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IMPROVE BOILER RELIABILITY WITH UNIT SPECIFIC STRATEGIC PLANNING

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ABSTRACT

Boiler tube failures remain the leading cause of lost availability in power boilers across global markets. The need for strategic planning in regard to inspections, preventative maintenance and targeted replacements has never been greater. Identifying the root problem(s) is essential and must be properly managed for continued safety, reliability and availability.

The process associated with integrating a boiler management program can be viewed as an insurmountable obstacle for many utility operators and owners. In many cases, the cookie cutter approach that is often used results in insufficient reliability recovery. However, using modern technology and tactics to strategically manage and properly identify specific operating and design conditions has proven exceedingly successful in reducing a unit's forced outage rate [EFOR].

Specific challenges plants are faced with include the reduction of onsite engineers, aging workforces and equipment, and the need to remain competitive in a challenging global energy market. Plant managers are routinely faced with the complex task of determining the current condition of their equipment, forecasting outage budgets and schedules, and performing risk assessments. Additionally, insurance companies are increasingly requiring inspection and maintenance records that are not always up-to-date or readily available. The solutions to reducing the EFOR of a unit involves taking a comprehensive approach to boiler management utilizing unit specific operational training, advanced data management, and strategic inspection, maintenance and replacement prioritization. Implementing this comprehensive approach has awarded millions in savings for plant managers that have adopted this strategy. Implementing a unit specific, target driven, and strategic plan enables utility owners and operators to succeed in today's competitive market by increasing the unit's reliability and availability without sacrificing safety or environmental standards.

Thielsch Engineering, Inc. developed a program titled: 4-SYTE System Strategy that is currently utilized in more than 60 power plants within the United States and Canada. Unit specific strategic planning is necessary for all facilities that rely on these critical components. Advanced technology must be adopted by all energy producers to ensure they remain competitive and profitable.

DEFINITIONS AND ACRONYMS:

Definitions:
<u>Base Load</u>: the minimum amount of power that a utility or distribution company must make available to its customers, or the amount of power required to meet minimum demands based on reasonable expectations of customer requirements.

<u>Base load plant</u>: is an energy plant devoted to the production of base load supply. Base load plants are the production facilities used to meet some or all of a given region's continuous energy demand, and produce energy at a constant rate, usually at a low cost relative to other production facilities available to the system.

<u>Code Cases</u>: provide rules that permit the use of materials and alternative methods of construction that are not covered by

existing BPVC rules. Codes Cases are usually intended to be incorporated in the Code in a later edition. When it is used, the Code Case specifies mandatory requirements which must be met as it would be with the Code.

Creep damage: occurs in metals and alloys after prolonged exposure to stress at elevated temperatures. It is usually associated with the tertiary stage of creep, and brings about the onset of creep failure. It can, however, initiate at the relatively early stages of creep, and develop gradually throughout creep life. Creep damage is manifested by the formation and growth of creep voids or cavities within the microstructure of the material.

Cycling operation: refers to the operation of power generating units at varying load levels, including on/off, load following, and minimum load operation, in response to changes in load requirements. Every time a power plant is cycled, the critical components go through unavoidably large thermal and pressure stresses, which cause damage ultimately reducing the life cycle of the materials.

Decommission: is a general term for a formal process to remove a power plant from an active status of producing power.

Dissimilar weld: refers to a weld created by joining two different alloys. For purposes of this paper, the dissimilar welds are those joined between stainless steel and common low alloy steels. These welds are generally created due to high material costs.

Forced outage: is the shutdown condition of a power station, when the boiler is unavailable to produce power due to unexpected breakdown. Forced outage can be caused by equipment failures, disruption in the power plant fuel supply chain, operator error etc.

Heat transfer: describes the exchange of thermal energy and heat between physical systems, a dissipative process. When an object is at a different temperature from another body or its surroundings, heat flows so that the body and the surroundings reach the same temperature, at which point they are in thermal equilibrium. Such spontaneous heat transfer always occurs from a region of high temperature to another region of lower temperature, as described by the second law of thermodynamics.

