Optimized Inspection and Maintenance Programs for Recovery and Power Boiler Tubes

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Process industries rely on dependable inspection and maintenance programs for recovery and power boilers while at the same time requiring methods to optimize these systems in order to reduce their costs without affecting production.

These optimized systems would ideally meet the following requirements, all lacking in the majority of previous inspection programs:

- The information gained from Inspections, Ultrasonic Thickness Surveys (UTS) and the components' performance history are used to establish firm criteria detailing current conditions, fit for service assessments and for future, accurate trending and planning.
- Using a risk-based inspection approach, Inspectors would be able to target this information to optimize the scope, frequencies and locations of future thickness surveys and visual inspections.
- The Users would have a software system which has automatic forecasting elements, capable of efficiently logging the data, processing and displaying the data and results and is user-friendly.
- The complete program would result in documented, real-time cost savings and produce a healthy return on investment.

This article examines and illustrates the challenges and solutions based on a recovery boiler situation. These challenges and solutions apply not only to recovery boiler tubes but also to the different types of watertube boilers found in various installations such as power generation facilities, refineries, pulp & paper mills, etc. We will examine the above desired improvements to inspection programs and demonstrate how one revolutionary asset management system has provided the solution – Visions Enterprise.

Developed by Metegrity Inc., Visions Enterprise combines state-of-the-art information technology with Enterprise systems, thereby providing information for the effective management of plant or process facility assets through risk-based assessment and inspection strategies. It integrates asset information from construction to operations and improves asset condition monitoring, analysis and reporting.

ABSTRACT

On most recovery and power boilers, ultrasonic thickness readings are taken on the tubes to determine remaining wall thickness, but in many instances these thickness values are only providing a “snapshot” of the current condition of the boiler tubes. Using boiler tube thickness measurements taken in consistent locations, with effectual computer software and developed boiler tube engineering standards, it is now possible to set up an efficient program for predicting boiler tube conditions and to accurately plan for tube replacements/repairs far into the future.

Many companies have implemented Boiler Inspection Programs without considering predictive or preventative tube failures. In more recent years, some of these same companies have integrated Visions Enterprise into their inspection programs and are now able to include an element of forecasting and, as a result, have vastly reduced the number of “surprises” during the boiler turnarounds.

INTRODUCTION

Boiler tube Ultrasonic Thickness Surveys (UTS) are a useful tool in determining the present condition of a recovery or power boiler. With a little work, the information resulting from the UTS can be utilized further to accurately trend the condition of the tubes and plan for tube replacements.

Visions Enterprise is based on a Risk Based Inspection approach, using UTS information to optimize the amounts and locations of subsequent thickness surveys and visual inspections. Eventually, inspection efforts can be concentrated on the documented “problem areas” of the boiler and the inspection scopes reduced on the more benign areas without affecting the integrity of the boiler.

In this paper, data and illustrations from a recovery boiler are utilized. However, this methodology can be applied, and is currently being used, for different types of boilers in various installations such as pulp mills, power utilities, etc.

DETAILS

Boiler or plant turnaround and production costs are always on the rise; however profits may not be rising sufficiently to cover these costs. It is becoming increasingly important to control costs in order to provide a healthy return on investments.

> **“The drive to simultaneously improve business, safety and environmental performance requires technical integrity to be secured and demonstrated in a cost optimized way. This is best achieved by adopting a risk based approach.”**[I]

Risk Based Inspection (RBI) is a method that uses risk as the basis for prioritizing and managing the efforts of an Inspection Management Program. Since a relatively large percentage of risk is associated with a small percentage of equipment, RBI permits allocating inspection and maintenance resources to provide higher level of coverage on the high-risk locations and an appropriate effort on the lower-risk locations. While RBI was initially developed to manage pressure equipment like vessels, tanks, piping etc., the same approach can be applied to recovery and power boilers and their sections and components.

Organizations such as the API[1] and the ASME[2] have recently developed "Standards for Risk Based Inspection" (i.e. API – 581[II], API - 580[III]). The RBI procedures and policies may also be developed in-house as long as the procedure is logical, documented and repeatable and takes into account all applicable aspects of the risks associated with the equipment[IV]. Visions Enterprise offers a flexible approach to Risk Based Inspection that can be customized according to clients' criteria or models.

> **Reducing the number of unplanned boiler outages due to tube failures and efficiently reducing inspection costs without affecting the boiler integrity are good examples of reducing costs.**
>
> Other cost-savings benefits of Visions Enterprise are its use of thin client technology, which ensures optimum network traffic, and reduced bandwidth requirements. Deployment is simplified with little configuration and reduced computing power is required for clients' workstations. Software maintenance costs are therefore also dramatically reduced.

To eliminate, or at least vastly reduce, the number of boiler tube failures due to thinning of the tube walls, analysis and optimization of the boiler tube thickness data are required. The process of analysis and optimization consists of four main components:

- Step 1 - Determining initial optimum elevations and mapping locations for ultrasonic thickness surveys (UTS) on the tubes utilizing RBI principles.
- Step 2 - Developing a set of Boiler Tube Thickness Criteria for all boiler sections based on experienced and/or anticipated metal loss rates.
- Step 3 - Conducting at least three sets of thickness surveys in these exact locations.
- Step 4 - Analyzing the data to determine trends and efficiencies.

