time-dependant degradation mechanisms that occur in the mid- and long-term, such as fatigue, creep, metallurgical degradation, and water chemistry effects. These mechanisms must be clearly differentiated from those acting "faster" or those more related to incidents or to accidental and circumstantial factors.
- It investigates in greater depth the integrity of parts that do not usually receive such attention during periodic inspections due to lack of time and difficulty in access: headers, drums, attemperators, main steam lines, structural elements, etc. (see **Figs. 1-3**).

Damage Mechanisms	Corrosion	Fatigue	Erosion	High Temp. Oxidation	Creep	Micro-Structural Degradation
Furnace	✔	✔	✔	—	—	—
Drums	✔	✔	—	—	—	—
Economizer	✔	✔	✔	—	—	—
Boiler bank	✔	✔	✔	—	—	—
Superheaters	✔	✔	✔	✔	✔	✔
High temperature headers	—	✔	—	✔	✔	✔
Non-refrigerated parts exposed to flue gas	✔	✔	✔	✔	—	✔
Main steam line	—	✔	—	—	✔	✔
Structures	✔	✔	—	—	—	—
Dissolving tank	✔	✔	✔	—	—	—
Deaerator	✔	✔	✔	—	—	—

I. Factors that limit the life of chemical recovery boiler components.



1. Inspection and non-destructive testing of lower waterwall header. Investigation as to ligament cracking.



2. Steam drum without its insulation to enable detailed examination and testing.

3. Access provided for inspection of elements in the interior of penthouse and other "cold" chambers in the recovery boiler.

- It evaluates the integrity of each boiler component *individually*, to determine the susceptibility of each one to the corresponding degradation mechanisms, indicating those whose useful life will expire before the others.
- It evaluates metallurgical aspects, mostly in high temperature parts, to identify nonvisual damage mechanisms that may not be indicated by changes in wall thickness. Examples of microstructural degradation include spheroidizing, graphitization, precipitation of carbides, and microvoids from creep. These are illustrated in **Figs. 4-7**. The main concern with corrosion in recovery boilers may divert the engineers' attention from this point.
- It evaluates and documents the kinetics of damage evolution, quantifying corrosion rates, wear, crack growth progress, etc.
- It focuses attention on the steam and water side, investigating the unit's history in relation to possible waterside contamination (e.g., with liquor) and evaluating possible consequences.
- It investigates possible alterations in behavior of structural elements, such as increases in hysteresis of elastic supports of steam piping.
- It takes operations above rated capacity and excessive cycling into consideration.

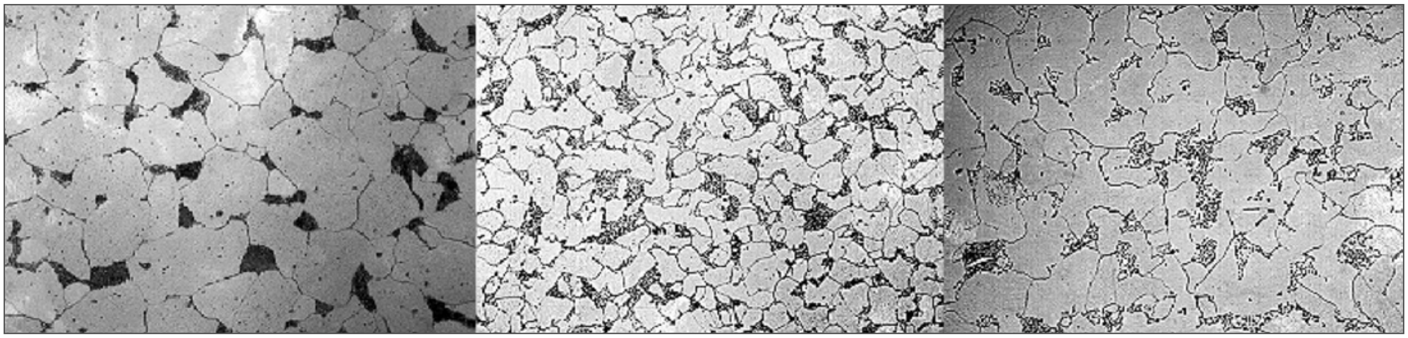
SIE should encompass more than the legally required evaluation of the boiler itself. Common sense and best practices dictate that SIEs should extend to peripheral and ancillary elements closely associated with the boiler, especially those subjected to high temperatures, such as the main steam line, headers, and accumulators, up to the turbine's inlet flange. Additionally, the mill should evaluate the integrity of the deaerator, feed water tank, feed water line, dissolving tank, and other support systems (see **Figure 8**).