Oxidation resistance: the ability of metallic materials to resist chemical degradation of the surface caused by the action of air or other gaseous mediums at high temperatures. The oxidation resistance of a metal or alloy in an oxidizing atmosphere is determined by the properties of the oxide layer—scale—that forms on the surface of the metal and inhibits the diffusion of gas into the metal, thus reducing the development of gaseous corrosion. Along with heat resistance, oxidation resistance is a basic criterion of the suitability of a given material for high-temperature service.

Primary failure mechanism: are the processes that degrade the tube and produce a failure.

Reliability: the ability of a system or component to perform its required functions under stated conditions for a specified period of time.

Remaining useful life: Remaining useful life (RUL) is the useful life left on an asset at a particular time of operation. RUL is typically random and unknown, and as such it must be estimated from available sources of information such as the information obtained in condition monitoring.

Thermal coefficient of expansion: describes how the size of an object changes with a change in temperature. Specifically, it measures the fractional change in size per degree change in temperature at a constant pressure.

Tube failure: A boiler tube is considered to have a failure when its pressure boundary is broken by a leak or rupture, or prone to be broken due to wall thinning before the next scheduled boiler inspection.

Acronyms:
ASME: American Society of Mechanical Engineers

B&PV: Boiler and Pressure Vessel

EFOR: Equivalent Forced Outage Rate

EPA: Environmental Protection Agency

DMW: Dissimilar Metal Weld

HRSG: Heat Recovery Steam Generator

RUL: Remaining Useful Life

INTRODUCTION

Lost availability in power boilers today is characteristically caused by boiler tube failures. These tubes failures are largely a result of a handful of damage mechanisms that can ultimately affect the integrity of the tubing. Many utilities have begun looking for ways to proactively track and prevent these failures from occurring by developing a boiler management program. Unfortunately, identifying where and how to begin such a program can be viewed as an insurmountable obstacle for many utility operators and owners. In many cases, instituting a generalized approach to preventing tube failures becomes the only answer that boiler owners and operators rely on. This “cookie-cutter” approach to preventing tube failures results in poor reliability improvement due to specific operating and design conditions not being identified and evaluated.

The solution to reducing the forced outage rate of a unit involves taking a comprehensive approach to boiler management utilizing unit specific operational training, advanced data management and strategic inspection, maintenance, and replacement prioritization. Based on over 18,000 custom inspections and reports, Thielsch Engineering, Inc. has developed a proven 3-Step process to improve overall boiler reliability and each unit's life expectancy that ultimately reduces costs associated with scheduled and unscheduled outages.

This paper will break down each of the three steps involved in this unit specific approach and will discuss some of the individual unit specific conditions that must be ultimately considered when developing a strategic plan of action to reduce the unit's EFOR.

IMPROVE RELIABILITY: UNIT SPECIFIC STRATEGY

Each boiler has its own unique operational history and conditions. In order to improve a boiler's reliability it's imperative to consider the boiler's unique conditions to develop a strategic plan to improve safety and reliability. Many plant managers and engineers never get started with a reliability program because the task is so challenging. This integrated 3-Step process includes a System Review, Historical Review and Budget Review. Each step has multiple key components that must be considered when implementing a proven unit specific strategy.

PROCESS STEP 1 - SYSTEM REVIEW KEY COMPONENTS

Age of the Unit

Facilities built in the 1960's and 70's experience damage related to the obvious number of hours of operation; however they were designed with heavier wall thickness in both tubing and header components. As a result, these units' tend to have longer life expectancies than some of the newer facilities. Facilities that were built in the 1980's pushed the limits with the "do more with less" approach. Tubing and headers were supplied with thinner walled components, conserving costs on construction, but ultimately reducing the service life of the critical components. Modern facilities are being constructed to adapt to the thermal cycling that has become a part of the energy culture of today and are experiencing earlier than expected failures. Many of these failures are the result of exotic materials that are being used which have not been in service long enough to know the true behavior of the material under the thermal and mechanical stresses of cycling a unit.