Step 1 – UTS Layout

Implementing UTS on a boiler requires access to the history of the specific boiler or of similar service/design boilers. Useful history includes areas of previous tube failures (due to rupture and not "mechanical" causes such as buckstay clip tears, fabrication damages, weld failures, etc.). The type and service of the boiler is important**.** BLRBAC[3] data on recovery boiler explosions and analysis of factors that cause critical leaks[V] are good sources of information while determining UTS locations and frequencies.
A Black Liquor Recovery Boiler with carbon steel tubes throughout the radiant and convection sections can normally be expected to experience significant tube metal loss near the hearth area, the bullnose and the leading edges of the screen tubes. The leading edges near the bottom of the secondary superheater can also be expected to show significant tube metal loss.

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[1] American Petroleum Institute
[2] American Society of Mechanical Engineers
[3] Black Liquor Recovery Boiler Advisory Committee

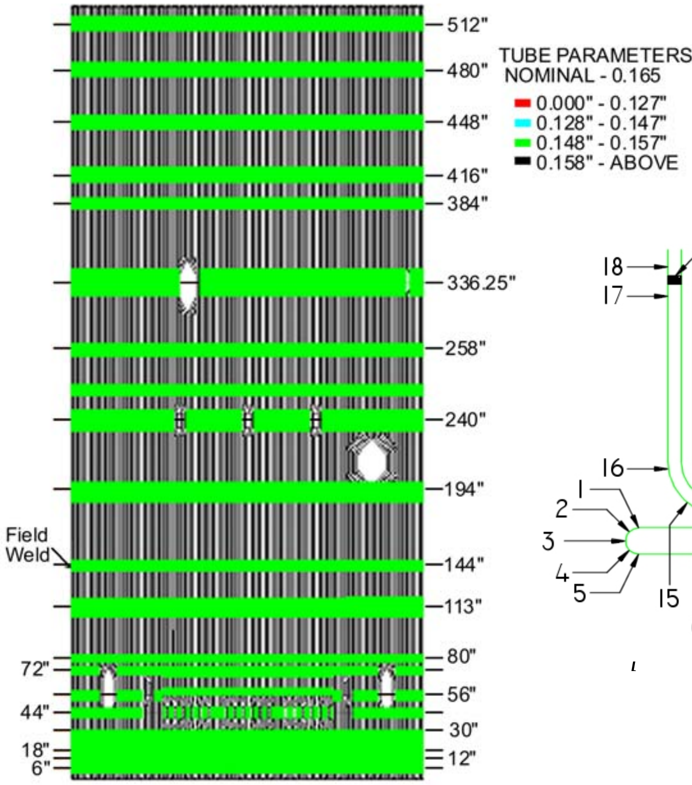

Figure 1: The initial UTS locations on the front waterwall of a recovery boiler[VI]

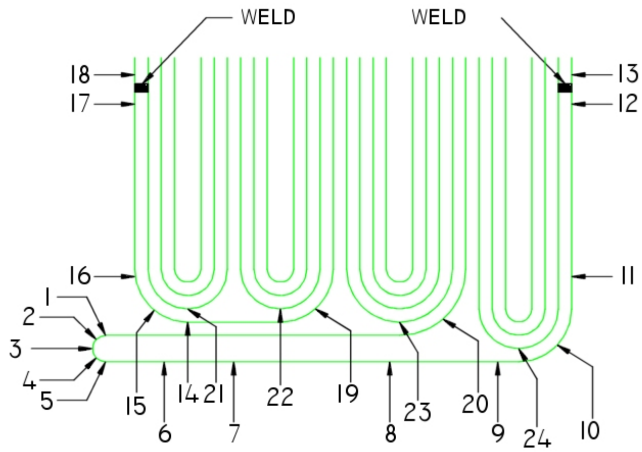

Figure 2: The initial UTS locations on the Secondary Superheater tubes[VI]

It is important that the UTS be completed in exactly the same locations and recorded consistently every time (*Figures 1 & 2*). One of the common practices for boilers with membrane water walls is welding little tabs or marks on the tube membranes in the furnace corners. This makes it possible to use a chalk string and snap the locations across the water wall, thereby ensuring the accurate repeatability necessary for trending.

Step 2 – Boiler Tube Thickness Criteria

Boiler Tube Criteria needs to be developed in order to correctly assess the current and future condition of the boiler tubes. These criteria are developed for each boiler section (economizer, primary superheater, waterwalls, etc.). Each section is evaluated to determine its tube thickness, which may be at one of the following levels:

- **Acceptable** – The boiler tube thickness is acceptable for several more years of boiler operation.
- **Alarm Next Shutdown Hit List** – These are tubes that will have top priority for completing thickness readings on during the next turnaround. This helps give an early alert concerning tubes that may require some action in the future.
- **Change Out Next Shutdown** – These tubes will require change out or new pup pieces installed during the next scheduled boiler outage.