SIE conceptual approaches

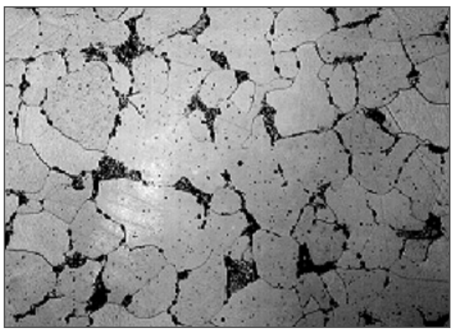
Mills vary in their approach to conducting SIEs, their objectives, and the criteria they may use to assess in-service damages and degradation. The two main approaches are as follows:

The "Project Code" approach—The evaluation of used and degraded equipment, exclusively from a design codes' point of view (American Society of Mechanical Engineers, for example) is the simplest and most traditional approach. It applies the same design and manufacturing criteria for evaluating the boiler's condition and damages resulting from service. Through testing and repairs and replacements, this approach aims to restore the boiler's condition and reliability to "as good as new."

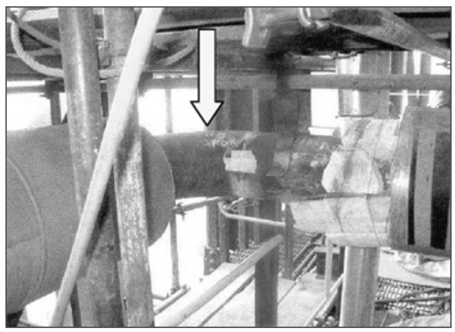
The "Fitness-for-Service" approach—This newer approach evaluates the equipment's fitness-for-service, in spite of accumulated damages, in its degraded condition. Analytical techniques to establish the possibility to continue operating with existing defects are applied (taking into consideration the flaws' dimensions, shape, localization, evolution, kinetics,



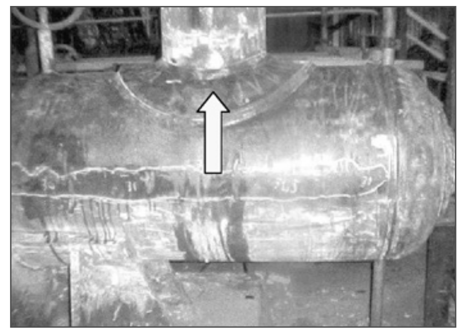
4. Micro-structural gradient of ferric material subjected to high temperature (typically superheaters). These figures are merely illustrative.



5. Structure showing microvoids from creep. Illustrative figure.



6. Preparation for field metallography in the main steam line.



7. Preparation for field metallography in a high pressure steam header.

etc.) The evaluation may include stress analyses, calculations through fracture mechanics, and use of API 579 and BS:7910 standards. Among other benefits, this approach seeks to minimize repairs and replacements, without compromising reliability.

The second approach, already consolidated in the power generation, oil, and chemistry industries, has also gained increasing recognition and acceptance in other industries. Both philosophies mentioned, and others, are acceptable from the technical point of view and recognized by legislation. It is up to the boiler owner to evaluate it and other approaches in terms of cost, time, availability of technical resources, company culture, and other factors.

PROCEDURES FOR EVALUATING STRUCTURAL INTEGRITY AND REMAINING LIFE

Integrity evaluations involve complex engineering work that must be carried out by extremely specialized and qualified professionals. While specific procedures may vary, the evaluation is usually conducted in three distinct phases:

Phase 1: Preliminary Evaluation

Objectives

- Define physical limits, or the "boiler island," within which analyses will be carried out.
- Collect information on the equipment (scrutinize the unit's operational, maintenance, and inspection history, and its design data).
- Identify in-service degradation mechanisms taking place in the boiler.
- Identify the boiler's critical parts or zones, and which damage mechanisms affect them.
- Analyze the collected information and determine whether available data are sufficient to establish the unit's structural condition.
- Plan inspection and additional non-destructive testing (NDT), as needed.

Phase 2: Non-destructive Testing

Objective

- To supplement data collected in Phase 1 (which in extremely rare cases are sufficient *per se*), verify through additional inspections and NDTs the presence of accumulated in-service damage, defining its extent and responsible mechanisms.

8. Preparation for inspection and non-destructive testing in the deaerator tank saddle. Simultaneously, the vessel itself had been tested internally by wet fluorescent magnetic particles.

Table II lists resources that are usually applicable in this phase, with examples, some of which are illustrated in **Figs. 9-12** [6].