Design of the Unit

Some boiler units clearly have inherent design flaws. Various design flaws include the placement of the burners in the furnace, how the tubing/headers are supported and/or the use of water guns or soot blowers. Understanding the inherent design flaws of a specific unit will help a company become proactive in their approach to preventative maintenance and ascertain areas to target for remaining useful life determinations.

Materials

The American Society of Mechanical Engineers (ASME) has approved certain steel materials for use as tubes in boilers designed according to the ASME Boiler and Pressure Vessel (B&PV) Code. Section I of the ASME B&PV Code specifies allowable materials in Paragraph PG-9. Other materials have also been approved by specific Code Cases. Understanding the materials specific to a unit and recognizing the inherent concerns of those materials (weldability, resistance to elevated temperatures and pressure, heat transfer ability) will enable facilities to be more progressive in their pursuit to preventing service related damage.

Understanding P91/T91

The use of modified 9Cr (grade 91) steel in modern power plants is derived from the superior properties of the material in comparison to carbon steels or lower chrome materials. It boasts superior creep and tensile strength characteristics, which allow thinner materials to be designed into piping systems, pressure vessels and tubing. These are enviable characteristics in terms of thermal cycling, hence the wide spread use of the material in newer combined cycle plants.

There are some critical drawbacks to this material that have been realized over its relatively short lifetime. It provides significant field welding challenges in terms of backing, preheat, and post weld, heat treat programs. There is little margin for error when welding and/or heat treating this material. Unlike carbon and low-alloy steels, the elevated creep strength in 9-Cr material depends on achieving and maintaining a specific microstructure.

Any event during manufacture, erection, or operation that disrupts this microstructure will compromise the integrity of the material and prevent it from achieving the creep properties upon which the Code allowable stresses are based. In such cases the premature failure of such components is a reality. Additionally, softening of the material resulting in lower creep strength and can initiate type IV cracking of the material. It is paramount that the use of this material be firmly understood. [1]

Code Case Materials

In the event there is an urgent need for alternative rules concerning materials, construction, or in-service inspection activities not covered by existing Boiler and Pressure Vessel Code rules, or for early implementation of an approved Code revision, ASME may issue a Code Case. [2] The use of Code Case materials are now being used extensively in superheaters and reheaters, specifically in new HRSGs. Many of these materials are an enhancement of 2.25 Cr-1 Mo steel to gain additional high temperature strength. Several facilities in the United States have experienced critical failures due to the use of such code case materials. Identifying where and how these materials are being used in a unit can greatly affect the ability to prevent premature tube failures.

Dissimilar Welds

Designers of boiler Superheater/Reheater pendants incorporate the favorable mechanical properties of stainless steel within these sections of the boiler that combine high heat and high gas flows. However, due to the high material costs, these sections are ultimately welded to more common low alloy steels. The resulting dissimilar metal welds (DMW's) have a tendency to suffer service related deteriorations (cracking) over time. Cracking of dissimilar metal welds is typically attributed to three primary factors. The most significant factor is the difference between the thermal coefficient of expansion of the weld deposit and tubing. This difference results in a significant temperature-induced stress at the weld interface. Fig. 1 illustrates a typical metallurgical sampling of a DMW tube segment.

The second factor contributing to the degradation of this type of weld is carbon diffusion. This diffusion occurs slightly during welding and more extensively during subsequent use in high-temperature service. The resulting band of carbon depleted low-alloy steel immediately adjacent to the weld interface has a greater propensity for failure due to creep.

The third factor affecting the integrity of this type of weld is a difference in oxidation resistance between low alloy and stainless steels. This difference results in an oxide wedge forming along the outside and inside diameters of the component in question at the interlace between these two materials. These wedges will continue to grow as a result of the difference in the oxidation resistance of the two materials. The oxide wedges reduce the available cross-sectional

Figure 1. Metallurgical tube sample section representing dissimilar metal weld joint of stainless steel material to lower-alloy steel material. As can be seen above, it is at this type of weld location that any failures occur as a result of the temperature induced stress, carbon diffusion and oxidation resistance.

thickness of the component, and thus, its load bearing capacity. DMW's must be identified and included in your unit specific plan. [3]

PROCESS STEP 2 - HISTORICAL REVIEW KEY COMPONENTS

Failure/Leak Locations

The ability to identify and track the locations of a tube failure and its root cause is essential to comprehensively reducing forced outages. Once the root cause of the failure is properly identified, a long term plan can be implemented to ensure the failures/leaks have been rectified. Proper and current documentation is critical to managing failures and leaks and can be done in real-time with the use of a data management program such as the 4-SYTE System Strategy.