- **Change Out This Shutdown** – Any tubes less than this thickness will be changed out or have pup pieces installed during the current boiler outage. This thickness is usually determined by adding two years of metal loss rates to the Code Min. thickness. The rationale is to permit two years of safe operation in the event something was missed during the examination of the thickness readings or if the metal loss on the tube is greater further from where the tube thickness readings were taken.

- **Code Min.** – This is the absolute minimum thickness acceptable for the specific boiler tubes. Nothing is permitted to be returned to service if it is less than this thickness.

Table 1 illustrates Boiler tube criteria for each section of the recovery boiler with a MAWP of 800 psig

Recovery Boiler Tube Criteria MAWP 800 psig **BOILER SECTION**	**CODE MIN**	MIN Change out	Change out Next Shutdown	Alarm Next Shutdown Hit List	Acceptable
		Deep Red	**Red**	**Blue**	**Green**
Water Wall Tubes (Original thickness 0.165") 2.0" OD x 0.200" thick wall replacement temperature: 700°F @ 800 psig material: SA-192 S = 11500 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{2.0x800}{(2 \times 11500) + 800} + .005(2) = 0.077$	**0.077"**	**0.127"**	**0.128" to 0.147"**	**0.148" to 0.157"**	**0.158" & above**
Bullnose Water Wall Tubes 2.0" OD x 0.165" thick wall temperature: 700°F @ 800 psig material: SA-192 S = 11500 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{2.0x800}{(2 \times 11500) + 800} + .005(2) = 0.077$	**0.077"**	**0.127"**	**0.128" to 0.147"**	**0.148" to 0.157"**	**0.158" & above**
Screen Tubes 2.0" OD x 0.150/0.200" thick wall temperature: 700°F @ 800 psig material: SA-192 S = 11500 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{2.0x800}{(2 \times 11500) + 800} + .005(2) = 0.077$	**0.077"**	**0.127"**	**0.128" to 0.137"**	**0.138" to 0.147"**	**0.148" & above**
Front (Secondary) Superheater Tubes 1.875" OD x 0.165" thick wall temperature: 840°F @ 800 psig material: SA-192 S = 7480 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{1.875x800}{(2 \times 7480) + 800} + .005(1.875) = 0.105$	**0.105"**	**0.125"**	**0.126" to 0.140"**	**0.141" to 0.150"**	**0.151" & above**
1.875" OD x 0.165" thick wall temperature: 945°F @ 800 psig material: SA-209-T1 S = 8650 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{1.875 x800}{(2 \times 8650) + 800} + .005(1.875) = 0.092$	**0.092"**	**0.120"**	**0.121" to 0.135"**	**0.136" to 0.145"**	**0.146" & above**
1.875" OD x 0.165/0.220" thick wall temperature: 965°F @ 800 psig material: SA-213-T11 S = 8400 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{1.875x800}{(2 \times 8400) + 800} + .005(1.875) = 0.095$	**0.095"**	**0.135"**	**0.136" to 0.155"**	**0.156" to 0.165"**	**0.166" & above**

Recovery Boiler Tube Criteria MAWP 800 psig **BOILER SECTION**	**CODE MIN**	MIN Change out	Change out Next Shutdown	Alarm Next Shutdown Hit List	Acceptable
		Deep Red	**Red**	**Blue**	**Green**
Intermediate Superheater Tubes 2.0” OD x 0.200” thick wall temperature: 840°F @ 800 psig material: SA-209-T1 S = 10900 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{2.0x800}{(2 \times 10900) + 800} + 0.005(2) = 0.081$	**0.081”**	**0.111”**	**0.112” to 0.131”**	**0.132” to 0.141”**	**0.142” & above**
2.0” OD x 0.165” thick wall temperature: 920°F @ 800 psig material: SA-192 S = 7480 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{2.0x800}{(2 \times 7480) + 800} + 0.005(2) = 0.112$	**0.112”**	**0.132”**	**0.133” to 0.142”**	**0.143” to 0.152”**	**0.153” & above**
Rear (Primary) Superheater Tubes 2.0” diameter x 0.165” thick wall temperature 780°F @ 800 psig material SA-192 S = 9680 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{2.0x800}{(2 \times 9680) + 800} + 0.005(2) = 0.089$	**0.089”**	**0.109”**	**0.110” to 0.124”**	**0.125” to 0.134”**	**0.135” & above**
Generating Bank Tubes 2.5” diameter x 0.125” thick wall temperature 700°F @ 800 psig material SA-192 S = 11500 psi $t = \frac{PD}{2S+P} + 0.005D + e$, $\frac{2.5x800}{(2 \times 11500) + 800} + .005(2.5) = 0.097$	**0.097”**	**0.105”**	**0.106” to 0.115”**	**0.116” to 0.125”**	**0.126” & above**
Economizer Tubes 2.0” diameter x 0.165” thick wall temperature 700°F @ 800 psig material SA-192 S = 11500 psi $t = \frac{PD}{2S+P} + 0.005D + e = \frac{2.0x800}{(2 \times 11500) + 800} + 0.005 = 0.077$	**0.077”**	**0.097”**	**0.098” to 0.107”**	**0.108” to 0.117”**	**0.118” & above**

Table 1: Boiler Tube Criteria for all sections of a Recovery Boiler

Step 3 – Conducting UT Surveys

Normally, it takes at least three sets of UTS readings before determining any meaningful interpretations of the data. This is chiefly due to equipment and operator tolerances in gathering the data.