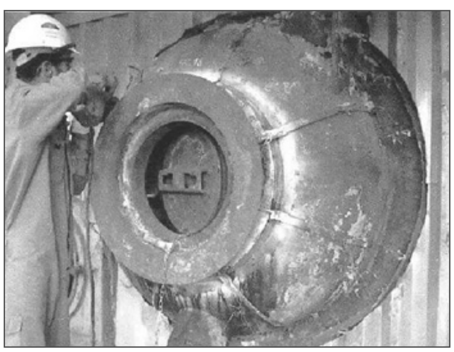
Phase 3: complementary analysis

Goals

- Analyze data collected in the previous phases.

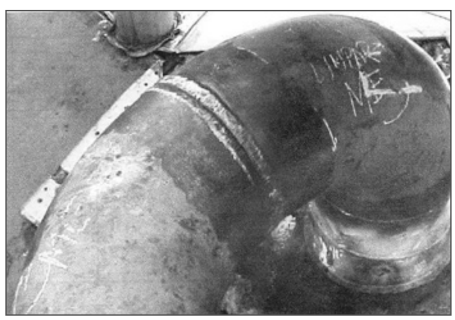
Non-Destructive Test	Usual Locations	Noteworthy SIE Applications
Dye penetrant	Composite tube furnaces, structures, membranes, spacers, welded attachments	Investigation of cracking on furnace openings
Magnetic particle	Weld seams of drums and headers	Investigation of ligament cracking in headers and drums
Ultrasonic thickness surveys	Tubing, headers, drums, deaerator	Remaining life estimations in the light of corrosion rates
Ultrasonic for flaw detection	Weld seams of drums and headers and other thick-walled elements	
Field metallography (direct or replication)	High temperature tubing and headers, furnace tubing	Investigation of creep, micro-structural degradation, localized over-heating, surveillance of known flaws, etc.
Dimensional examinations	High temperature tubing and headers	Investigation of creep
Hardness readings	High temperature tubing and headers	Complementary investigation of microstructural degradation
Internal Rotary Inspection System (I.R.I.S.), near drum inspection	Boiler bank	Investigation of near mud drum corrosion [7]
Endoscope inspection	Attemperators (sometimes also called a de-super heater), economizer, headers, downcomers	
Destructive testing	As necessary	
Digital radiography	Superheaters, lower bends	
Load analysis in pipelines supports	Live steam piping	Investigation of changes in the support reactions of the piping [8]

II. Non-destructive tests that may be used as part of system integrity evaluations of recovery boilers.



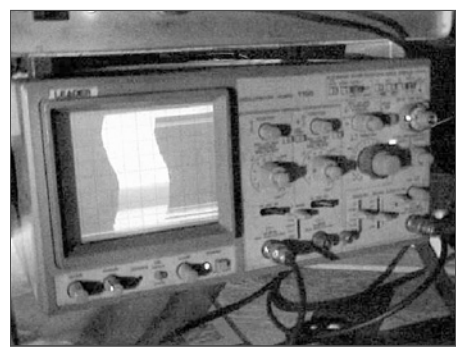
9. Non-destructive testing (magnetic particles) in progress in the water drum of a recovery boiler.

- Confirm the hypotheses formulated during Phase 2, using complementary tests to samples taken from the equipment, double-checks, actual stress analysis, etc.
- Reach final evaluation of the structural condition and the remaining life.



10. Preparation for non-destructive testing (ultrasonic and magnetic particles) of a crossover pipe welding.

A final report must then be issued, containing all the information regarding the evaluation: the current structural condition and remaining life of each boiler component; recommended procedures for future similar evaluations; possible recommendations for repairs or replacements, re-rating of components, possible process changes; calculations; and all applicable planning.



11. Equipment for I.R.I.S. testing, being used to inspect tubes of the boiler bank. The corrosion of tubes in the region near the lower drum (known as near mud drum corrosion) in a recovery boiler is a typical concern.

RECOMMENDATIONS FOR NEW BOILERS

The procedures addressed in this paper are mainly intended for owners of older boilers, especially those approaching the legally established time for starting the integrity evaluation. However, the discussion and suggestions also may be useful to those dealing with new boilers, and even for projects in the early stages of specification and procurement for a future unit.

The following suggestions may be helpful to *owners of newer boilers*, or those specifying or procuring a future unit:

- Require that the vendor who is offering a new boiler provide recommendations or guidelines for future SIE of the equipment being supplied.
- Keep samples of all materials of construction of a newly erected boiler, as a reference for future comparison as to micro-structural degradation and creep.
- Conduct dimensional examinations of the high temperature tubes before the initial start-up as a reference for future comparison as to creep.
- Consider installing instrumentation to monitor the temperature of the hottest and most critical parts of the future boiler.
- Perform an "early start" of the SIE program, collecting data of interest and recording relevant information through the life of the boiler from the beginning of its operations.