Failure/Leak Mechanisms

Since boiler tube failures have been the subject of immense concern to utility companies and boiler manufacturers, there is a tremendous amount of reports, theories, studies, factual and unfactual communications and investigations concerning the different failure modes and mechanisms. As illustrated in Figure 2, the significant failure mechanisms seen most commonly in the industry have been

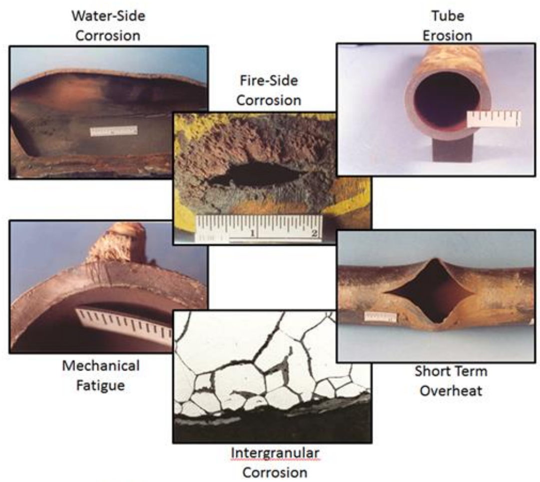

Figure 2. Metallurgical samples representing several significant failure mechanisms affecting tubing in the utility industry. Identifying the root cause of the failure, as seen above, is paramount to comprehensively reducing future forced outages.

identified by six broad classifications [4]:

Stress Rupture
Water-Side Corrosion
Fire-Side Corrosion
Erosion
Fatigue
Lack of Quality Control

The most likely failure mechanisms can occur in waterwall, economizer and superheater or reheater tube circuits. Only those mechanisms listed for that specific location need be considered during a failure incident when time is essential.

Primary failure mechanisms are the processes that degrade the tube and produce a failure. Each failure mechanism may include several circumstances such as poor fuel quality, equipment malfunction or improper operation. Each would be considered a root cause since they have created the conditions for a failure mechanism to exist. Verification of the root cause is a vital activity in a failure investigation and is necessary to assure the correction of a failure problem. Secondary failure mechanisms such as adjacent tube washing or adjacent tube impact can produce a tube failure and are always a concern after an initial failure. This is commonly referred to as collateral damage. Often times following a forced outage as a result of a tube failure, there is such an urgency to return a unit to service, that identifying areas of collateral damage are overlooked. Consequently, the unit is forced offline again as the result of additional tube failures in these collateral damage locations.

Modifications

On occasion inherent deficiencies of a unit design will be identified. As a result, the unit may undergo design modifications which can resolve the original design flaw concerns, but ultimately can create other issues such as steam flow restrictions and temperature excursions etc. Additionally, as part of the clean air initiatives currently underway, many units are being modified to burn alternative fuels. Recognizing what modifications have transpired in a specific unit can lend perspective into potential side effects which may be occurring as a result of those modifications.

Replacements

As an aging plant begins to experience repeated failures, sections of tubing and other critical components will require replacement. These replaced sections will have fewer hours of operation; therefore will not need to be considered for inspection on the same schedule as original equipment within the unit. This observation is particularly unit specific and is a major basis for why a cookie-cutter approach to inspection/maintenance is ineffective and can lead to squandering of precious budget funding inspecting equipment that has not yet reached a point in its life cycle to require examination.

Operational Changes

Most power generation facilities were designed on the assumption that they would be operated in a base-load mode or infrequently cycled. However, in response to local power market conditions and the terms of their power purchase agreements, many plants are now cycling their units more frequently than designers had intended. This results in greater thermal stresses, more pressure cycles, and therefore more cyclic fatigue damage and overall faster wear and degradation to the critical components due to both the mechanical and corrosion processes.