Based on discussions with Ultrasonic Thickness equipment suppliers and Technicians, we are using an acceptable tolerance of ± 0.010” for this research. This is important when developing the Boiler Tube Thickness Criteria.

A minimum of three sets of thickness readings will smooth out any irregularities in the boiler tube thickness graphs and allow for a more accurate assessment of the long term metal loss rates, short term metal loss rates, remaining life, etc.

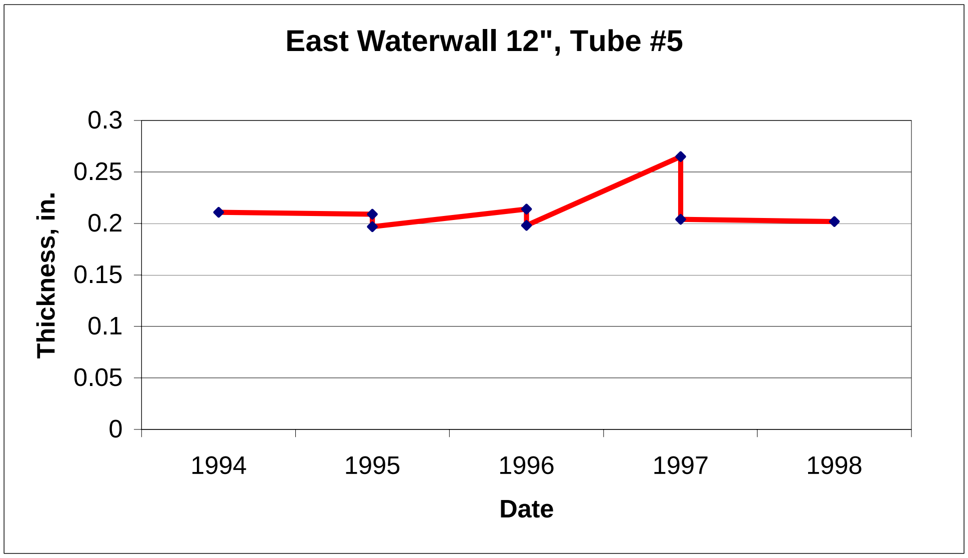

Figure 3: Thickness readings on a tube over a time span of 5 years.

Figure 3 indicates the thickness readings on a tube over a time span of 5 years and illustrates how the tube metal thickness can "grow" over a period of time. For this boiler, two sets of readings were obtained in 1995, 1996 & 1997, as there were two planned boiler outages in each of those years. This is an excellent justification of the established minimum of 3 sets of thickness readings.

Collecting thickness readings can be far more efficient by utilizing instruments with data logging capabilities and appropriate IT systems. These IT systems should be capable of exporting the UT locations and previous readings to the instrument, as well as receiving collected data, calculating trends, pinpointing erroneous readings and displaying results in an easily readable format (*Figures 4 & 5*). The quality of the collected data can also be improved by utilizing UT instruments' low and high alarm functionality. At the time of measurement, these instruments compare previous readings with a collected one, thereby providing the operator with immediate feedback if the new reading exceeds previously set criteria. Alarms could be set based on the discrepancies with the previous reading's absolute value or percentage for both growth and deterioration.

66-273

North Waterwall

Elev # / Tube #	6	12	18	30	80	113	192	240	336	512		
1	0.225 0.212 0.200	0.208 0.220 0.197	0.206 0.199 0.200	0.205 0.202 0.196	0.221 0.218 0.221	0.191 0.181 0.178	0.176 0.175 0.176	0.188 0.180 0.178	0.182 0.177 0.181	0.184 0.182 0.184		
2	0.188 0.195 0.189	0.202 0.205 0.210	0.192 0.197 0.195	0.196 0.196 0.198	0.218 0.215 0.219	0.180 0.173 0.179	0.163 0.177 0.184	0.175 0.170 0.165	0.181 0.179 0.188	0.182 0.181 0.185		
3	0.199 0.211 0.211	0.188 0.195 0.194	0.198 0.204 0.208	0.200 0.204 0.208	0.217 0.219 0.217	0.178 0.179 0.166	0.167 0.176 0.178	0.181 0.174 0.182	0.186 0.167 0.179	0.185 0.177 0.184		
4	0.197 0.207 0.216	0.206 0.212 0.205	0.211 0.205 0.204	0.195 0.189 0.204	0.218 0.215 0.215	0.172 0.172 0.186	0.182 0.184 0.183	0.181 0.178 0.183	0.189 0.187 0.186	0.184 0.178 0.181		
5	0.203 0.208 0.198	0.196 0.197 0.197	0.199 0.198 0.203	0.199 0.190 0.197	0.219 0.217 0.222	0.178 0.174 0.183	0.173 0.170 0.176	0.179 0.173 0.173	0.182 0.179 0.184	0.183 0.176 0.172		

Figure 4: Tabular display of the boiler section tube thickness readings

Ideally systems would become capable of extrapolating data collected during the survey, transmitting the data to the drawing and ultimately generating accurate views of the boiler's condition in a tabular or graphical format. This becomes a reality with the implementation of Visions Enterprise into an inspection program.