FINAL CONSIDERATIONS

An integrity evaluation is not just an extensive program of inspections and testing, or life-time projections, although elements of those are markedly present. It is rather an ongoing, multi-disciplinary program that should be established from the beginning of the boiler life cycle. It must be customized for each individual plant, taking into consideration its actual status as to accumulated damage. Thus, the boiler owner should be cautious about vendors offering a predetermined, "standardized" program of inspections. The integrity evaluation also presumes a close participation and co-operation of the boiler owner and the professionals commissioned to do the evaluation.

The following are some of the benefits afforded by integrity evaluations and remaining life assessment programs:

- Establishment of a base line of the boiler's structural condition
- Increased safety for personnel and facilities
- Increased availability of the boiler at maturity
- Economic flexibility, allowing the mill more time to explore replacement and repair options, and possibly postpone investments
- "Good will" through a positive image of the mill, associated with safety and proper engineering practices
- Training for the mill's engineers
- Legal compliance.

12. *Ultrasonic thickness survey on a studded tube of a recovery furnace.*

13. *CENIBRA's recovery boiler No. 1. This unit had its first start-up in 1977, and underwent an integrity evaluation program in 2002, according to the guidelines described in this paper.*

Author's Note: *the information and recommendations contained in this paper reflect the author's best knowledge and belief at the time of writing. However, the text should serve only as a general reference to the reader. No warranties are offered or responsibilities taken that the information provided is perfectly adequate or sufficient for the purpose in question.* **TJ**

LITERATURE CITED

1. Singer, J.G., *Combustion, Fossil Power.* ABB Combustion Engineering, Windsor, Connecticut, 1991.
2. French, D.N., *Microstructural Degradation. The National Board of Boiler and Pressure Vessel Inspectors web site, Classic Articles*, available online at www.nationalboard.org/classics.
3. *Manual Técnico de Caldeiras e Vasos de Pressão*, Ministério do Trabalho, Brasília, 1996.
4. *Procedimento Geral de Avaliação de Vida Restante de Componentes Estáticos Submetidos a Alta Temperatura*. Instituto de Soldadura e Qualidade, Lisboa.
5. *Prática Recomendada para Análise de Danos Acumulados em Serviço por Equipamentos Pressurizados que Operam a Alta Temperatura*, Recomendação Geral para Inspeção de Equipamentos que Operam em Temperaturas Elevadas, Associação Brasileira de Ciências Mecânicas, Rio de Janeiro, 1992.
6. Babcock & Wilcox Condition Assessment Services. Available at www.babcock.com.
7. Adams, T.N., Frederick, W.J., Grace, T.M., et al, *Kraft Recovery Boilers*, TAPPI Press, Atlanta, 1997.
8. Caldeira, R. B., *Relatório de Avaliação de Integridade e Vida Remanescente de Caldeira de Recuperação 1*, CENIBRA. Instituto de Soldadura e Qualidade - ISQ Brasil, Belo Horizonte, 2002.

This paper was originally published in the June, 2004 issue of *O Papel*, the official publication of the Brazilian Technical Association of Pulp and Paper (ABTCP). It is being reprinted by *TAPPI JOURNAL* through a cooperative agreement between TAPPI and ABTCP.

This paper is also published on TAPPI's web site <www.tappi.org> and summarized in the February *Solutions! for People, Processes and Paper* magazine (Vol. 88 No. 2).

INSIGHTS FROM THE AUTHORS

Facing the need to conduct an integrity evaluation and remaining life assessment program to a recovery boiler in the mill I work for, I soon realized there was limited information available about this subject within the Brazilian pulp industry, in spite of its importance. Also, I found diverse interpretations (by previous users and inspection services suppliers) of the official requirements, and no written guidelines with a specific focus on recovery boilers. That prompted me to write this article.

Brazilian official standards require that boilers undergo an integrity evaluation at 25 years. But they give no technical guidance and do not highlight the special needs and risks associated with recovery boilers. This paper is therefore intended to help provide mill engineers with some complementary support when they carry out such programs.

The most difficult aspect of preparing for an integrity evaluation, and in writing this paper, is the lack of references and successful past experiences in Brazilian mills. I searched the procedures used in other industries, and by pulp mills abroad, then adapted them to our reality.

Through my research, I was particularly impressed by the wide array of available engineering disciplines and testing techniques that now can help engineers evaluate the conditions of a used recovery boiler, giving an excellent level of confidence in the results of such evaluations.

Some Brazilian mills are systematizing and improving their procedures in evaluating the integrity of aged recovery boilers. This paper, while not intended to be a complete or definitive guide, could be a first step towards this improvement.

With time, more recommendations and aspects pertaining specifically to recovery boiler in-service evaluations should be added to the contents of this paper, making it more and more comprehensive.

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