As a general comment, cycling service has an adverse effect on the life expectancy of a unit. This is due to the fact that cycling results in fatigue loading (alternating cyclic stresses); whereas base load operation results in creep (sustained stresses). Depending on the severity of the stresses, and the number of cycles, fatigue loading can result in cracking, particularly at restraint locations. [5]

Upset Conditions

When a unit trips and is brought offline suddenly or experiences a water hammer event, an immense amount of thermal and mechanical fatigue can be introduced to the involved components. It is beneficial to understand if a unit has experienced any major upsets during its life cycle in order to determine if evaluating areas that wouldn't normally come under the microscope is necessary. This is similarly unit specific and would be comparable to the considerations you would evaluate if you were purchasing a used car. Just as the purchaser would investigate any past maintenance troubles or collisions of the vehicle prior to purchasing, plant managers must consider the history of their units prior to determining the inspection prioritization of their critical components.

Operational Training

Many times the operators of units are responding to directives from a senior authority to bring the unit online or offline to meet the load requirements and capacity. Understanding the effects of ramping constraints in both unit commitment and economic dispatch is imperative. Operators can have a tremendous effect on the life expectancy of a unit simply by recognizing the effects of proper ramp rate execution. Operators have direct control of the temperature of the unit; therefore proper unit specific training can add years to the life of the unit.

PROCESS STEP 3 - BUDGET REVIEW KEY COMPONENTS

Remaining Useful Life Determinations

Determining the remaining useful life of critical components/tubing will allow for proper budgeting for replacements. Additionally, as systems begin to reach the end of their life cycle, more failures will inevitably begin to occur.

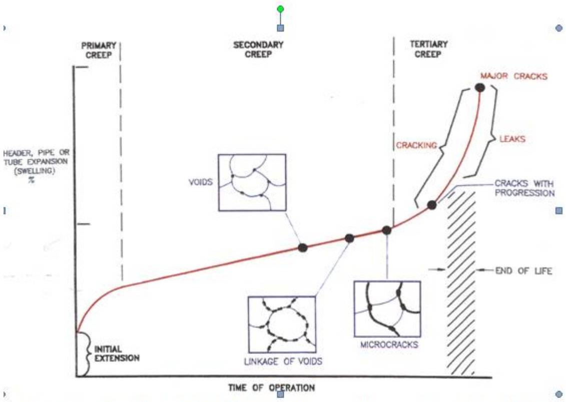

Figure 4. Stages of Creep Development. As creep stages progress, illustrated in the graphic above, the voids begin to link with one another, developing into cracks which then propagate through the material eventually causing leaks or failures.

Understanding when to "cut your losses" and replace sections will improve reliability. Many factors can affect the life expectancy of key components in a boiler including water chemistry, fuel type and quality, thermal cycles, materials, temperature excursions, inadequate heat transfer and flow rate. Understanding key factors associated with a specific unit that can ultimately contribute to shortening the life expectancy is paramount to predicting remaining useful life of critical components. Figure 4 below illustrates the stages of creep development which progresses as material reach the end of their useful life.

Prioritization: Inspection, Repairs, Replacement

The ability (and necessity) to develop a plan of action that includes prioritization for inspection, repairs and/or replacements established from the unit specific design and historical operation will dramatically improve the budgetary process. Allotted funds will be used in an effective manner and outage planners will have the ability to provide "back-up" documentation required to warrant the necessity for such funding during the company fiscal budget planning process.

Outage Schedules

Facilities typically have an outage schedule to provide regularly scheduled maintenance and inspection of major components. Short outages typically occur once a year and last about 7-10 days. Major outages typically occur every two-three years and last in upwards of 3-6 weeks depending on if replacements are scheduled or major overhauls of equipment are required. Developing a firm plan of action and having a concrete understanding of when and why these outages are scheduled can help allocate funding for prioritization of inspections and maintenance.