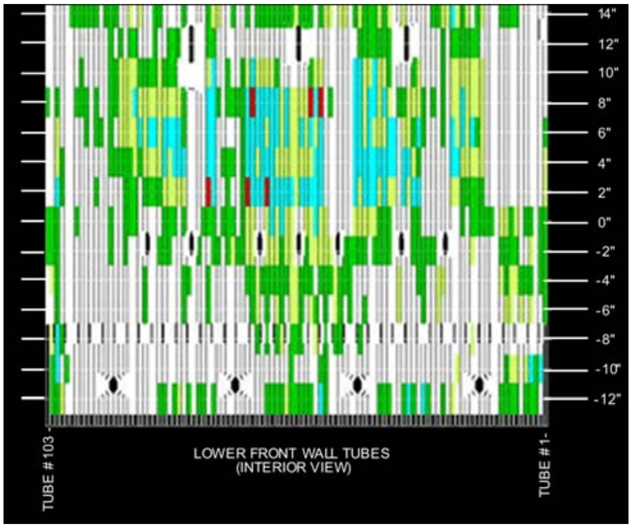

Figure 5: Graphical display of tube thickness from a Recovery Boiler Front Water Wall[VI]

Figure 5 shows several tubes in red. According to the Boiler Tube Thickness Criteria (step 2), red means these tubes will have to be changed out during the next shutdown. It will be necessary to establish the tube replacement cut lines using an ultrasonic thickness meter. The correct amount of replacement tube material can then be ordered and made available for the next planned boiler shutdown.

Step 4 - Predictive/Preventative Analysis

This is the interesting and practical aspect of obtaining the boiler tube thickness data. It is now possible to accurately predict which tubes will require replacement several years into the future, assuming the boiler operating conditions, boiler feed water treatment, etc. remain constant.

To calculate the boiler tube metal loss rate, the formula is:

(Initial Tube Thickness Reading – Current Tube Thickness Reading) / Time

If the Initial Tube Thickness Reading = 0.185”
Current Tube Thickness Reading = 0.144”
Time =3 years

Then the metal loss rate is:
(0.185 – 0.144) / 3 = 0.014”/year.

With this metal loss rate, it is now possible to take the current tube thickness and calculate the tube’s projected thickness in four years, five years, six years, etc.

Current Tube Thickness – (Time * Metal Loss Rate) = Projected Thickness

Current Tube Thickness = 0.144”
Time = 5 years
Metal Loss Rate = 0.014”/year

The projected tube thickness in five years would be:

0.144 – (5 * 0.014) = 0.074”

It is also possible to determine how long it will take the tube to reach the “Change Out Next Shutdown Thickness” or “Change Out This Shutdown”, etc. levels.

Utilizing “Change Out This Shutdown” level from the Boiler Thickness Criteria, we can predict when the tubes will require replacement.

Change Out This Shutdown	= 0.127”
Current thickness	= 0.144”
Metal loss rate	= 0.014”/year

(Current Thickness – Change Out Now Thickness)/Metal Loss Rate = Years Remaining

(0.144” – 0.127”)/0.014”/yr = 1.2 yr

In just over a year this tube would require changing out. Again, this can be shown graphically utilizing the functionality of a drawing with links to the database (*Figures 6 & 7*).

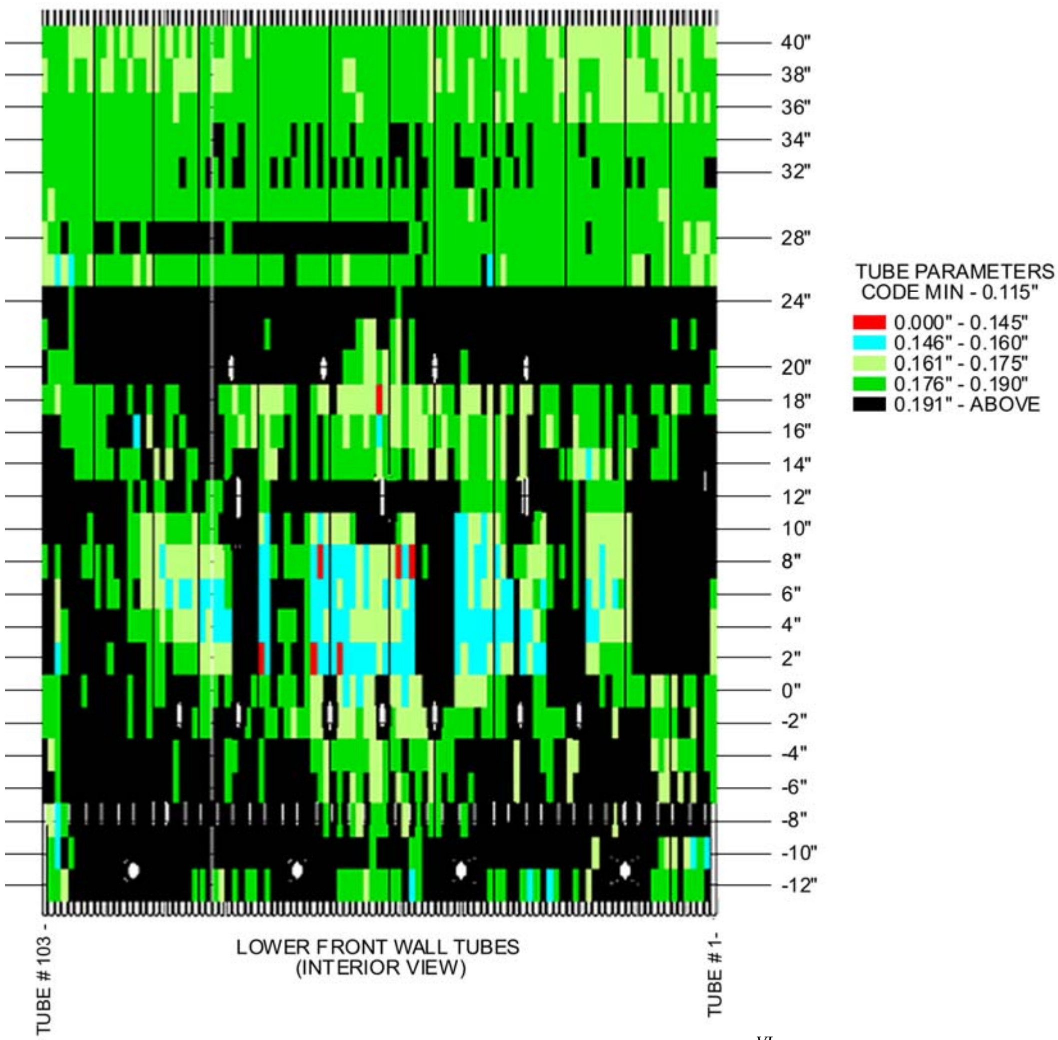

Figure 6: Projected tube thickness on the front waterwall in five years[VI]