For example, if a plant is experiencing tube leaks, but aren't scheduled for a major outage for another year, it may elect to do a "quick fix" or "band aid" type of repair to continue operations until the major outage. It is paramount that the problem be properly analyzed to ensure that the temporary method to "hold" will be effective. This determination requires experience, expertise and documentation of the components in question. All of this can be obtained by utilizing a unit specific strategic plan with a custom data management program.

Budgetary Allocation

Alas, the budget. A common frustration among plant managers and planners occurs when the hurdles associated with identifying what needs done have been surpassed; yet retaining the appropriate funds becomes a challenge. Planners must justify the priority for the proposed funds and with that, clear documentation and professional support is essential. Figure 5 illustrates the importance in reducing confusion in budgetary allocations by the utilization of clear documentation of trouble areas within the unit.

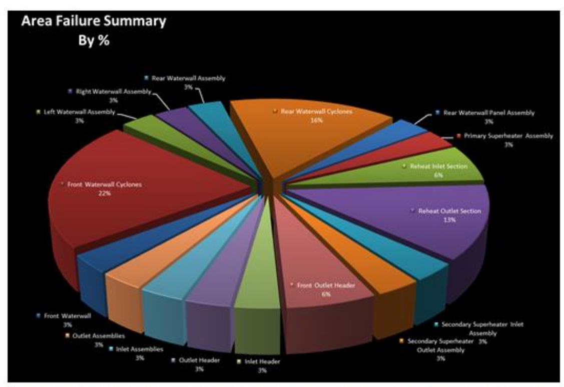

Figure 5. Clear documentation to support the budgetary requirements for inspection prioritization or component replacement is vital to securing proper funding. Creating such documentation can readily be accomplished with the use of a proven data management program.

Once the requested funds have been allocated, it must be utilized in the most effective manner with a clear plan of action. A unit specific plan and a real time management plan will not only maximize the return, but also improve overall safety and reliability. Budgets can be justified when the system review and historical data have been retained and readily available by way of a data management program.

EPA Regulations

EPA regulations change constantly and facilities are faced with having to upgrade emissions or retrofit to meet these EPA regulations. Funding that would have otherwise been used for maintenance and inspection or replacements are then reallocated. A comprehensive unit specific strategic plan combined with a data management program will assist in early detection of a unit's remaining useful life cycle and/or identify solutions that could potentially void the need to decommission or upgrade. More and more facilities are being decommissioned rather than upgrading because the cost of performing the needed modifications outweigh the profitability of the unit's potential output.

Safety and Risk Management

Safety and risk management are highly regulated and are vital to a facilities success. A comprehensive program that focusses on operator training, maintenance and testing, as well as replacing components that have reached the end of their useful life can reduce the risk of component failures within a power boiler. The need to create this custom plan is essential to the overall operation of the facility and most importantly the safety of the workers. Additionally, a progressive data management plan can offer extensive reductions in insurance costs as this establishes a proactive philosophy to prevent catastrophic events.

CONCLUSIONS

Modern and Proven Solutions

Thielsch Engineering, Inc. has spent the past 30 years working with America's power producers and advanced manufacturers to ensure safety, reliability and profitability. Every power producing facility must have a system in order to better handle overall operations and data management. Having a unit specific strategic approach to preventing forced outages by addressing the particular conditions affecting the integrity of the boiler is imperative to reliable power production. The combined process of integrated engineering that includes unit specific education, observation, tracking, proper maintenance and data collection provides a modern approach to a complex and highly competitive market.

References:

[1] Thielsch Engineering, June 2013, "Grade 91, is it passing the test?, Technical Bulletin

[2] ASME, April 4, 2014, "Code Cases of the ASME Boiler and Pressure Vessel Code." https://www.asme.org/shop/standards/bpvc-resources/code-cases-of-the-asme-boiler-and-pressure-vessel

[3] Thielsch Engineering, July 2013, "Boiler Tubing Dissimilar Metal Welds (DMW's).", Technical Bulletin

[4] EPRI, 2009, "Field Guide: Boiler Tube Failure", EPRI, Palo Alto, CA. 1017471.

[5] Thielsch Engineering. July 2013, "A Brief Look at the Effects of Cycling.", Technical Bulletin