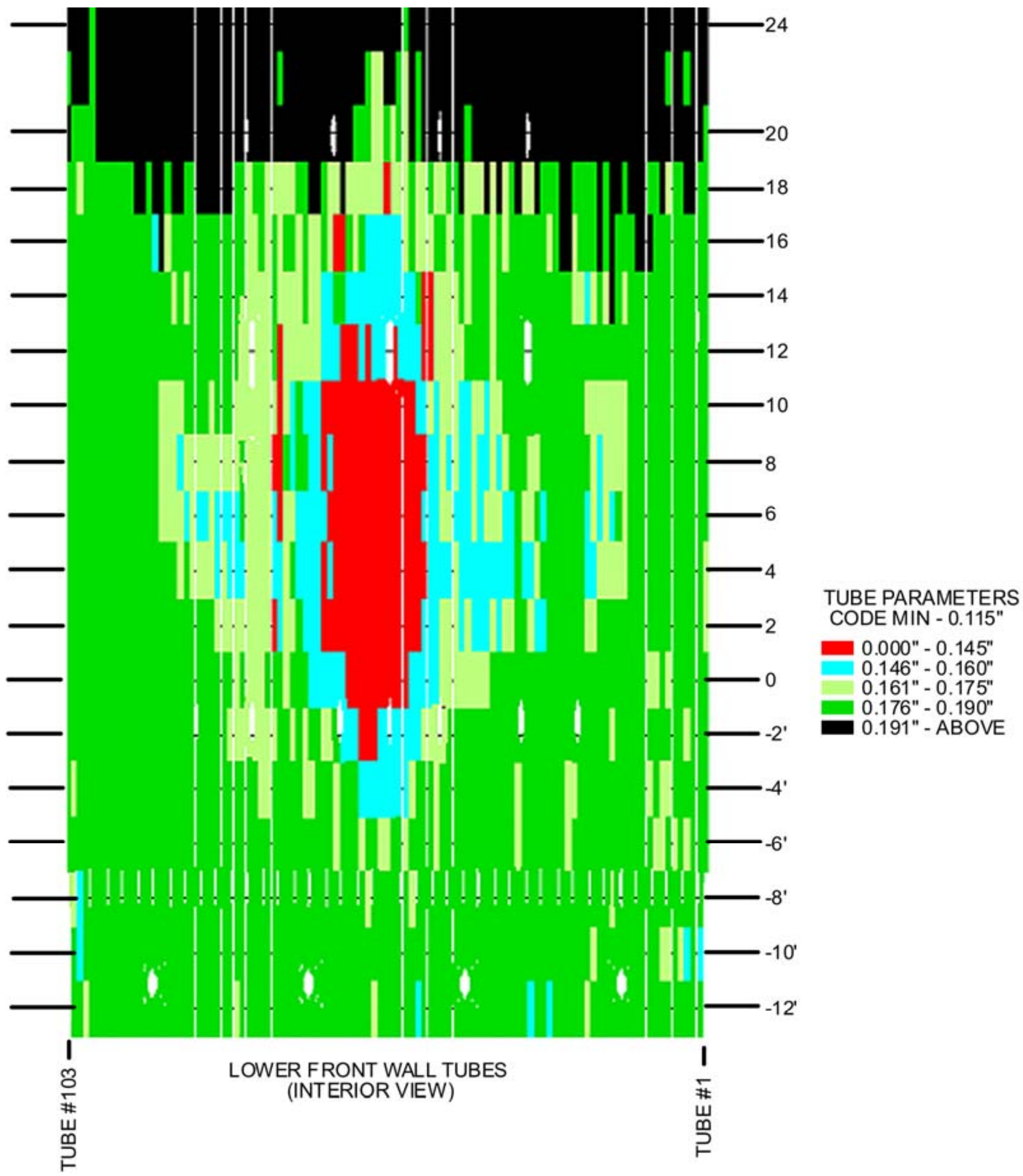

Figure 7: Tubes requiring changing out during the boiler shutdown in one year[VI]

The graphical displays are easily produced by Visions Enterprise. They are very useful in planning meetings and communication. Additionally, most people find it easier to comprehend complex information from a picture as opposed to a book full of numbers.

With this graphical information, it is possible to easily review all of the boiler's sections and elevations to accurately determine metal loss rates. If there are areas where there are very low or negligible metal loss rates, the thickness testing scope can be reduced or the inspection intervals increased. If there are areas where there are significant metal losses occurring, preventative measures can be developed. If the metal losses are severe the inspection scope and/or frequencies can be increased.

For example, at a specific pulp mill's Recovery Boiler (which had carbon steel tubes throughout the water wall, floor and roof sections) the above methodology and results of many thickness surveys were used to justify the application of external protective coating on the floor and waterwall tubes up to 20' elevation (*Figure 8*). As a result, the pulp mill has reduced the UTS scope from over 30,000 reading points to less than 8,000 points, without compromising the boiler integrity and meeting all regulatory and insurance requirements. This boiler has not had a forced outage due to tube thinning failure in the past 6 years of continuous operation. These are significant savings from the original inspection costs and boiler reliability and production costs.

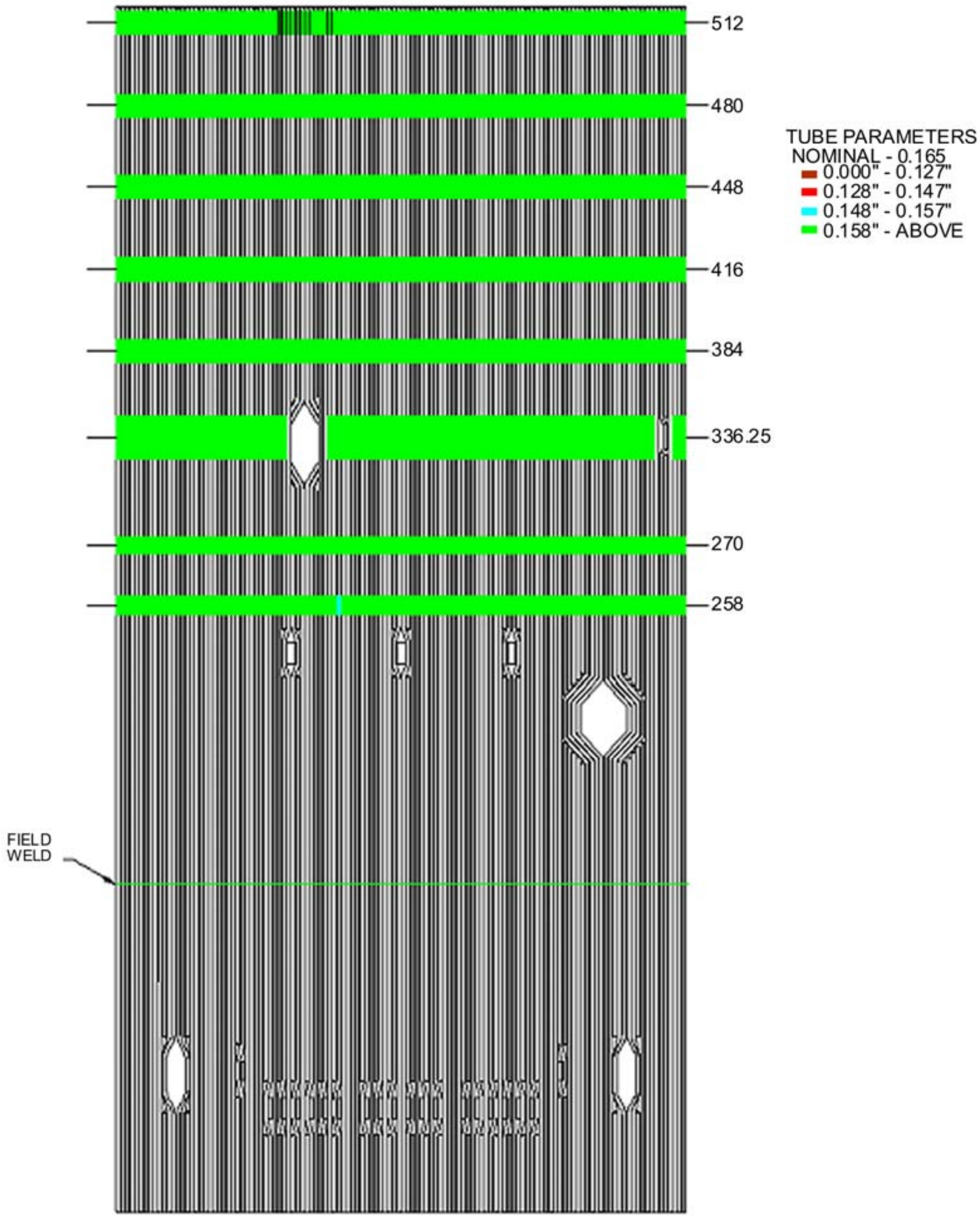

Figure 8: Revised UTS scope for a Recovery Boiler after the application of the protective external tube coating from the floor to the 20' elevation[vi]

CONCLUSION

There is a great deal of useful, predictive/preventative information that can be obtained from the boiler UTS results. Some planning is required to set up and maintain the boiler UTS, but with the application Visions Enterprise's computer software and graphics capabilities, the output will result in significant cost reductions (inspection, production reliability, safety, etc.).

All of the above examples illustrate the added value in practicality, efficiency and good organization that Visions Enterprise can deliver to a company's inspection and maintenance programs.

It is important to note that the above methodology is accurate and relevant to boiler tube thinning degradations for all types of water tube boilers (recovery boilers, power boilers, utility boilers, etc.). However it cannot address other types of boiler tube failures due to cracking, buckstay tears, superheater tube creep, overheating, etc.

Visions Enterprise combines state-of-the-art information technology with Enterprise systems, thereby providing information for the effective management of plant or process facility assets through risk-based assessment and inspection strategies. This was accomplished using state-of-the-art multi-tier technology with Oracle's database and Borland's thin client technologies for the client and server tiers. It integrates asset information from construction to operations and improves asset condition monitoring, analysis and reporting. More than just software, Visions Enterprise is provided as a package together with consulting, training, implementation and support services.

Based on giving careful consideration to clients' needs, best and next practices, Visions Enterprise **is revolutionary in the market. It is unique from its competitors in its ability to provide information on assets that will maximize their performance and minimize costs throughout their lifecycles in an integrated and collaborative manner.** Currently, there are no other integrated systems capable of achieving this.

History of Visions Enterprise and Metegrity

Metegrity has been in business since January 2001 providing asset solutions to clients in Canada, the United States and Europe through its Visions software. However, Visions software has been in existence since 1993. Metegrity's clients consist of large corporations in refining, petro-chemical, power, oil & gas processing, and pulp and paper industries. These include Shell Canada, Petro-Canada, Nova Chemicals, Devon Energy, Duke Energy, Chevron Canada, TransAlta, Celanese, Methanex, ExxonMobil, Ceska Rafinerska, Diashowa-Marubeni, and Tolko Industries.

Visions was originally developed to assist inspection departments in process facilities using NDE techniques to maintain and analyze thickness data collected from inspection of pressure equipment. The incorporation of approximately one thousand client requests and suggestions into its design, resulted in Visions Enterprise being developed on the basis of clients' needs and best practices. In 1995, its focus changed towards asset management. Visions evolved from an asset reliability system for static equipment with local area network database capabilities to being able to maintain information on equipment from all facilities within an Enterprise system capable of communicating effectively with the clients' own ERP's.

Acknowledgments

The writers would like to acknowledge the cooperation of the personnel at the Tolko Kraft Paper Mill, in particular Mr. Donald Russick, Inspection/Quality Control, for their assistance and permission to use their Recovery Boiler data.

Rick Peterson, P.Eng, 1st Class Power Engineer, 2nd Class Marine Steam Engineer. Mr. Peterson has more than 30 years' experience in the operation, inspection, repair and alteration of stationary and marine boilers, pressure vessels and piping systems.

Robert Jablonski is the General Manager of Metegrity. He oversaw the development of Visions in 1993, and has over fifteen years experience in information technology and Enterprise systems. As the General Manager, Mr. Jablonski is responsible for overseeing Metegrity's operations and marketing Visions Enterprise.

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[I] Lloyd's Register – quote from Lloyd's Register website www.lr.org

[II] API Publication 581 – Risk Based Inspection, Base Resource Document – 1st edition 2000

[III] API Publication 580 – Recommended Practice for Risk Based Inspection – 1st edition 2002

[IV] "Risk Based Inspection As Part Of An Overall Inspection Management Program", Rick Peterson, Robert Jablonski CORROSION/2003 Conference Paper, NACE Item #51300-03638-SG

[V] "The inspection of recovery boilers to detect factors that cause critical leaks", Donald Bauer and W.B.A. Sharp, *Tappi Journal,* September 1991, pp. 92 - 100.

[VI] All drawings utilized in this paper were created using Visions Enterprise™ and AutoCAD® software, www.visions-enterprise.com, www.autodesk.com